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PRE-OPERATIONAL TESTING PROGRAM

One Earth CCS

Facility Information

Facility name:	One Earth Sequestration LLC Injection Wells: OES #1, OES #2, OES #3
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Well location:	McLean County, IL OES #1: 40.845427°N, -88.480010°W (NAD 1983) OES #2: 40.500096°N, -88.474625°W (NAD 1983) OES #3: 40.515829°N, -88.479947°W (NAD 1983)

Introduction

The testing activities at the One Earth CCS project described in this attachment are restricted to the pre-injection phase. Testing and monitoring activities during the injection and post-injection phases are described in the Testing and Monitoring Plan, along with other non-well related pre-injection baseline activities such as geochemical monitoring.

A stratigraphic test well (OEE #1) was constructed for the purpose of site characterization. The well and the testing results are described in the permit application Narrative. OEE #1 will be converted to an in-zone monitoring well (IZM #1) for the project. The pre-operational formation testing program will be implemented at each injection well to verify the chemical and physical characteristics of the injection zone and confining zone(s). The data gathered from OEE #1 is used to guide the scope of testing at each injection well and deep, in-zone monitoring well.

The program is developed to meet the testing requirements of 40 CFR 146.87 and well construction requirements of 40 CFR 146.86. The pre-operational testing program will include a combination of wireline logging and side-wall coring. In addition, formation geohydrologic testing will be completed to verify injectivity of the storage formation.

The pre-operational testing program will determine or verify the depth, thickness, mineralogy, lithology, porosity, permeability, and geomechanical information of the Mount Simon Sandstone (CO_2 injection zone), the overlying Eau Claire Formation (confining zone), and other relevant geologic formations. In addition, formation fluid characteristics will be obtained from the Mount Simon Sandstone to establish baseline data against which future measurements may be compared. The results of the testing activities will be documented in a "Pre-operational Testing Narrative" report and submitted to the EPA after the well drilling and testing activities have been completed, and before the start of CO_2 injection operations.

After completing the characterization and testing, the borehole will be completed as an injection well. Mechanical integrity tests (e.g., wireline and pressure tests) will verify well construction and integrity.

Pre-Injection Testing Plan – Injection Wells

The following tests and logs will be conducted during drilling, casing installation and after casing installation in accordance with the testing required under 40 CFR 146.87(a), (b), (c), and (d). The tests and procedures are described below and in the proposed Injection Well Construction Information section of the permit application Narrative.

Deviation Checks

Two single shot surveys will be acquired during the surface section installation, then at least every 500' below the surface casing set depth to total depth. If wellbore deviation issues develop, additional surveys will be performed as necessary and drilling methods will be adapted as needed.

Tests and Logs

Open-borehole logs will be run to obtain densely spaced, in situ, structural, stratigraphic, physical, chemical, and geomechanical information for Mount Simon Sandstone, the Eau Claire confining zone, and other key formations. Open-borehole characterization logs will be obtained at the surface casing point, the intermediate casing point, and at the long-string casing point (i.e., total borehole depth). No open-borehole wireline logs are planned to be run in the conductor casing borehole. Open-borehole logs may include caliper, gamma, spontaneous potential (or brine formation equivalent), resistivity, neutron, density, photoelectric cross-section, sonic (full waveform), nuclear magnetic resonance, resistivity-based and/or acoustic-based micro-image, and gamma spectroscopy logs.

Fluid temperature, pH, conductivity, reservoir pressure and static fluid level of the injection zone will be measured prior to injection.

Coring

Side wall core samples will be collected from the Mount Simon CO_2 injection zone and the overlying Eau Claire confining zone. The coring program will provide core to augment core data obtained from OEE#1.

Demonstration of mechanical integrity

Tests and logs will be conducted as needed (per 40 CFR § 146.8(c)) to demonstrate the internal and external mechanical integrity of the injection wells prior to initiating regular CO_2 injection.

Internal mechanical integrity refers to the absence of leaks in the tubing, packer, and casing above the packer. External mechanical integrity refers to the absence of fluid movement/leaks through channels adjacent to the injection well bore that could result in fluid migration into an USDW.

External Mechanical integrity tests are required to demonstrate no significant fluid movement into an underground source of drinking water through vertical channels adjacent to the injection well bore. This is typically demonstrated through an oxygen activation log, a temperature log, a noise log, or an alternative test approved by the Director of the EPA. The procedure and type of MIT

will depend on the conditions of the site and the well. At present, temperature logs as well as cement bond logs as noted in Table 1 are planned.

