IMPROVED CHARACTERIZATION AND MODELING OF TIGHT OIL FORMATIONS FOR CO_2 ENHANCED OIL RECOVERY POTENTIAL AND STORAGE CAPACITY ESTIMATION

Research Performance Progress Report (quarterly)

(for the period October 1 – December 31, 2015)

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IMPROVED CHARACTERIZATION AND MODELING OF TIGHT OIL FORMATIONS FOR CO_2 ENHANCED OIL RECOVERY POTENTIAL AND STORAGE CAPACITY ESTIMATION

Quarterly Progress Report
October 1 – December 31, 2015

EXECUTIVE SUMMARY

The injection of carbon dioxide (CO_2) into oil reservoirs for simultaneous enhanced oil recovery (EOR) and CO_2 storage continues to be an important tool which has the potential to reduce anthropogenic CO_2 emissions to the atmosphere. CO_2 EOR and storage operations in conventional oil reservoirs have been conducted at many locations for decades, and the mechanisms that control successful EOR and storage in conventional reservoirs are well understood. However, there has been little experience injecting CO_2 into unconventional tight oil formations, and the controlling factors are not well understood. The Energy & Environmental Research Center (EERC) is conducting a research program to evaluate the characteristics of the rocks and physical–chemical mechanisms affecting CO_2 permeation and oil extraction in tight, organic-rich, oil-wet and mixed-wet systems. The project is using samples from the Bakken Formation in North Dakota, which is one of the most prolific oil-producing unconventional tight formations in the world. The objective is to assess and validate CO_2 transport and flow in the Bakken by conducting a series of laboratory- and modeling-based activities to determine the effects of micro- and nanoscale fracture and pore networks, as well as the nature of the wetting fluid, on CO_2 storage and EOR in the Bakken tight oil formation. This effort will also generate data to further illuminate the roles that the shale members may play with respect to CO_2 storage, containment, EOR or, possibly, even all three. The overall project goal will be accomplished through two phases. The Phase I objective is the development of advanced characterization methods to better understand and quantify the petrophysical and geomechanical factors that control CO_2 and oil mobility within tight oil formation samples. Phase II has two objectives. The first objective of Phase II is the determination of CO_2 permeation and oil extraction rates in tight reservoir rocks and organic-rich shales. The second Phase II objective is to integrate the laboratory-based CO_2 permeation and oil extraction data and the characterization data from Phase I into geologic models and dynamic simulations to develop predictions of CO_2 storage capacity and EOR in the Bakken tight oil formation. During this quarter, Deliverable (D)3 – Sample Characterization Data Sheets was completed and Milestone (M)4 – Completion of Baseline Sample Characterization was achieved. Laboratory activities to characterize the kerogen-bitumen content of selected Bakken samples were conducted. The results of micro- and nanoscale fractures and pores using micro-computerized tomography (micro-CT) and advanced scanning electron microscopy (SEM) techniques at Ingrain were evaluated, interpreted, and integrated into the overall project results database. An abstract for a paper entitled "The Use of Advanced Analytical Techniques to Characterize Micro- and Nanoscale Pores and Fractures in the Bakken" was submitted for presentation at the 2016 Unconventional Resources Technical Conference (URTeC).

Task 1.0 – Project Management and Planning

Monthly project progress summaries were compiled and provided to the U.S. Department of Energy (DOE) Technical Monitor. Milestone M4 – Completion of Baseline Sample Characterization was completed. Deliverable report D3 – Sample Characterization Data Sheets was submitted to the DOE Technical Monitor. A representative of the EERC met with representatives of Marathon Oil Co. (MOC) in Houston, Texas, to discuss recent results and future activities.

Task 2.0 – Sample Selection and Detailed Baseline Characterization

Milestone M4 – Completion of Baseline Sample Characterization, has been achieved. A suite of geochemical, geomechanical, and petrophysical analyses have been performed on the rock samples. The characterization data generated by this effort includes breakthrough pressure testing, mercury injection capillary entry pressure (MICP) testing, porosity/grain density determinations, optical microscopy (OM), x-ray fluorescence (XRF), x-ray diffractometry (XRD), SEM coupled with energy dispersive x-ray spectroscopy (EDS) and mechanical strength testing. These data have been compiled into data sheets for each sample.

