



**RESPEC**

# **ACCURACY OF TEMPERATURE LOGGING FOR CALCULATING GAS INVENTORY**

# DISCUSSION TOPICS



- › BACKGROUND
- › APPROACH
- › RESULTS
- › SUMMARY

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› **BACKGROUND**

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# BACKGROUND

- › The API RP-1170 states that *“Once in operation and throughout its life, the cavern system shall be monitored to ensure the continuance of functional integrity.”*
- › Four cavern integrity monitoring methods are defined by the API RP-1170
  - / Gas Filled Mechanical Integrity Test (requires gas inventory calculation)
  - / Inventory Verification Analysis (requires gas inventory calculation)
  - / Continuous Downhole Monitoring (requires gas inventory calculation)
  - / Hysteresis Curve Analysis
- › 3 out of the 4 methods are *anchored* on an accurate calculation of the gas inventory
- › **How is gas inventory calculated? Are the calculations accurate?**



# BACKGROUND

The gas inventory is calculated based on the natural gas equation:

$$V_{std} = \frac{T_{std} \times Z_{std}}{P_{std}} \times \frac{V_{cavern} \times P_{cavern}}{T_{cavern} \times Z_{cavern}}$$

- /  $V_{cavern}$  is measured using a sonar survey
- /  $P_{cavern}$  is measured using downhole wireline logging or estimated based on wellhead pressure
- ➔ /  $T_{cavern}$  is measured using downhole wireline logging
- /  $Z_{cavern}$  is calculated based on the gas composition, temperature, and pressure



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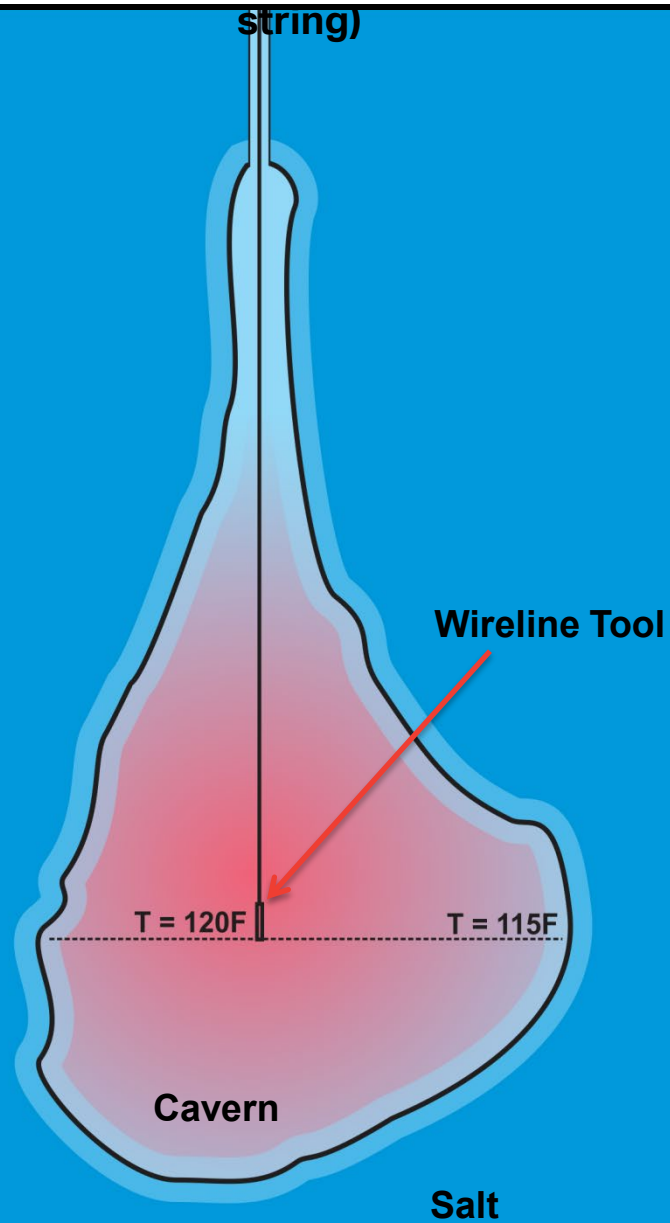
# BACKGROUND

- › A wireline temperature log only measures the temperature along the *centerline* of the cavern... it cannot measure the temperature away from the centerline
- › Currently, we have to assume that the entire gas temperature at a particular depth is the same as the centerline temperature
  - / Is this accurate?
  - / The surrounding salt is slow to change temperature and will create a gas temperature gradient near the cavern walls
  - / Horizontal variations in the gas temperature may exist
- › If the cavern has a hanging brine string, the wireline temperature log measures the brine temperature and not the gas temperature
  - / Is the brine string temperature the same as the gas temperature?
  - / Like the surrounding salt, the brine string is slow to change temperature

