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Downhole Reservoir Raman System for Pre-, Peri-, and Post-Injection Characterization of Wellbores During a Sequestration Field Trial in Abandoned Coal Bed Methane Wells in the Powder River Basin.

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Abstract

The goal of this project is to demonstrate the utility of the Downhole Reservoir Raman Spectrometer (DRRS) during sequestration operations to characterize formation conditions in real time and in-situ before, during, and after injection.

Four coal bed methane wells in two formations were logged with the DRRS for composition, temperature, pressure, and conductivity across three phases of the trial. In pre-injection, residual methane gas content was logged. A step-rate injection test was performed to measure changes in pressure and composition of fluid in the monitor during the injection of produced water and characterize communication between wells. In the injection phase, disparate injections of dissolved CO₂ were made over the course of a month. The monitor was intermittently logged to characterize wellbore fluid composition and identify any breakthrough of injection fluids. Post injection, the monitor was logged for breakthrough. The injector wellbore was also logged to characterize the concentration of CO₂ down the water column.

Pre-injection logs of wellbores exhibited undersaturated methane conditions and slight variations in the salinity of fluids among the two formations. These differences in water produced from each formation were useful in characterization of the communication of the injector and monitor during trial. During injections, changes in methane and salinity were observed, suggesting that injection fluid reached the monitor. However, no breakthrough of CO₂ was observed in the monitor during the trial. The log of the injector post injection showed 3 distinct zones of

concentration. In the shallowest ‘Saturated’ zone, beginning at 500’ measured depth (md), a steadily increasing concentration gradient of dissolved CO₂ was observed, which corresponded to the Henry’s saturation prediction based on local pressure, temperature and salinity. In the second ‘Undersaturated’ zone below 750’ md, the concentration leveled off, corresponding with the concentration of dissolved CO₂ in the final injection into the formation, concentration dropped slightly below the Undersaturated level, suggesting that the formation was actively take up CO₂ from the wellbore and depleting the localized dissolved CO₂.

The WellDog DRRS logging tool provides a powerful real-time, *in-situ*, and direct measurement of the composition of formation fluids in a sequestration setting.

Introduction

Carbon capture and storage is a vital tool for managing carbon emissions from heavy industries including cement, steel, oil and gas, data centers and AI, and chemicals. Carbon GeoCapture have revitalized and reinvigorated an approach to carbon capture and storage in unmineable coal seams. Over the past 30 years, the underlying science of carbon sequestration in coal has been extensively researched, including several studies managed by the US Department of Energy (US-DOE) (Stevens 1998; Reeves 2003; Robertson, 2010). The National Energy Technology Laboratory (NETL) Carbon Storage Atlas notes that in contrast to conventional strategies, coal storage involves a significant amount of adsorption trapping (NETL 2015 p. 27). In other words, in addition to or instead of filling the pore-space of the storage formation, in coalbeds gas interacts with and adsorbs to the immense surface area of coal, which has an intricate nanoporous structure. Consider that a single gram of low-rank coal can have a surface area exceeding that of a couple of tennis courts, >200 m²/g (Medeiros 1979). Coalbeds are characteristically saturated with hundreds of feet of water head pressure. It is this pressure which supports high populations of adsorbed gas molecules on these large surface areas. Over thousands of years, catagenic (and biogenic) gases, including CO₂ and methane accumulate in coalbeds. It is the latter of these that is the basis of the unconventional coalbed natural gas industry, which in 2018 reported >10 trillion cubic feet of proved US reserves (Mastalerz 2019). Coal is known to preferentially adsorb CO₂ over methane at ratios from 2 to 13x (Arri 1992; Shi 2008; NETL, 2015)

To observe the interactions between gas and coal, WellDog has developed a downhole reservoir Raman system (DRRS) that characterizes abandoned coalbed wellbores. The DRRS utilizes Raman spectroscopy, a well-established analytical method for observing vibrational, rotational, and other low-frequency modes in molecules. This optically based chemically selective method provides a unique molecular fingerprint for identification. When material is illuminated with light, typically from an intense monochromatic laser, both elastic and scattering (Rayleigh scattering) and inelastic scattering (Raman scattering) of light can result. In Raman scattering, the laser light interacts with molecular vibrations, resulting in a change in the energy of scattered light (Bryndzia 2016). As a result, the DRRS gives real-time downhole analysis and comprehensive quantitative reservoir fluid characterization (Myers 2019, 2025).

Theory and/or Methods

In the Powder River Basin, two pads with two sets of wells perforated through two coalbed methane formations were selected for the sequestration field trial. The distance between pads was 0.4 miles apart with an elevation of ~+60 ft. The DRRS was lowered in each well to log

changes in temperature, gas composition, pressure, and conductivity across the three phases of the trial. First phase is pre-injection, in which the DRRS logged the residual methane gas content. A step-rate injection test was performed to measure changes in pressure and composition of fluid in the monitor during the injection of produced water and characterize communication between wells. In the injection phase, disparate injections of dissolved CO₂ were made over the course of a month. The monitor was intermittently logged to characterize wellbore fluid composition and identify any breakthrough of injection fluids. Post injection, the monitor was logged for breakthrough of injection fluid. The injector wellbore was also logged to characterize the residual concentration of CO₂ down the water column.

