The U-Tube: A Novel System for Sampling and Analyzing Multiphase Borehole Fluid Samples during the Frio Brine Pilot Test

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ABSTRACT

A novel system has been deployed to sample and analyze multiphase fluids during a geologic CO_2 sequestraion experiment conducted in the Frio brine aquifer beneath Dayton, Texas. Project goals required high frequency recovery of representative and uncontaminated samples of a rapidly changing two-phase (supercritical CO_2-brine) fluid from 1.5 km depth. High quality liquid and gas samples and the relative portion of these constituents to one another, provide insight into the coupled hydrogeochemical issues affecting CO2 sequestration in brine formations. The U-tube consists of a continuous loop of tubing open to the formation using a check valve. High purity compressed nitrogen is used to close the downhole check valve and drive the sample to the surface. The sample is collected at formation pressure, preventing degassing and contamination with outside gases, which lead to rapid changes in sample chemistry. While the basic premise underlying the U-Tube sampler is not new, the system is unique because careful consideration was given to the processing of the recovered two-phase fluids. More specifically strain gages mounted beneath th high pressure surface sample cylinders measure the ratio of recovered brine to supercritical CO_2. A quadrupole mass spectrometer provided real time gas analysis for perfluorocarbon and noble gas tracers that were injected along with the CO_2.

Figure 1. Observation well in foreground.

STATEMENT OF PROBLEM

The Frio Carbon Sequestration Pilot Study was faced with the challenge of performing deep well sampling and downhole monitoring in a small diameter (12.7 cm diameter) observation well (Fig. 1) at a depth of 1.5 km, while injecting over 1,800 tons of CO_2 in a nearby injection well.

STATEMENT OF PROBLEM - CONTINUED

Data Measurements Competing for Space in the Well Include:

- First arrvial and breakthrough of the CO_2 and tracers
- High quality brine and gas chemistry at reservoir conditions
- Brine density and dissolved gases at reservoir conditions
- Formation properties from surface-based wireline geophysical logs
- Bottomhole temperature and pressures

Fig. 2. Electrical Submersible pump

Conventional Approaches and Their Limitations
- Pumps (Fig. 2) or gas-lift techniques degas and contaminate samples, thus compromising brine and gas chemistry
- Wireline samplers cannot take frequent samples and have limited capacity potentially missing CO_2/tracer arrival
- Pumps, geophysical tools, samplers, and sensors compete for space and simultaneous operation is impractical

MATERIALS & METHODS

U-Tube Description
- Consists of a continuous loop of stainless steel tubing that starts and ends at land surface and is strapped to the outside of standard oil field production tubing lowered into the observation well (Fig. 3). Bottom of the U is located 1,513.9 m below land surface just above the production interval
- A check valve at the bottom of the U-tube and above an inflatable packer, controls the movement of fluid from the production interval into the U-tube
- A short tube (or stinger) passes through the packer, connecting the check (and U-tube) to a filter in the production interval below the packer
- The filter passes water and prevents debris from clogging the check valve
- The packer isolates the production interval from the upper portion of the well, minimizing the volume purged to obtain representative fluid samples

U-Tube Operation
- Liquid N_2 is evaporated and resulting gas is compressed to 260 atm (Fig. 3).
- When N2 is injected into the "drive leg" of the U-tube, it closes the check valve at the bottom and forces fluid to the surface via the "sample leg"
- U-tube was purged before sampling to remove residual fluid. After purging, the U-tube was allowed to fill with formation fluid by relieving the pressure

MATERIALS & METHODS - CONTINUED

- N2 was then injected a second time to force fluid out of the U-tube into four high pressure sample vessels where fluid was weighed using strain gauges
- Pressure in vessels was lowered by opening valve at top of vessels. Dissolved and free gases flowing from the vessels were separated from the liquid and then analyzed on site using a quadrupole mass spectrometer
- Data acquisition and U-tube control were automated to improve repeatability