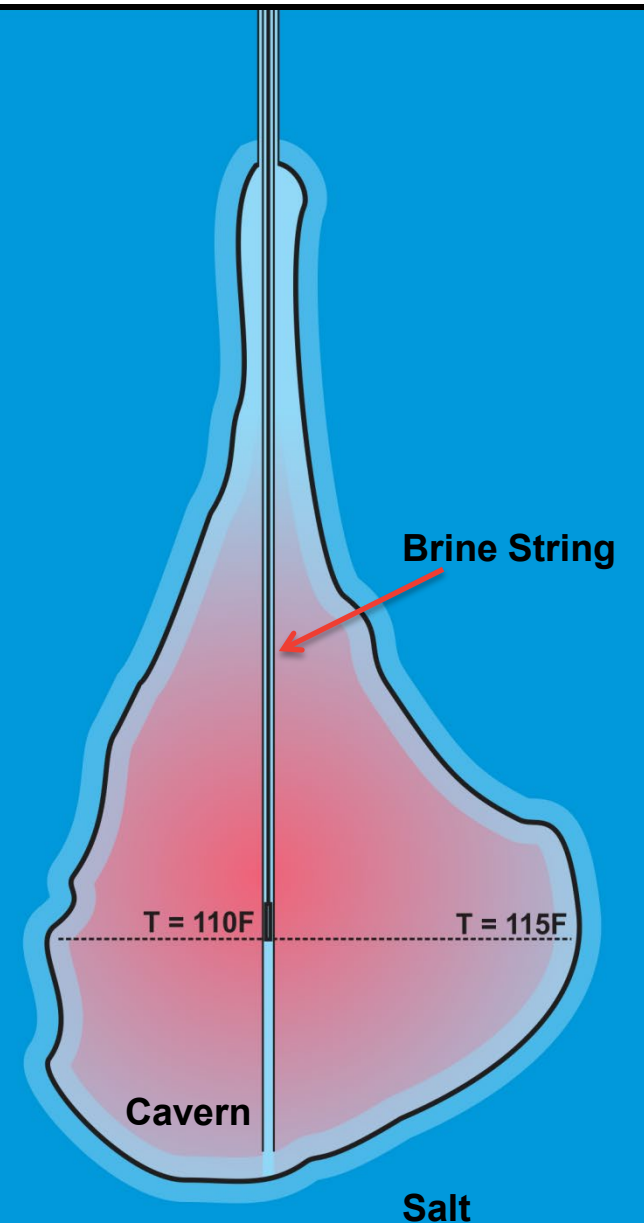


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### Temperature Wireline Log (no brine string)



### Temperature Wireline Log (brine string)





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# BACKGROUND

- › If the wireline temperature log does not accurately represent the entire gas temperature, the calculated inventories may be in error
  
- › These errors may cause a false-negative or false-positive of cavern integrity
  - / False-negative: unnecessary downtime and cost for additional tests (\$\$)
  - / False-positive: a cavern remains in service that does not have integrity (\$\$\$\$)

# DISCUSSION TOPICS



- › BACKGROUND
- › **APPROACH**
- › RESULTS
- › SUMMARY



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# APPROACH

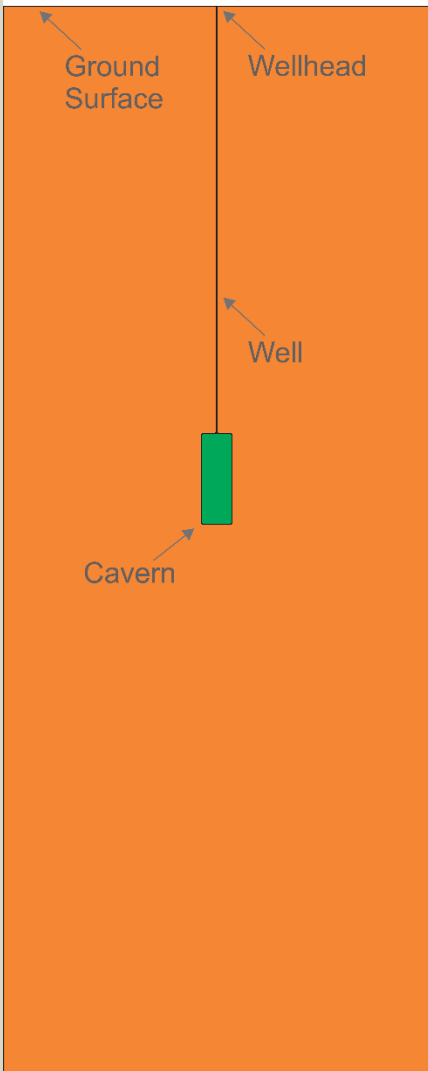
- › **Computation fluid dynamics (CFD) modeling was used to evaluate the cavern inventory behavior**
  - / Simulate thermodynamic behavior of the gas
  - / Includes heat transfer between gas, salt, and the well
  
- › **Task 1 – Well configuration:** Brine string vs. no brine string
- › **Task 2 – Cavern shape/size:** Tall/narrow vs. short/wide
- › **Task 3 – Recent flows:** Injections and withdrawals