Task 3.0 – Development of Improved Methodologies to Identify Multiscale Fracture Networks and Pore Characteristics

The results of its micro-CT and advanced SEM techniques on the MOC samples were evaluated and interpreted. The data on bulk density, organic matter volume, mineralogy, porosity, fracture and pore throat geometry and distribution at the micro- and nanoscales were evaluated and interpreted in the context of the previously generated rock properties data.

ACCOMPLISHMENTS

Major Goals of the Project

The goal of this project is to develop advanced analytical characterization and geomodeling techniques to better estimate the potential for CO_2-based EOR and CO_2 storage in unconventional tight oil formations. The project will accomplish this goal by using samples collected from the tight, fractured reservoir and oil-wet, organic-rich shales within the Bakken petroleum system to do the following:

- Develop methods to better detect and characterize the macro-, micro-, and nanoscale pores and fracture networks within tight, fractured reservoirs and within organic-rich shales.

- Determine if there are significant correlations between fracture network characteristics and the physical, geochemical, and/or geomechanical properties of the rock that can be used to improve well log calibration and interpretation, thereby allowing for improved identification of fracture networks using well logs.

- Determine the rates of CO_2 permeation within, and oil extraction from, the matrix of tight oil formation rocks, including oil-wet, organic-rich shales.

- Assess how CO_2 capillary entry pressure at the reservoir–seal interface is affected by the wetting fluid of tight oil formation rocks, including oil-wet and mixed-wet reservoir rocks and oil-wet organic-rich shales.

- Develop improved methods to integrate detailed rock characterization data into geocellular and simulation models to improve their accuracy in predicting the CO_2 storage capacities and potential incremental oil production through EOR in a tight oil reservoir and to evaluate the ability of oil-wet, organic-rich shales to store and/or contain CO_2 and possibly produce oil.

Task 1.0 – Project Management and Planning

Monthly project progress summaries and Deliverable report D3 – Sample Characterization Data Sheets were submitted to the DOE Technical Monitor. A representative of the EERC met with representatives of MOC in Houston, Texas, to discuss recent results of characterization of core samples provided by MOC. Future activities were also discussed.

Task 2.0 – Sample Selection and Detailed Baseline Characterization

Subtask 2.1 was completed in a previous quarter.

Subtask 2.1 – Sample Identification and Selection

This subtask is complete.

Subtask 2.2 – Laboratory Determination of Baseline Rock Properties.

Milestone 4 – Completion of Baseline Sample Characterization, has been achieved. A suite of geochemical, geomechanical, and petrophysical analyses have been performed on the rock samples. The characterization data generated by this effort includes breakthrough pressure testing, MICP testing, porosity/grain density determinations, OM, XRF, XRD, SEM coupled with EDS, and mechanical strength testing. These data have been compiled into data sheets for each sample. Those data sheets were provided to the DOE project manager during this quarter as D3 – Sample Characterization Data Sheets. The data sheets are maintained electronically and are considered to be a living document, as the specialized data (e.g., micro-CT, advanced SEM, kerogen content, etc.) that will be generated over the course of the project will be added to those sheets as that data becomes available.

Subtask 2.3 – Laboratory Evaluation of the Effects of CO_2 on Kerogen and Bitumen in Bakken Shale

A series of laboratory experiments under reservoir temperature and pressure conditions on samples of Bakken shale were initiated to develop an improved understanding of the kerogen-

bitumen content of Bakken shale samples. Specifically, maturation studies were conducted using a standard RockEval test. A subsequent array of experiments is planned to be conducted in the next quarter using CO_2, with the precise conditions to be determined by the initial RockEval results. Insight regarding the effect that CO_2 has on kerogen and bitumen will be developed by comparing the results of the experiments that used inert gas in the maturation process with those that used CO_2. These data will ultimately be incorporated into the models to be developed under Task 5.

Task 3.0 – Development of Improved Methodologies to Identify Multiscale Fracture Networks and Pore Characteristics

Subtask 3.1 – Core-Scale Fracture Analysis.

Whole-core CT scanning over the fractured reservoir and shale interval from three wells has been completed. The fracture analysis results from the whole-core CT scanning were provided to the technical team in July 2015.

