Shell’s Colorado Oil Shale Freeze Wall Test

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The Target

- In-situ conversion of kerogen in oil shale to producible hydrocarbons
- Requires
  - Means to contain product to maximize recovery
  - Means to protect and exclude ground water
Containment Systems

■ Natural

■ Process volume surrounded by impermeable formation excluding water and containing conversion products to maximize recovery
  • Gas storage cavern (leached salt dome)
  • Shell’s East RDD Project

■ Combination: Natural and Modified Subsurface

■ Roof and floor rely on natural seals

■ Around periphery permeability sealed by
  • Subsurface or formation grouting
  • Ground freezing if porosity is water filled
Freeze Wall Test Location
Freeze Wall Test Project

- Demonstrate that a freeze wall is a robust containment system for commercial oil shale development

- Evaluate and Test
  - Two containment methods
    - Freeze Wall
    - Grout Wall
  - Dual containment system consisting of external and internal freeze walls separated by a fluid filled compartment
  - Techniques for freeze monitoring freeze wall formation, detecting breaching, and locating breaches
The Freeze Wall Test Site

Facility to assess viability of a freeze wall for ICP subsurface containment. Comprises:

1. Control room, process and data acquisition buildings, offices, and warehouse
2. Three refrigeration units and associated circulation systems (pumps and piping)
3. The freeze ring where the testing was conducted as well as surrounding monitoring wells
4. Additional monitoring and injection wells on remote pads (not shown)
Freeze Wall Formation

- Formed by circulating chilled aqua ammonia through 136 dedicated freeze holes
  - Total cooled subsurface length: 212,800 feet (40 miles)

- Facilities included:
  - Three refrigeration units
  - Three circulation pumps
Freeze Wall Closure

- Freeze wall closed across entire commercial interval in Oct. ‘09
- Closure confirmed in Dec. ‘09 and Jan. ‘10 by:
  - Continued water level rise inside freeze wall following wall closure.
  - Lack of pressure communication across freeze wall in response to active pumping inside and outside the freeze wall
  - Absence of temperature spikes in Dec. ‘09 freeze hole temperature build-up
    - Temperature spikes are caused by warmer water flowing through a location where the freeze wall has not yet fully formed.
Freeze Wall Pressure Test: Low Internal Pressure

- Reduce pressure in each zone tested to 100 psi
- Saw no pressure response in test interval outside freeze wall for each zone tested
- Confirmed wall closure and integrity in that zone
- Achieved following inside to outside pressure differentials:
  - A-Groove: 227 psi
  - B-Groove: 263 psi
  - L-5: 259 psi
  - L-3: 430 psi
Pressure Test of Freeze Wall: High Internal Pressure

- Raised pressure inside cell B until wall breached.
  - Test involved an intentional breach
  - Division wall between cells B and C breached somewhere above 550'
    - Breaching confirmed by pressure response in cell C
  - Surface pressure when wall breached: ~150 psi
- Breach healed as soon as pumping into cell B was halted
  - Minimal flow through breach
- No breach associated temperature change noted in cell B division wall freeze holes
  - Flow period too short to determine exact breach location.
Evaluation of Containment Systems

- **Freeze wall** optimum
  - Impermeable once formed

- **Grout wall** leaked
  - At least one natural fracture not sealed by grout

- **Dual freeze wall** test
  - Successfully breached wall twice.
  - Both times wall rehealed almost instantaneously
  - Breach induced likely not natural fracture
    - Induced fracture width too small when pressure reduced to sustain flow
    - Result: Closure and rapid re-freezing of fracture
North Wall Breach: Will Wall Unzip?

- Wall breached Aug. 31, 2010 using dedicated breaching well located in center of freeze wall
  - 25’ tall breach located in the test interval
  - Breaching pressure: 2.95 psi/ft
- Breach kept open for 75+ days without growing
  - Produced 2 gpm water from test cell at 410 to 475 foot outside to inside head difference
    - Flow through breach remained constant
    - Verified unzipping of wall in test interval unlikely in fractured formation due to highly localized flow channels
- Breach repaired via pressure equalization across freeze wall
FWT Site: Current Status

- 1,700’ deep freeze holes
- 1,500’ deep freeze holes
- 1,500’ deep “FC” holes

Legend:
- Subsurface frozen
Freeze Wall Test Completed

Objective: Demonstrate freeze wall is robust oil shale subsurface ICP containment system

- Can we form freeze wall on commercial acreage?
- Is freeze wall robust?
- How “strong” is the freeze wall?
- Can we detect and locate failures?

Freeze Wall Test Accomplishments:

1. Confirmed freeze wall forms across entire commercial interval
2. Demonstrated freeze wall withstands expected commercial inside to outside pressure differential.
3. Tested Freeze wall to over 150 psi above full hydrostatic head.
4. Demonstrated ability to monitor freeze wall formation and to detect and locate breaches in the freeze wall.