Monitoring an Underground Gas Storage Field with Optical EDAS and DTS Sensors

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Summary

In 2021 Paulsson, Inc. (Paulsson) partnered with Pacific Gas & Electric (PG&E) and California Energy Commission (CEC) to research, develop, manufacture, deploy, and operate a robust, cost-effective, and all-optical Underground Gas Storage (UGS) reservoir surveying and monitoring system. Enhanced Distributed Acoustic Sensor (EDAS) and Distributed Temperature Sensor (DTS) data have been recorded, processed, and analyzed for more than 6 months.

Introduction

Paulsson and PG&E staff installed the optical sensor system in July 2021 and it has been operated 24/7 since October 23, 2021. The system is comprised of about 2,600 sequential Enhanced Distributed Acoustic Sensors (EDAS) and 1,600 sequential Distributed Temperature Sensors (DTS), deployed in a 5,500 ft well servicing a large PG&E UGS field near Stockton in central California (Figures 1 and 2).

Figure 1.The PG&E Underground Gas Storage (UGS) facility at McDonald Island, Central California.

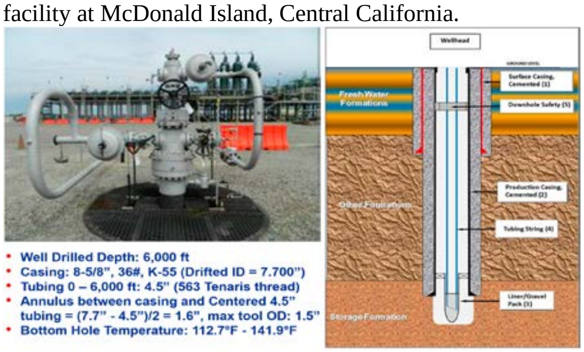

Figure 2. Gas Storage Well at the PG&E McDonald Island.

The primary objective of the project was to determine and demonstrate both the reliability and capability of fiber optic sensor technologies for monitoring natural gas wellbores and UGS reservoirs. Our optical sensor system records the acoustic and temperature data from UGS operations, including gas injection, withdrawal, and formation gas flows. The sensor array has also recorded the impact on the UGS reservoir from many local earthquakes as well as large and distant earthquakes in Japan, Peru, and Fiji, which have all provided seismic sources usable for site characterization, as seen in Figures 5 - 8. The preliminary results of this UGS monitoring project are discussed and its implications for safeguarding Carbon Capture Usage & Storage (CCUS) & Carbon Capture & Storage (CCS) sites is implied.

Background

UGS is an efficient technology to store massive quantities of energy in the form of natural gas. It is six orders of magnitude more effective for long-term and large scale energy storage than battery technologies. UGS is a huge, $500 Billion business in the United States today, with over 15,000 wells, 400 sites, and 120 operators and is expected to grow to a $750 Billion industry within 5 years. In the future, UGS fields that store Green Hydrogen and/or Synthetic Natural Gas, may provide the lowest cost and most flexible approach to storing excess energy from solar, wind and geothermal operations, as well as storing CO2 captured from the air, power generation, and industrial emissions.

Theory & Method

Two distributed fiber sensing technologies were deployed in this project: Enhanced Distributed Acoustic Sensing (EDAS) and Distributed Temperature Sensing (DTS). Both technologies measure the backscatter of light in an optical fiber but use different optical scattering effects within the backscatter. DAS, typically, is an interrogation technique for fiber optic cables that uses the inherent Rayleigh Scattering from a pulse of light to map the relative radian length changes in a fiber optic cable. Since the first patent was granted in 1993, this technology has evolved to become a much used fiber optic sensing option for a number of applications. In contrast, DTS uses Raman Scattering of the propagating pulse of light to record the temperature of the environment surrounding the fiber. Rayleigh Scattering is the strongest scattering effect in the fiber, and thus perturbations can be measured at much higher sampling rates when compared to Raman Scattering DTS measurements. Typical DAS units have a sampling rate that is limited by the sensing length of the fiber, which usually falls in the range of 1-10 kHz. The lower amplitude Raman Scattering requires several tens to hundreds of seconds to make a temperature measurement. Essentially, DTS must be averaged to improve the accuracy of the temperature measurement, and therefore, can take several minutes to make an accurate temperature measurement along the fiber.