# APPROACH



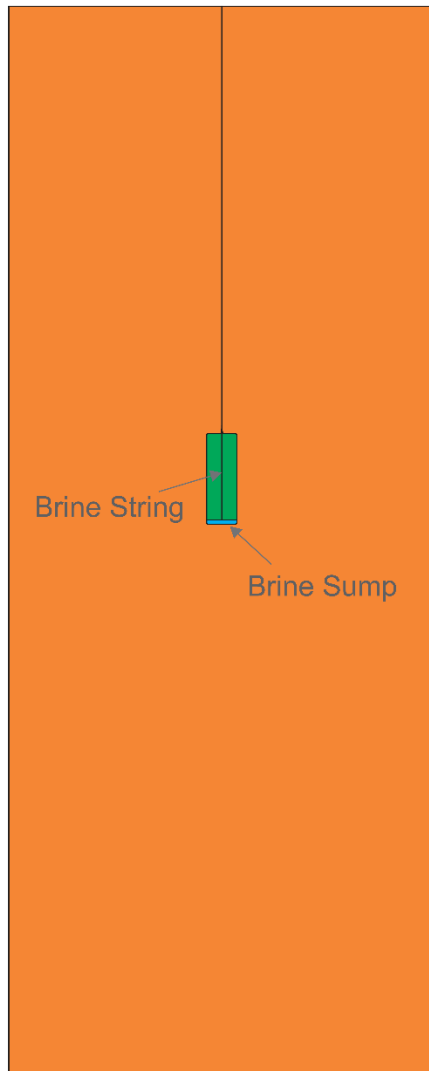
**Model 1**

Task 1 & 3



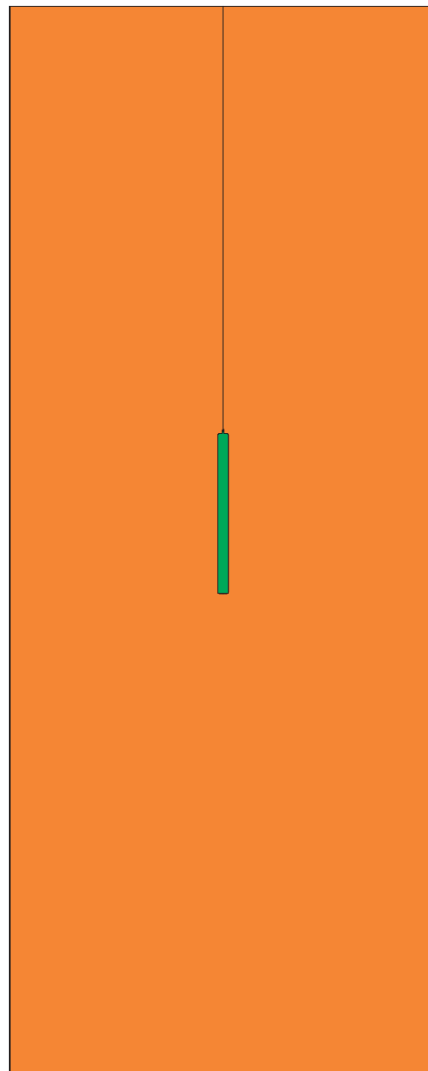
**Model 2**

Task 1



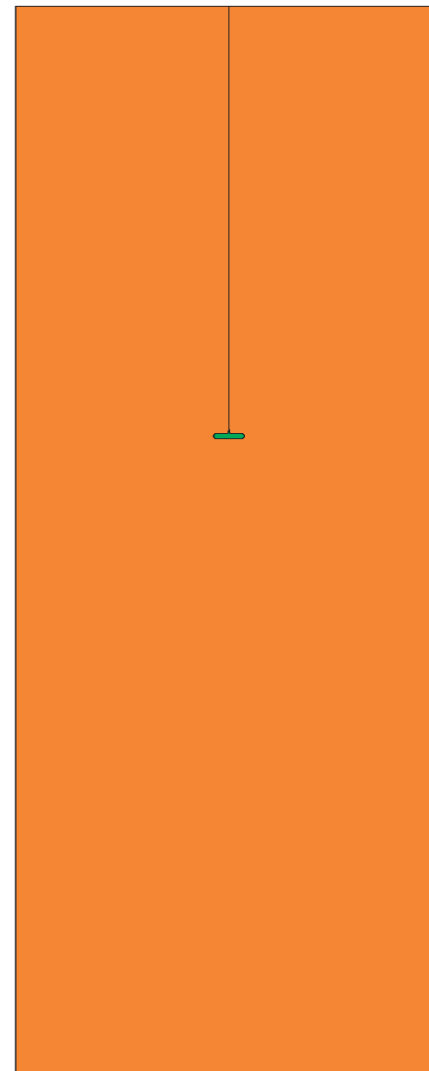
**Model 3**

Task 2



**Model 4**

Task 2





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# APPROACH

## Task 1 (brine string) and Task 2 (cavern shape) simulation

- 1. Initialize Model:** Apply temperature gradient, 2000 psi (13.8 MPa) wellhead pressure (0.58 psi/ft [13.1 kPa/m] gradient at casing seat)
- 2. Shut-in to Equilibrium:** Temperature and density difference in gas causes natural convection, surrounding salt temperature is perturbed, long-duration shut-in
- 3. Run Wireline Log:** Measure gas pressure and temperature along centerline of cavern and well (just like an actual wireline log), estimate inventory based on wireline log and compare to known inventory



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# APPROACH

## Task 3 (recent injections and withdrawals) simulation

- 1. Initialize Model:** Apply temperature gradient, 2000 psi (13.8 MPa) wellhead pressure (0.58 psi/ft [13.1 kPa/m] gradient at casing seat)
- 2. Shut-in to Equilibrium:** Temperature and density difference in gas causes natural convection, surrounding salt temperature is perturbed, long-duration shut-in
- 3. Injections and Withdrawals:** Inject or withdraw gas at a rate of 100 MMscf/d for three days ( $2.8 \times 10^6 \text{ m}^3/\text{d}$ )
- 4. Shut in and Run Wireline Log:** Stop injections/withdrawals and shut in the cavern. Measure gas pressure and temperature along centerline of cavern and well (just like an actual wireline log), estimate inventory based on wireline log and compare to known inventory

# DISCUSSION TOPICS



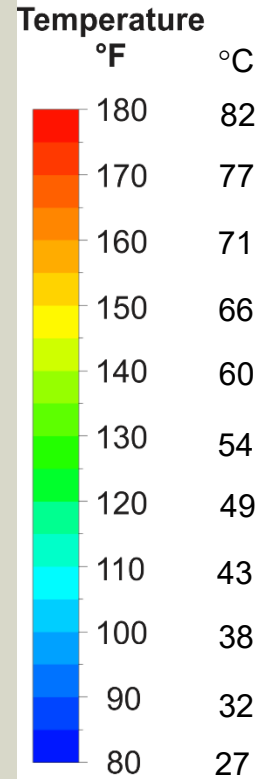
- › BACKGROUND
- › APPROACH
- › **RESULTS**
- › SUMMARY



