CAES Geo Performance for Natural Gas and Salt Reservoirs,

Thermal-Mechanical-Hydraulic Response of Geological Storage Formations for CAES

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- **Problem**: Siting of CAES facilities may be limited by specific geologic conditions

- **Opportunity**: Fundamental understanding of T-M-H will enable/extend CAES siting potential throughout the US
1. CAES in Mined Salt Caverns
   - Model large scale salt cavern response to air pressure cycling
   - Experimentally evaluate thermal cycling effect on domal salt

2. CAES in Depleted Natural Gas Reservoirs:
   - Model multiphase flow in a depleted natural gas reservoir for CAES
   - Experimentally evaluate pore pressure cycling effect on sandstone deformation
Large scale salt cavern response to air pressure cycling

- Assess long term performance, efficiency and economics.
- Cavern gas thermodynamics is coupled with energy transfer to and from the salt formation.
- Minimize creep/damage of the cavern and minimize efficiency-reducing energy losses to and from the formation.

Coupled 3D simulation of cavern gas thermodynamics and heat/mass flow in salt

Walls are 30m thick. Cavern is made up of cylinder midsection (height=65m; radius 40m) with hemispheres (radius=40m) at top and bottom.
Response of CAES to pressure/temperature cycling: Closeup

Cycle: 5 days on, 2 days off (weekend)
- Extract for 16 hours (154 kg/s)
- Inject for 7 hours (352 kg/sec, 40 °C)
- Hold for 1 hour

Upper row of figures: Salt response
- temperature fluctuation ~ 1-2 m
- pressure fluctuation ~ 40 m

Lower row of figures: Cavern T & P response
- start-up transient
Experimental System Developed to detect and record Acoustic Emissions (cracking events) in salt as it was heated and cooled.

Observation: For this temperature range and slow heating and cooling rate, only a small amount of acoustic emissions (thermal cracking) are detected.

Future work: thermally cycle rock salt at realistic heating and cooling rates.
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Images taken from: http://www.rwe.com/
Formation Analysis for CAES in Depleted Natural Gas Reservoirs

Cylindrical Region

Days From Initial Injection

Mass Injection/Extraction Rate (kg/s)
After natural gas production, residual CH$_4$ is left behind.
Residual gas saturation for the given formation parameters is between 10-20% of the total porosity.
This gas phase is composed of 100% CH$_4$. 
Forming an Air bubble - Gas Composition During Bubble Formation

- $N_2$ bubble is formed and pushes the $CH_4$ to the fringes.
- Relatively little mixing during bubble formation.
- $N_2$ rich bubble next to bore
Reservoir Pressure During Cycling
Cycling – Pressure
Pore pressure cycling of sandstone

Experimental System Developed
to cycle pore pressure in a
sandstone in hydrostatic stress state

Observation: Sandstone compacts over time,
repeated cycles: permeability decreases

Future work: Evaluate cycling effect on other
stress state, additional sandstone lithologies
(rocks with different cement, porosity, permeability)

Volume strain versus time:
Compaction observed

Decrease in permeability
with cycle/time
Cycling – Methane in Produced Gas

![Graph showing methane in produced gas over time and depth.](image)
CAES in Depleted Natural Gas Reservoirs is a Viable Option

- Have a numerical framework in place to simulate air, methane, and water movement in a porous reservoir
  - First CAES simulations in a depleted natural gas reservoir
- CAES in depleted natural gas reservoirs appears to be a viable option
Summary/Conclusions

- Developed numerical analysis method to evaluate thermal and mechanical effects of air mass flow cycling in a salt cavern
- Developed experimental system to evaluate thermal cycling effect on rocksalt

- Developed numerical analysis method to model multiphase flow of air, H2O and methane for a CAES evaluation in a depleted natural gas reservoir
- Developed experimental system to evaluate pore pressure cycling effect on sandstone
Future Tasks

- Evaluate thermal cycling effect on rocksalt using thermal cycles determined from analyses (below)
- Evaluate model comparing to actual real pressure/temperature cycling data from industry partner
- Develop operational (cycle variations) and geologic (i.e. depth) assessments to probe geo-system flexibility
- Evaluate pore pressure cycling effect for other stress conditions and reservoir rocks
- Improve on multiphase flow model for depleted natural gas reservoir; evaluate different cycles (i.e. wind generated), examine the effect of heterogeneity
Publications

- Pore pressure cycling effects in a sandstone, 2012, S. Bauer, Sandia National Laboratories, SAND report in prep
- Permeability and heterogeneity restrain compressed air energy storage in the Mount Simon Sandstone, Dallas Center structure, Iowa, 2012, J. Heath, and S. Bauer, Sandia National Laboratories, SAND report in prep
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