Results

For the present expanded abstract, we will describe a log of the injector wellbore 5 days post-injection shown in Figure 1 below. The stable water column in the wellbore exhibited a gradient in the measured dissolved carbon dioxide that followed the hydrostatic pressure gradient from 500' measured depth (md) down to 750' md. Below that, the DRRS-measured concentration of dissolved CO₂ plateaued for 550 feet of the vertical water column at 340 mM, corresponding to a partial pressure of carbon dioxide of 120 PSI. The concentration of dissolved gas in this undersaturated interval is indicative of the concentration of gas injected into the target coal formation. The logged concentration remained at that level down to the depth of the perforations into the target coal formation near 1300' md. Significantly, in the DRRS log over the perforation interval, the measured concentration of dissolved carbon dioxide decreased to 80% of the plateau level, indicating that the local formation coal continued to take up diffusing dissolved carbon dioxide from the wellbore after active injection was halted, depleting the local concentration in the wellbore. Figure 1 also shows the pressure and temperature logs of the injector fluid column. The saturated (500-750' md), undersaturated plateau (750-1300' md), and depleted perforation-interval (1300-1400' md) zones of the fluid column are called out.

Discussion

In this field trial, we demonstrate that DRRS logging can provide critical information in three phases of sequestration in coalbeds: First, in baseline formation characterization to measure formation fluid composition and residual amounts of natural gas, as well as during injectivity testing to characterize communication between wells. Second, during injections to monitor for changes in monitoring wells as fluid is injected, where we determined that injection fluid was reaching the monitoring well depleted of CO₂. Third, post injection, where a final log of the monitoring well confirmed no breakthrough of CO₂, and a log of injection well verified the concentration of injected CO₂ and even suggested that the formation may be actively sorbing and depleting the residual CO₂ from the injection wellbore even days after the injection concluded.

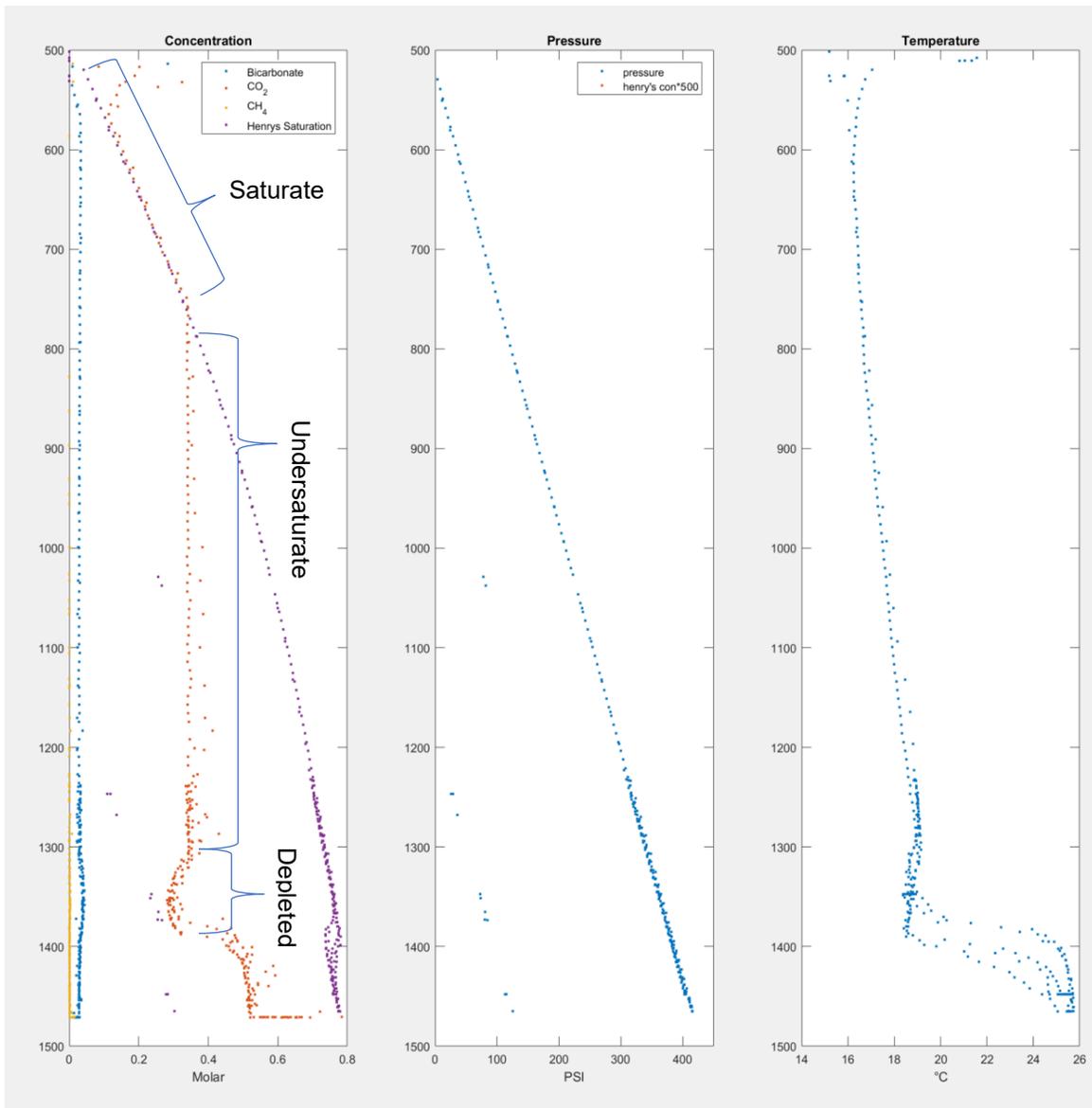


Figure 1, DRRS log of the injector fluid column concentrations, pressure and temperature post injection, with the saturated, undersaturated and depleted zones call out

Conclusions

The DRRS efficiently characterized *in situ* interactions of gas and coal in four abandoned coalbed methane wells, showing in real-time monitoring during pre-, peri-, and post-injection. The results pave a way to understand future carbon capture sequestration efforts.

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