Table 1. *External mechanical integrity tests for injection wells*

Name	Depth Interval (feet)	Open Hole Logs	Cased Hole Logs
Surface	0 – 374	Resistivity SP Caliper	Radial CBL/VDL or Ultrasonic Temperature Oxygen Activation
Intermediate	374 – 4,046	Resistivity SP Caliper	Radial CBL/VDL or Ultrasonic Temperature
Long	4,046 – 7,100	Resistivity SP Caliper Porosity Gamma Ray Fracture Finder	Radial CBL/VDL or Ultrasonic Temperature Oxygen Activation

A baseline temperature log and oxygen-activation log will be run on the well after well construction but prior to commencing CO_2 injection to provide a baseline reference for comparing future temperature logs and oxygen-activation logs as they relate to the well's external mechanical integrity. In addition, each injection and in-zone monitoring well will be equipped with a fiber optic cable to measure temperature.

A more detailed discussion of internal and external mechanical integrity testing during the service life of the injection wells is provided in the Testing and Monitoring Plan.

Oxygen Activation Log

A wireline tool is deployed to activate oxygen by emitting high-energy neutrons from a neutron source. The activated isotopes emit gamma radiation which is measured by the wireline tool. Gamma ray measurements are used to calculate water flow direction and velocity. If water flow outside of the casing is detected it could indicate the potential loss of external mechanical integrity. To minimize false positives, a calibration will be performed and measurements will be confirmed at several nearby depths and/or under a minimum of three varying injection rates.

Temperature Log

Temperature logging detects leaks by measuring temperature anomalies due to fluid movement adjacent to the well bore. Fluid leaks from the wellbore are typically a different temperature compared to native fluids. Temperature logs are run after the well has been shut-in long enough for temperature effects to dissipate, leaving a relatively simple temperature profile (typically ~36 hours). While the absolute gradients may differ due to injection history, the relative profiles should be consistent. If there has been a leak of fluid out of the well, there may be anomalous heating or cooling effect as compared to the baseline or another log. Gradient variation due to lithologic changes are expected. Distributed fiber sensing or electric wireline deployed temperature measurement devices can be used and should be of sufficient resolution and sufficiently calibrated to detect changes.

Pulsed Neutron Monitoring

Pulsed neutron logging detects leaks by measuring changes in the capture cross section of the fluids and gasses in the pore space of the rock using a wireline tool that emits neutrons which are slowed to a thermal velocity through elastic and inelastic collisions with the nuclei of the environment's elements and ultimately captured. These interactions are sensitive to fluid type and saturation changes in the formation and in the casing-formation annulus. Therefore, pulsed neutron measurements can be used to monitor the formation fluids as well as identify mechanical integrity problems. The pulsed neutron Sigma (Σ) is the thermal neutron capture cross section or the rate at which thermal neutrons are captured by the formation matrix and fluids. The capture cross section can be used to detect fluid changes behind casing over time to verify the well external mechanical integrity. Open hole wireline logs for lithologic definition and baseline pulsed neutron logs are key inputs to this type of monitoring.

Below is a summary of the MITs and pressure fall-off tests to be performed prior to injection:

Table 2. *Pre-Operational Testing Schedule*

Class VI Rule Citation	Rule Description	Test Description	Program Period
40 CFR 146.89(a)(1)	MIT - Internal	Annulus pressure test	After well completion
40 CFR 146.87(a)(4)	MIT - External	Cement bond log	After cementing shallow, intermediate, and long strings
40 CFR 146.87(a)(4)	MIT - External	Temperature log	After cementing shallow, intermediate, and long string
40 CFR 146.87(a)(4)	MIT - External	Pulsed Neutron	After cementing long string
40 CFR 146.87(e)(1)	Testing prior to operating	Injection and Pressure fall-off test	After well completion

One Earth Sequestration, LLC will notify EPA at least 30 days prior to conducting the tests and provide a detailed description of the testing procedure. Notice and the opportunity to witness these tests/logs shall be provided to EPA at least 48 hours in advance of a given test/log.

Pre-Injection Testing Plan – Deep Monitoring

The testing and logging procedure for the deep monitoring wells will be similar to the injection well program.

Well Deviation Checks

Two single shot surveys will be acquired during the surface section, then at least every 500' below the surface casing set depth to total depth. If wellbore deviation issues develop, additional surveys will be performed as necessary and drilling methods will be adapted as needed.

Tests and Logs

Open-borehole logs will be run to obtain densely spaced, in situ, structural, stratigraphic, physical, chemical, and geomechanical information for Mount Simon Sandstone, the Eau Claire confining zone, and other key formations. Open-borehole characterization logs will be obtained at the surface casing point, the intermediate casing point, and at the long-string casing point (i.e., total borehole depth). No open-borehole wireline logs are planned to be run in the conductor casing borehole. Open-borehole logs may include caliper, gamma, spontaneous potential (or brine formation equivalent), resistivity, neutron, density, photoelectric cross-section, sonic (full waveform), nuclear magnetic resonance, resistivity-based and/or acoustic-based micro-image, and gamma spectroscopy logs.