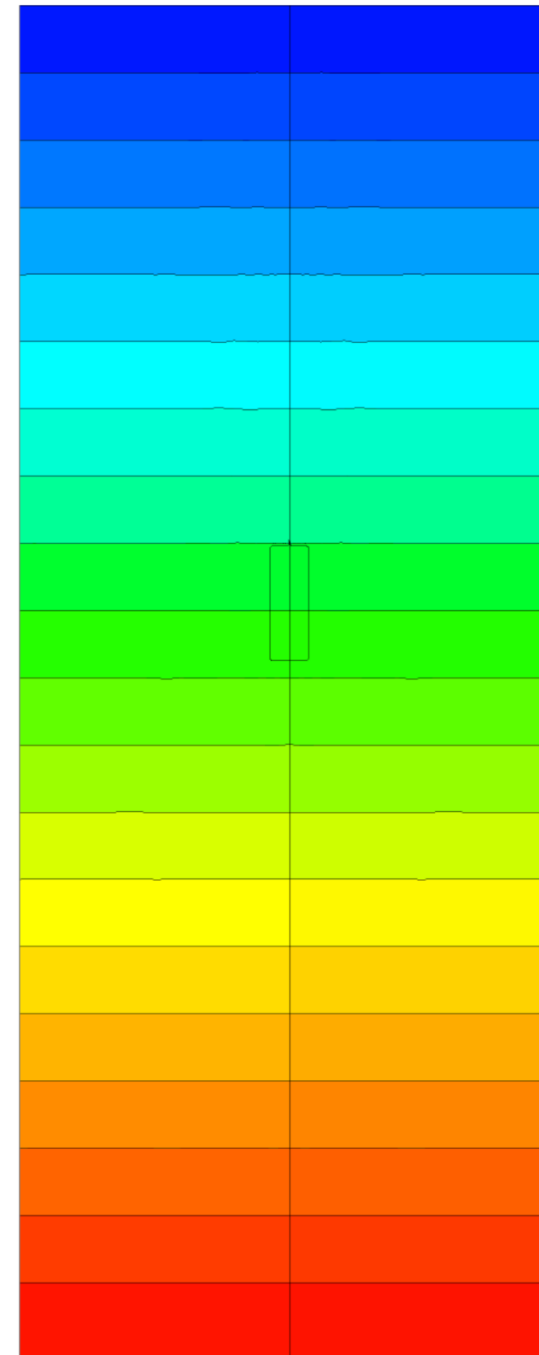
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# RESULTS

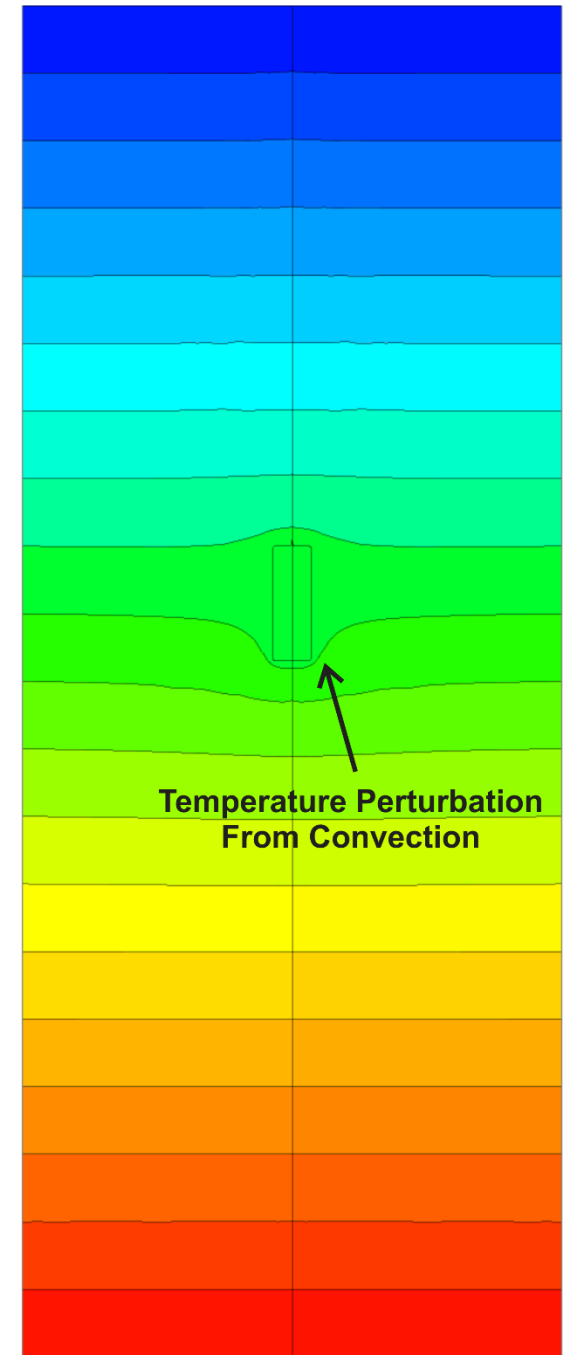
- After shutting in the cavern for a long duration, the gas is thoroughly mixed
- Nearly constant and uniform gas temperature in the cavern
- Temperature in the salt is perturbed because of gas convection/mixing