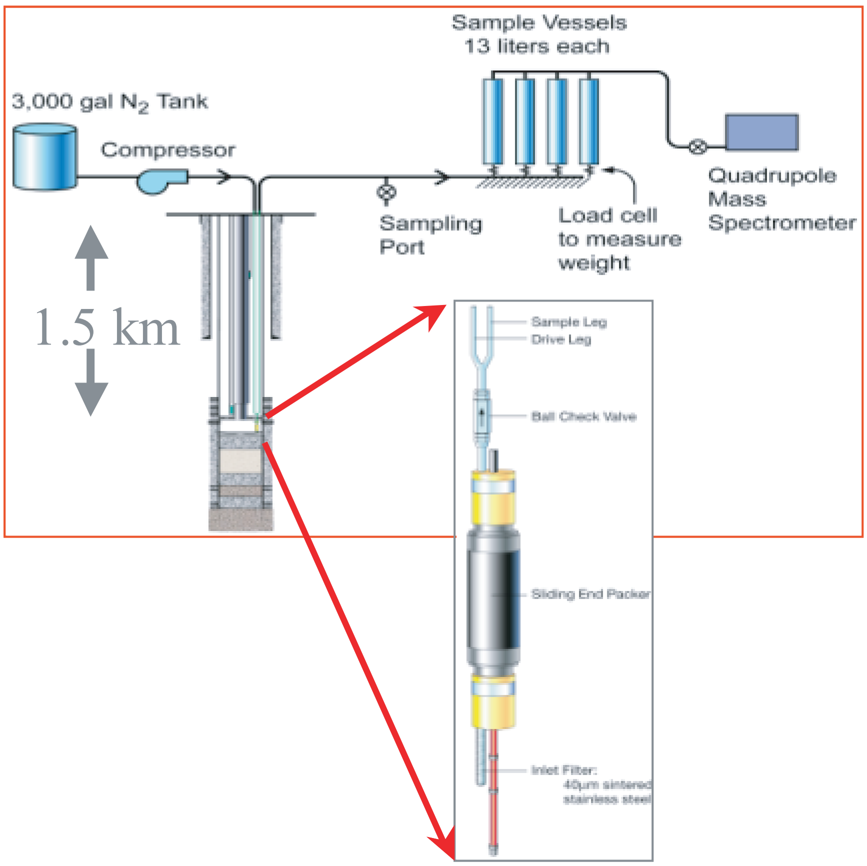


Fig. 3. Schematic of U-tube sampler

RESULTS

- Frequent sampling and real-time analysis allowed quantification of CO2 and tracer break-through (Fig. 4)

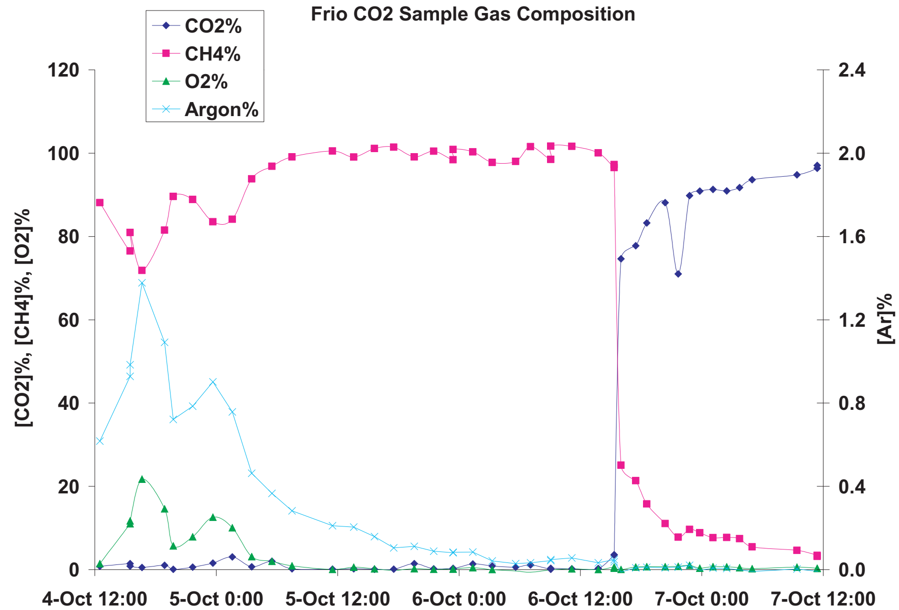


Fig. 4. CO2 breakthrough after 50.9 hours

- High quality hydrochemical samples (Fig. 5)
  * No degassing or atmospheric contamination of fluid
- Center production tube remained open for geophysical logging (Fig. 6)

Fig. 5. Yousif Kharaka (USGS) and Seah Nance (TBEG) collect water samples as CO_2 arrives.