Fluid temperature, pH, conductivity, reservoir pressure and static fluid level of the injection zone will be measured prior to injection.

Below is a summary of the MITs to be performed on the deep monitoring well(s), IZM#1 and IZM#2, after installation and prior to commencing CO_2 injection operations:

***Table 3**. Mechanical Integrity Tests*

Test Name	Test Description	Program Period
MIT – Internal	Annulus Pressure Test	After well completion
MIT – External	Cement Bond Log	During installation

Notice and the opportunity to witness the test/log shall be provided to EPA at least 48 hours in advance of a given test/log.

Annulus Pressure Test Procedures for Injection Well:

After the injection wells are completed, including the installation of tubing, packer, and annular fluid, a test of the well's internal mechanical integrity will be performed by conducting an annular pressure test (Standard Annulus Pressure Test (SAPT)). This is a short-term test wherein the fluid in the annular space between the tubing and casing is pressurized, the well is shut-in, and the pressure of the annular fluid is monitored for leak-off. EPA Region 5 (EPA [2008)] * requires comparison of the pressure change throughout the test period to 3 percent of the test pressure (0.03 x test pressure). If the annulus test pressure decreases by this amount or more, the well has failed to demonstrate internal mechanical integrity. If the annulus pressure changes by less than 3 percent during the test period, the well has demonstrated internal mechanical integrity. If the well does not meet this requirement, the tubing and packer may need to be removed from the well to determine the cause of the leak. EPA Region 5 guidance (EPA [2008)] * for conducting the test will be consulted when performing this test.

The general procedure for the test is summarized from EPA 2008 and includes:

1. The tubing/casing annulus (annulus) will be filled with liquid. Temperature stabilization of the well and annulus liquid is necessary prior to conducting the test. This will be achieved by filling the annulus with liquid and either ceasing injection

or maintaining stabilized injection (i.e., continuous injection at a constant rate and constant injection fluid temperature) before and through the test.

2. No unapproved substances will be added to the annulus liquid.
3. After stabilization, the annulus will be pressurized to a surface pressure of no less than 300 psig. A positive pressure differential between the pressure in the annular space and the injection tubing pressure of at least 100 psi will be maintained throughout the entire annulus (from the top of the packer to the surface). Specific gravity differences between liquids in the annulus and the tubing should be accounted for when determining the appropriate test pressure.
4. Following pressurization, the annular system will be isolated from the source of pressure. The annulus system will remain isolated for a period of no less than 60 minutes.
5. During the active CO_2 injection phase, internal mechanical integrity will be continuously monitored by the well annular pressure maintenance and monitoring system, as discussed in more detail in the Testing and Monitoring Plan. After the SAPT test period has been completed, the valve to the annulus will be opened and liquid returns from the annulus observed and measured.

Annulus Pressure Test Procedures for Monitoring Well:

The Standard Annulus Pressure Test (SAPT) as described above and in EPA 2008 will also be used to determine internal mechanical integrity of the in zone and above zone monitoring wells. See additional detail for Injection well annulus pressure test.

Injection and Pressure Fall-Off Test Procedures:

Baseline pressure fall-off tests (PFO) will be conducted as described in the Testing and Monitoring Plan and in the Pre-Operational Testing Plan. The objective of the testing is to periodically monitor for changes in the near well bore environment that would impact injectivity or cause injection pressures to increase (US EPA, 2013). Testing location and frequency

Baseline pressure fall-off testing will be performed in each injection well (OES#1, OES#2, OES#3):

A pressure falloff test has a period of injection followed by a period of no-injection or shut-in. Normal injection will be used during the injection period preceding the shut-in portion of the falloff tests. However, if the rate causes relatively large changes in bottomhole pressure, the rate may be decreased. A minimum, one week of relatively continuous injection will precede the shut-in portion of the falloff test. The pressure Fall-Off data will be measured using a downhole gauge sampling at 5-second intervals. The gauges may be those used for day-to-day data acquisition, or a pressure gauge conveyed via wireline. Surface or downhole gauges will be used to inform test duration. The shut-in period of the falloff test will be adequate to assure that enough pressure transient data are collected to calculate the average pressure. Quantitative analysis of the measured data is used to estimate formation characteristics, including transmissivity, permeability, and a skin factor. The measured parameters will be compared to those used in site computational modeling and Area of Review delineation.

References

U.S. Environmental Protection Agency, 2008. *Determination of the Mechanical Integrity of Injection Wells, Region 5, Underground Injection Control (UIC) Branch Regional Guidance* #5.

U.S. Environmental Protection Agency, 2013. *Geologic Sequestration of Carbon Dioxide – Underground Injection Control (UIC) Program Class VI Well Testing and Monitoring Guidance*.