Initialized Temperature



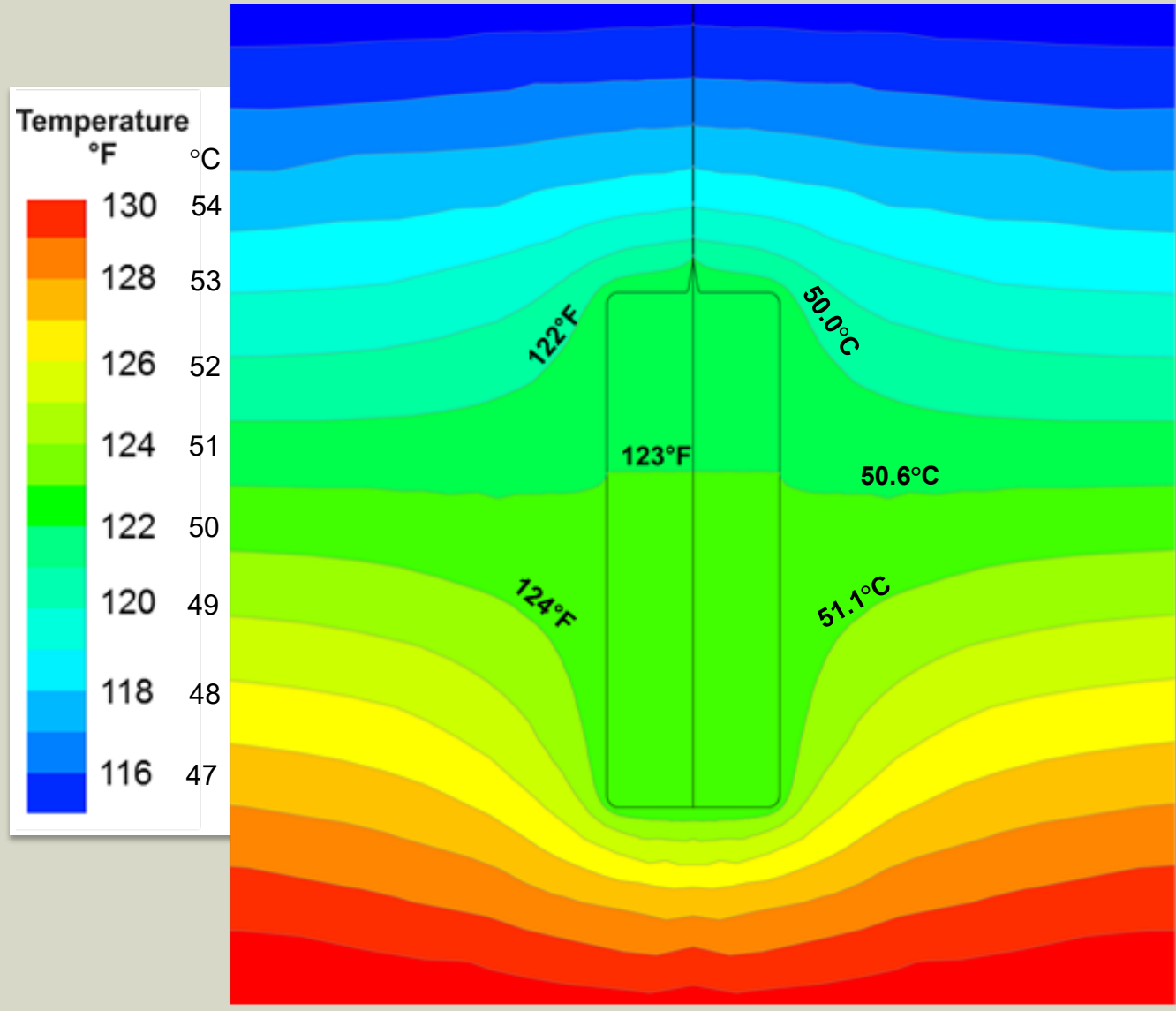
Shut-In Temperature



# RESULTS



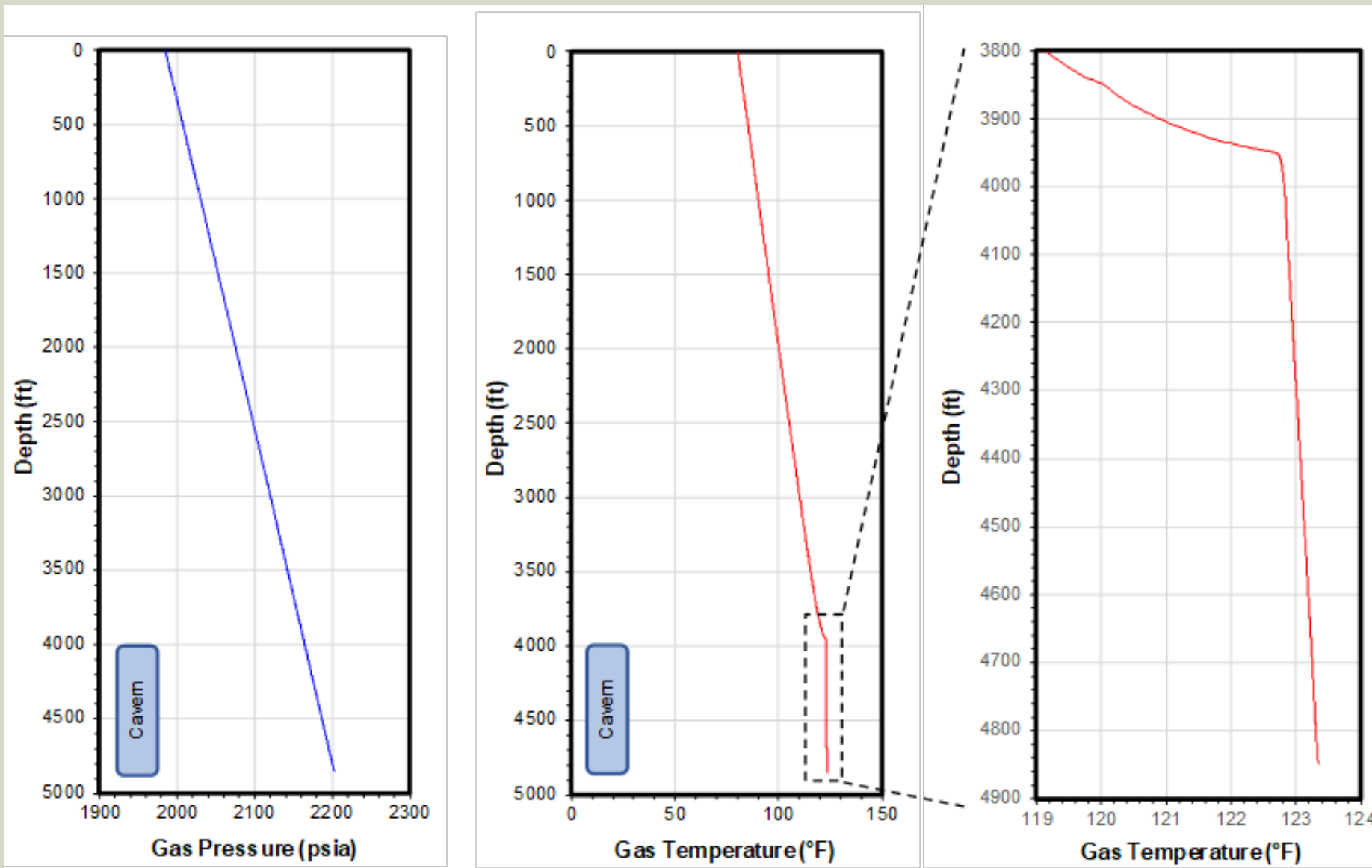
- › (zoomed in temperature contour)
- › After being shut-in for a long duration, the cavern temperature is mostly uniform
- › Gas temperature is approximately 123°F (50.6°C)
- › Very little temperature variation in the cavern





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# RESULTS

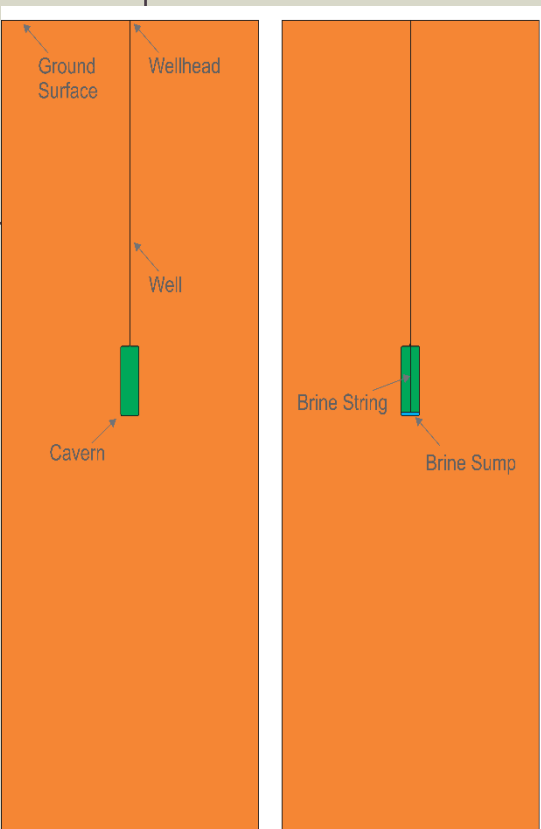




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# RESULTS – TASK 1 (BRINE STRING)

- How accurate is the estimated inventory based on the wireline temperature? Quite accurate **without a brine string... 0.04 % error**