Fig. 6. Schlumberger setting up for geophysical survey of the observation well durig CO_2 food

- Measured fluid density (gas/brine ratio) at reservoir conditions (Fig. 7)

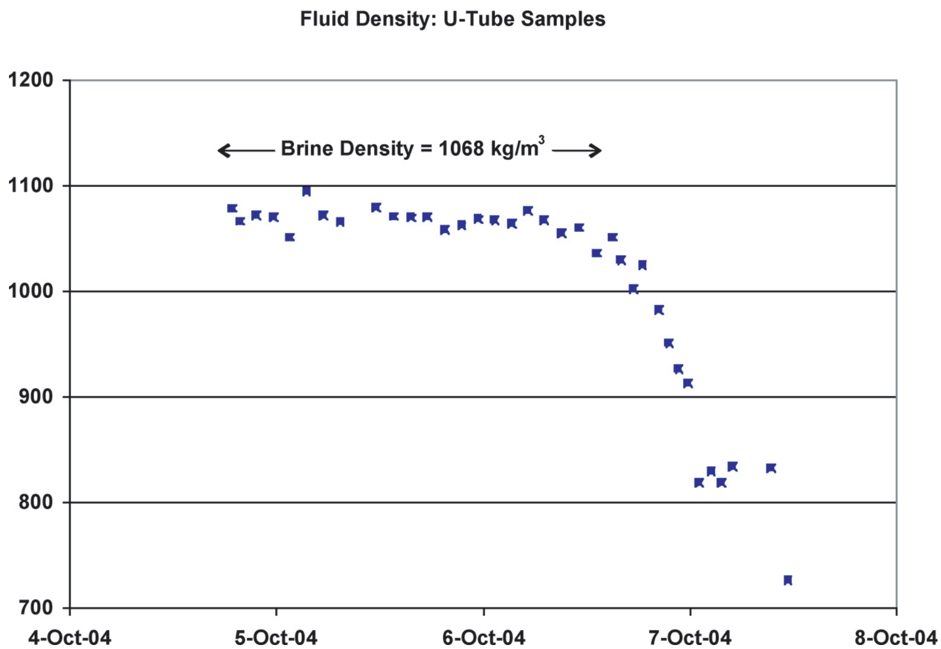
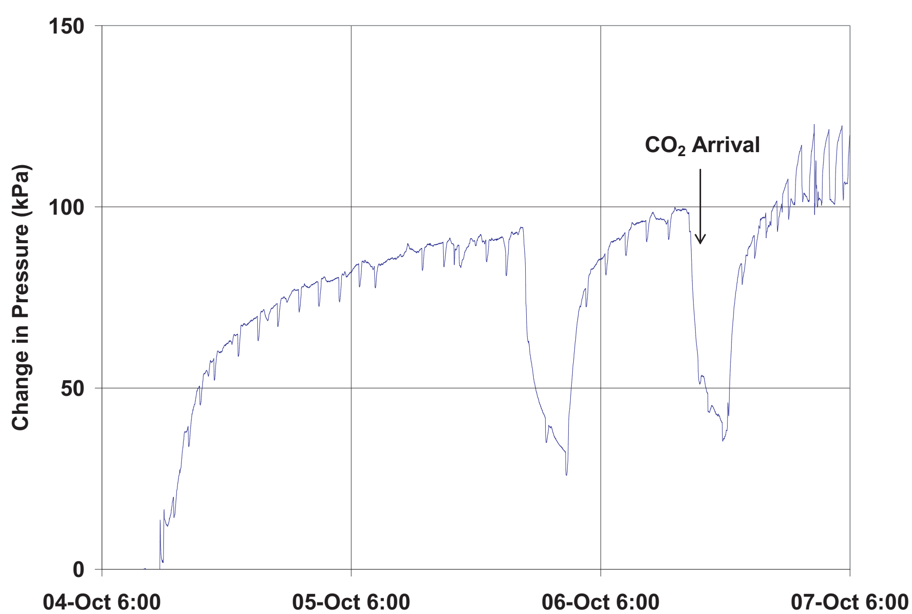


Fig. 7. Change in Fluid density caused by CO_2 arrival

- Bottomhole temperature and pressure sensors incorporated in the design (Fig. 8)

Fig. 8. Pressure Response in observation well during CO_2 injection



CONCLUSION

The goal of simultaneously measuring CO_2 breakthrough, collecting high quality fluid samples, and measuring changes in brine density at reservoir conditions were realized using the U-tube sampler. The U-tube successfully acquired frequent brine and gas samples, allowing accurate delineation fo the arrival of the CO2 plume at a distance of 32 m from the inection well. On-site water and gas analysis revealed rapid changes in geochemical conditions. In addition, the U-tube design incorporated additional program data requirements including measurement of bottom hole temperature and pressure and unfettered access to the center production tube allowed surface-based wireline borehole and geophysical surveys to tak place across the production interval during the experiment.

REFERENCES

Freifeld, Barry M., Christine A. Doughty, Robert C. Trautz, Susan Hovorka, Larry R. Myer and Sally M. Benson, The Frio brine pilot CO2 sequestration test - comparison of field data and predicted results, Chapman Conference of the Science and Technology of Carbon Sequestration, San Diego, CA, January 16-20, 2005

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