This project used a Fotech Helios Theta DAS interrogator to monitor a specially engineered fiber optic cable that has a 10 dB enhancement over that of a standard fiber. The raw data capture of the DAS unit results in spatial sampling of 0.68 meters (2 ft). The gauge length and averaging window have been modified throughout the project; however, the gauge is typically set between 4.0 and 5.3 meters and the averaging window is set to 5 samples, resulting in a window of about 3.4 meters. Enabling an averaging window allows for suppression of noise and other non-advantageous optical effects at the cost of some 'smearing' of the optical signal. The resulting system produces a vibration sensor every 0.68 meters that is the average of the surrounding 3.4 meters of signal along the fiber in the wellbore for a total of 2,616 vibration/acoustic sensors. For DTS a commercial Optical Frequency Domain Reflectometry (OFDR) interrogator based on Raman Scattering was used to monitor a pure silica core fiber, which is engineered to inhibit hydrogen darkening, a common problem in Oil & Gas applications. The unit was setup to average the response for 260 seconds, resulting in a very accurate reading of the temperature sampled every 1 meter (3.28 feet) along the wellbore for a total of 1,646 sensors. DTS data as function of depth is seen in Figure 3 and compared with a temperature log.

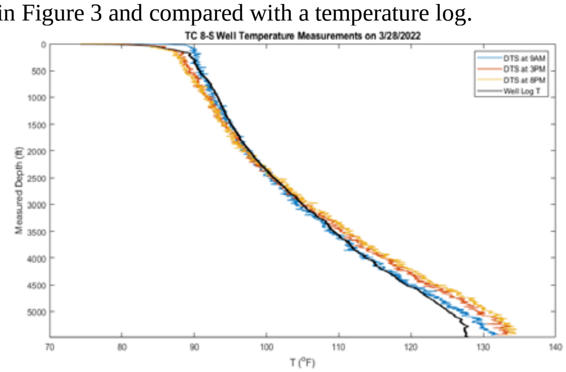

Figure 3. Wireline temperature log (black curve) and the optical DTS data (blue/orange/yellow curves) are shown at three different times. The wireline probe temperature at bottom is artificially low due to mixing of the borehole fluid tool movements. The DTS steady state data is very likely the more accurate data.

A temperature and vibration insulated instrument room, embedded into a 20 ft sea container, was deployed onsite to house instruments and a direct burial cable was trenched from the instrument room to the wellhead, where a splice from Draka Bendbright XS fiber to the downhole fibers was performed. The splice enclosure was rated for explosive environments in accordance with PG&E requirements.

Data Acquisition, Processing and Analysis

The optical sensing data are continuously acquired by an interrogator through a field computer. Software with graphic user interfaces greatly facilitates data acquisition. The field computer can be logged into for remotely operating the interrogator and monitor the data being acquired. Real-time recorded data are displayed remotely in real time. When portions of low-resolution data appear of interest the original recorded data can be downloaded and enhanced to a much higher resolution for further analysis. The DAS data was acquired with a 3kHz sampling rate, from 2,616 channels at a spatial resolution of 0.68 meters. For continuous data acquisition, about 2TB of data are recorded each day. Five, 18 TB external hard drives were used for onsite data storage, so each drive can store one week of DAS data. When the hard drives with recorded DAS data are retrieved and brought to the processing center, an auto-search of the data is performed to screen for possible events. This auto processing can screen five days of DAS data in a single day. It is also possible to run the auto-search on site, enabling the calculation of a Coherent Event Index (CEI) that summarizes the data coherency in each 30-second recording DAS data file. The resulting data is shown in Figure 4. A higher CEI value means the existence of a more coherent event which is caused by outside sources such as wellhead works, earthquakes, and gas injection/withdrawal activities. Figure 4 shows about 30 days of data acquisition out of six months.

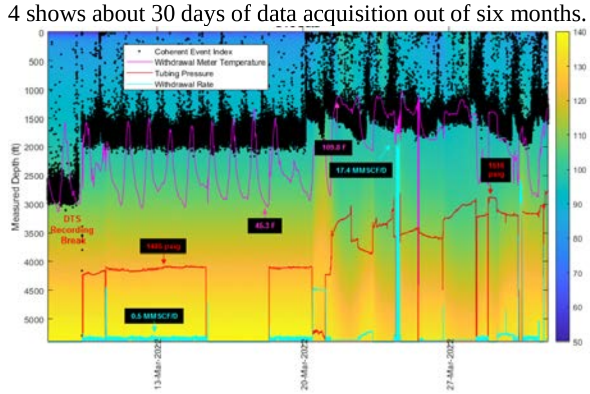

Figure 4. EDAS and DTS data, tubing pressure, gas withdrawal rate and well head temperatures (°F) displayed showing excellent cross-data correlations.