- How does a **brine string** influence the inventory estimate? More error (**0.17 % error**).

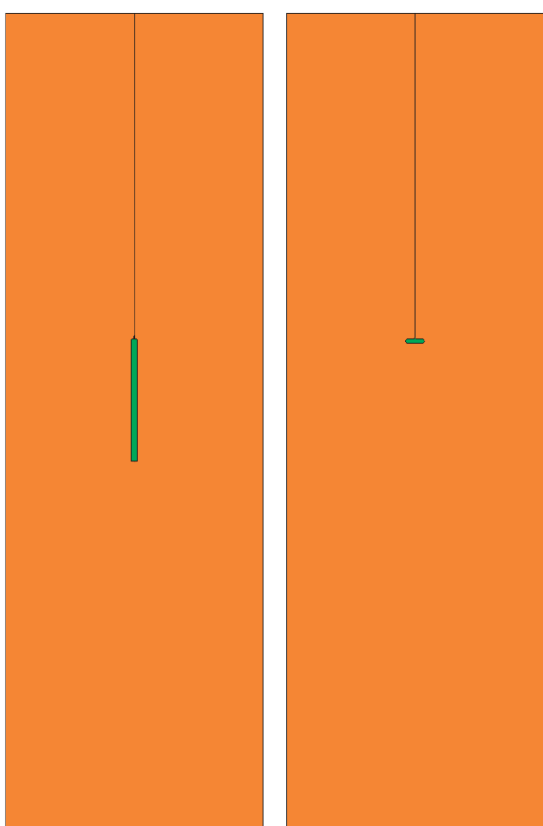


Model	Result	Value	Units	
Cavern Without Brine String	Estimated Inventory From Wireline Log	8.1377	bcf	0.23043 x 10 <sup>6</sup> m <sup>3</sup>
	Known Inventory as Defined in Cavern Model	8.1347	bcf	0.23034 x 10 <sup>6</sup> m <sup>3</sup>
	Difference Between Estimated and Known Inventory	0.04	%	←
Cavern With Brine String	Estimated Inventory From Wireline Log	7.2377	bcf	0.20495 x 10 <sup>6</sup> m <sup>3</sup>
	Known Inventory as Defined in Cavern Model	7.2254	bcf	0.20460 x 10 <sup>6</sup> m <sup>3</sup>
	Difference Between Estimated and Known Inventory	0.17	%	←



# RESULTS – TASK 2 (CAVERN SHAPE AND SIZE)

- › How does the cavern shape/size influence the inventory estimate?
- › Smaller cavern volumes show more percent error... less gas mixing?
- › Wide/short cavern has the greatest percent error... large radius compared to height = less accurate temperature measurements?



Model	Result	Value	Units	
Model 3 Tall and Narrow Cavern	Estimated Inventory From Wireline Log	0.7496	bcf	0.02123 x 10 <sup>6</sup> m <sup>3</sup>
	Known Inventory as Defined in Cavern Model	0.7505	bcf	0.2125 x 10 <sup>6</sup> m <sup>3</sup>
	<b>Difference Between Estimated and Known Inventory</b>	<b>0.12</b>	<b>percent</b>	
Model 4 Short and Small Cavern	Estimated Inventory From Wireline Log	0.1955	bcf	0.00554 x 10 <sup>6</sup> m <sup>3</sup>
	Known Inventory as Defined in Cavern Model	0.1960	bcf	0.00555 x 10 <sup>6</sup> m <sup>3</sup>
	<b>Difference Between Estimated and Known Inventory</b>	<b>0.26</b>	<b>percent</b>	



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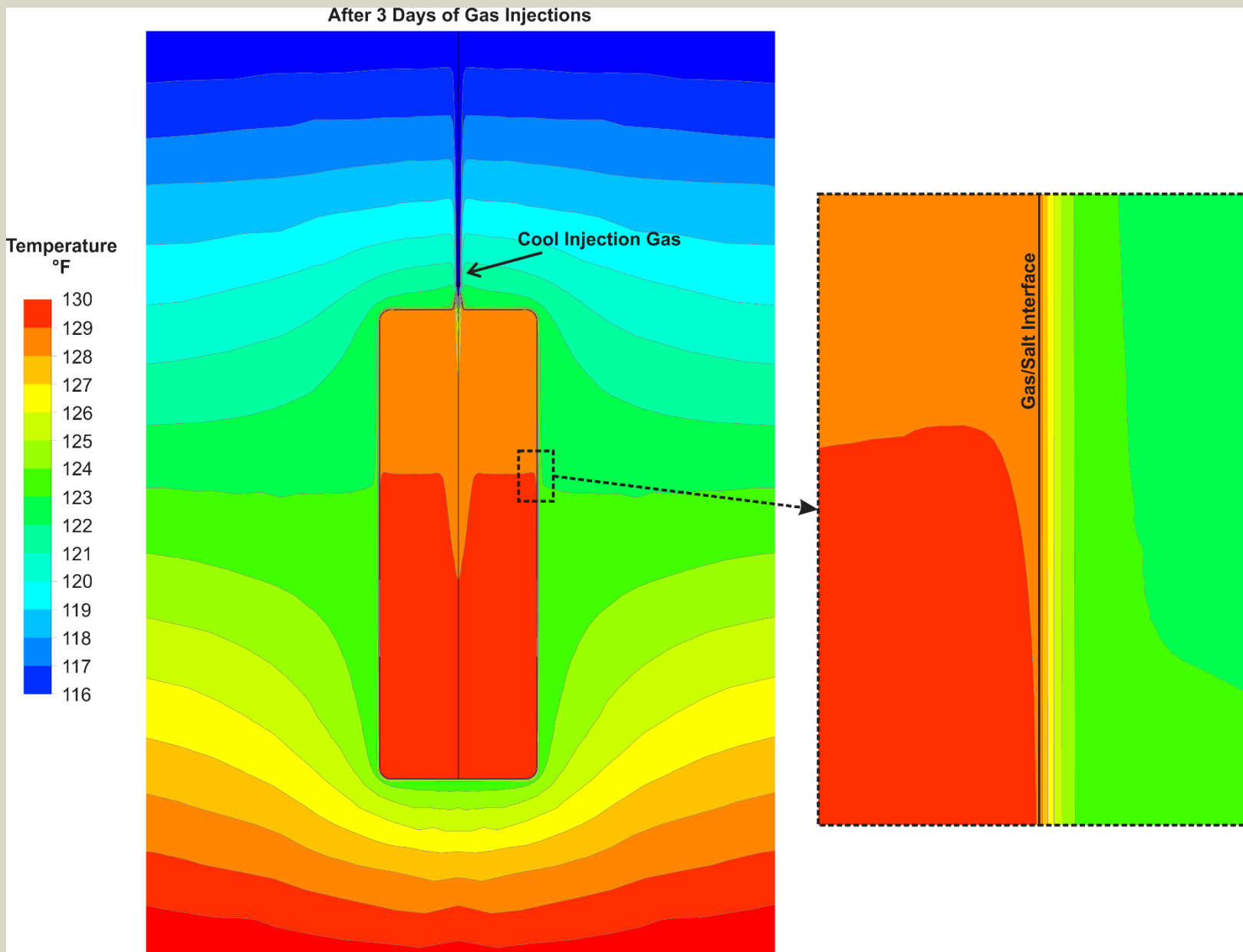
## RESULTS — TASK 3 (RECENT FLOWS)

- › How do recent gas injections/withdrawals influence the inventory estimate?
- › Three days of injection or withdrawals at 100 MMscfd ( $2.8 \times 10^6$  m<sup>3</sup>/d) with an injection gas temperature of 90°F (32°C)
- › How much shut-in time is required until the gas injection and withdrawals do not impact the inventory estimate?