Conclusions

UGS integrity management programs can find significant value in deploying fiber-optic survey and monitoring systems to address several operational issues. As was shown in Figure 4 above, the Paulsson/PG&E monitoring system was able to detect and map different flowing conditions of the well during flow periods. This optical sensor data can also be used to show how the thermal conditions of the well change as the well acclimates to the temperature of the flowing gas. The optical systems can also be used to monitor earthquakes and other seismic events occurring near and far to the fiber optic monitoring systems installation. Additional research is being performed to identify the well and reservoir integrity related aspects of the fiber optic monitoring system as well as any

Figure 3. The epicenter of the Fukushima M7.3 earthquake on 3/16/2022 and the fiber optical sensor arrays installation on Macdonald Island 5,000 miles from Japan.

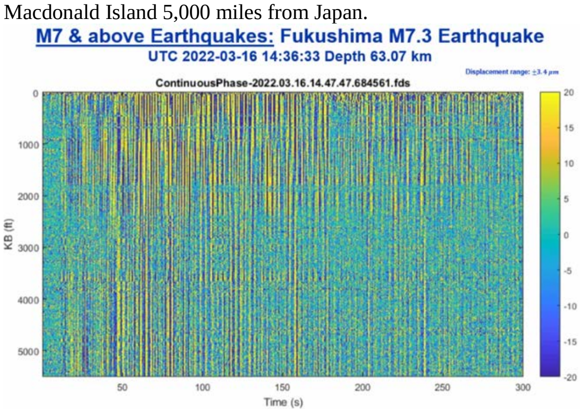

Figure 4. The Fukushima M 7.3 major earthquake recorded by EDAS at the PG&E UGS site with strong amplitudes and long duration (more than 5 minutes). The signal fading around 3,000 ft might be due to reservoir properties.

observations related to lithology, stratigraphy, and the gas permeability of the reservoir. Additional research should pay particular attention to the changes in wellbore and reservoir related information describing the wells operating condition during different phases of operation. The system can be solar powered which will reduce its carbon footprint by eliminating generator power. The immense volume of data being recorded and stored is a challenge, likely necessitating the use of machine learning, artificial intelligence processing and high-speed data links. Finally, the current capital and operating cost of our first monitoring system, including installation, and recurring data capture and processing expenses, needs to be reduced. It is highly likely that many of these challenges will be overcome as the systems are scaled up from one well to an entire field application. The desire to increase monitoring capabilities continues to grow and this technology could offer the capability to acquire monitoring data more frequently with a much lower execution risk than wireline or rig-deployed surveys. The same technologies develop for UGS applications are directly applicable to CCUS/CCS projects, as well as monitoring other subsurface infrastructure including pipelines.

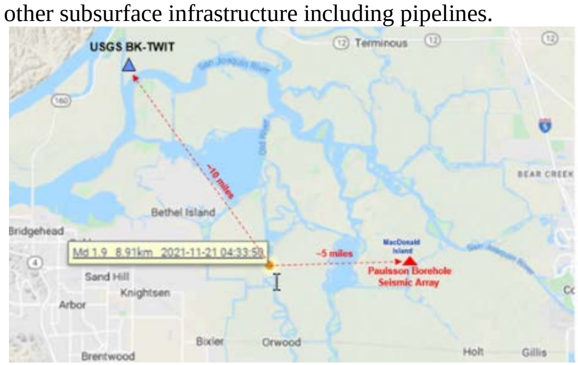

Figure 5. A map of a small earthquake (M1.9), close to the borehole with fiber optic sensors (5 miles or 8 km).

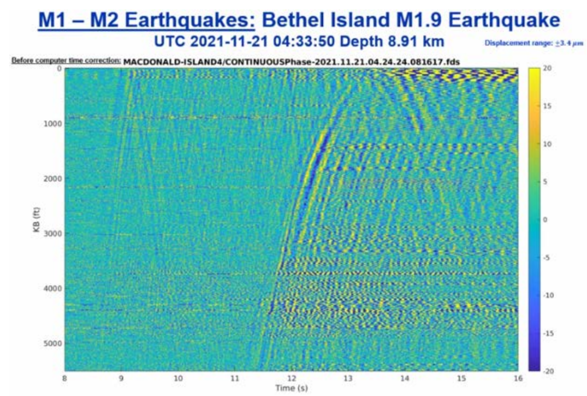

Figure 6. A minor local earthquake, M 1.9, recorded by the EDAS system with P and S waves, and reflections from the surface. The high frequency events @ 12 seconds correlate with lithology.

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