# RESULTS — TASK 3 (RECENT FLOWS)

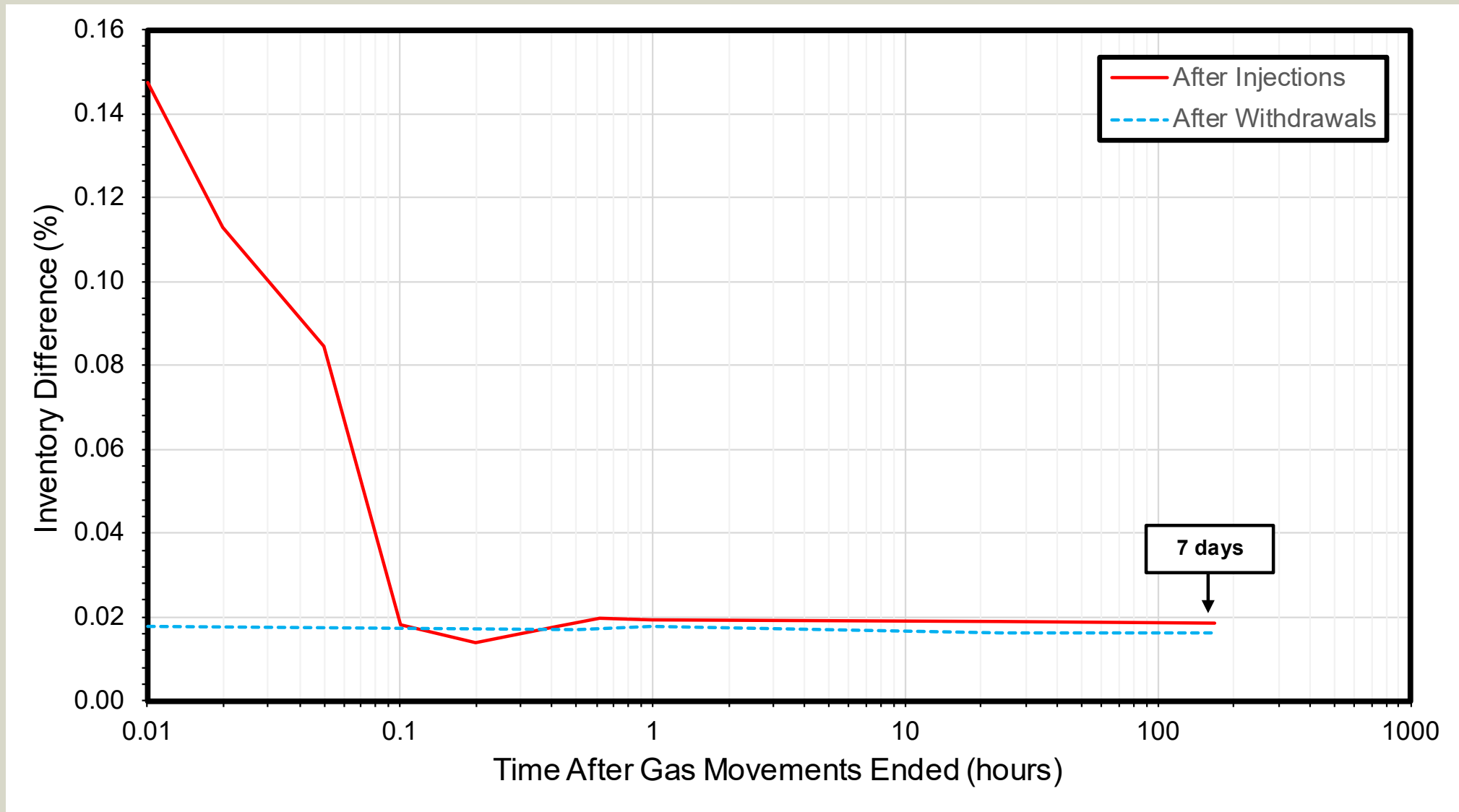


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# RESULTS — TASK 3 (RECENT FLOWS)



# DISCUSSION TOPICS



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# SUMMARY

## Task 1 (with and without brine string):

- › A brine string increases the estimated inventory error by approximately 4x, but the error is less than 0.2%.

## Task 2 (cavern shape/size):

- › Smaller volume and short/wide caverns appear to increase the estimated inventory error, but the error is less than 0.3%.

## Task 3 (recent flows)

- › Compared to withdrawals, injections have more impact on inventory estimates... regardless, error is less than 0.2%



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# SUMMARY

## What does this mean and what are the limitations?

- › **A wireline temperature log at the centerline of a gas cavern appears to accurately represent the gas temperature throughout the entire cavern**
- › **Other factors that were not addressed, but could affect wireline temperature measurements:**
  - / Tool calibration
  - / Measurement noise
  - / Drift
  - / Measurement response time
  - / Humidity
  - / Irregular cavern shapes
  - / Complex flow and/or rewater history
- › **Future step: Validate model based on actual caverns and logs**



# THANK YOU

## QUESTIONS?

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