Subtask 3.2 – Macrofracture Characterization

Dual-energy x-ray CT was conducted on slabbed core across the entire interval from the top of the Upper Bakken Shale, through the entire portion of the Middle Bakken reservoir, and to the bottom of the Lower Bakken Shale for three wells. The CT results were provided in July 2015 and will be integrated into future modeling activities.

Subtask 3.3 – Micro- and Nanoscale Fracture and Pore Analysis

Based on the results of Ingrain's initial characterization activities on the MOC samples, sample points were selected for more detailed characterization using micro-CT and advanced SEM techniques. These techniques will enable characterization of features such as fractures and pore throat networks at the micro- to nanoscale. The sample points were selected with input and guidance from MOC's technical staff. In September, Ingrain provided the results of its micro-CT and advanced SEM techniques on the MOC samples. Specifically, white light, XRF, fluorescence, micro-CT imaging, and ion-milled 2-D and 3-D SEM was conducted on slabbed core across the entire interval from the top of the Upper Bakken Shale, through the entire portion of the Middle Bakken reservoir, and to the bottom of the Lower Bakken Shale. This provided bulk density, organic matter volume, mineralogy, porosity, fracture, and pore throat analysis data at the micro- and nanoscales and other relevant petrophysical characteristics. The results were evaluated and interpreted in the context of the previously generated rock property data. Relationships between the distribution of organic matter and clays relative to nanoscale connected pore network features were noted and will be the subject of future examination and scrutiny by the technical team.

Subtask 3.4 – Development of Multiscale Pore and Fracture Models

The laboratory-based rock characterization information is being used to develop a multiscale pore and fracture model for use in the development of a geologic model. Specifically,

fractal analysis of fracture networks and pore distributions are being conducted on a range of scales, from the nano- and microscale (using field emission scanning electron microscopy FESEM) to the macroscale (using conventional SEM, OM, ultraviolet fluorescence, and visual core analysis). Techniques described in the literature to characterize the fractal properties of features and to develop multiscale models of fracture and pore networks are being used for this effort. The laboratory-derived characterization data on the core used in Subtasks 2.2, 2.3, 3.1, 3.2, and 3.3 are being incorporated into a series of models in an effort to fully understand the relationship between the rock matrix and pore systems within the Bakken Formation. This will ultimately lead to a better understanding of fracture flow, geochemical reactions, kinetic rates of reactions, and geomechanical properties affected by fluid flow.

The next quarter will see the initiation of fractal modeling that will also be used to estimate sample permeability through image analysis techniques. The results of these analyses will be compared to MICP analyses collected through Task 2.

MILESTONE STATUS REPORT

Task/ Subtask	Milestone Title	Planned Completion Date	Actual Completion Date	Verification Method	Comments
1.1	M1 – Update Project Management Plan (PMP)	12/31/14	12/31/14	PMP file	
1.2	M2 – Kickoff Meeting	1/31/15	12/4/14	Presentation file	
2.1	M3 – First Samples Collected for Characterization	12/31/14	12/31/14	Status reported in subsequent quarterly report	
2.2	M4 – Completion of Baseline Sample Characterization	10/31/15	10/31/15	Sample characterization data sheets	
3.2	M5 – First Macroscale Fracture Data Sets Generated	6/30/15	6/30/15	Status reported in subsequent quarterly report	
3.3	M6 – Completion of Fracture Network Characterization	4/30/16		Interim report at conclusion of Phase I	
4.2	M7 – Completion of CO_2 Permeation Testing	2/28/17		Status reported in subsequent quarterly report	
4.4	M8 – Completion of Hydrocarbon Extraction Testing	7/31/17		Status reported in subsequent quarterly report	
5.1	M9 – MMPA (multimineral petrophysical analysis) Complete	10/31/16		Status reported in subsequent quarterly report	
5.2	M10 – Completion of Geocellular Models	12/31/16		Status reported in subsequent quarterly report	
5.3	M11 – Completion of Simulations	4/30/17		Status reported in subsequent quarterly report	

FUTURE ACTIVITIES

Activities planned for the next quarter include the following:

- Under Subtask 2.3, maturity studies on shale samples using CO_2 will be conducted and results compared to the initial RockEval results.
- Under Subtask 3.3, micro- and nanoscale fracture and pore analysis activities will be conducted.
- Under Subtask 3.4, fractal modeling will also be used to estimate sample permeability through image analysis techniques.

PRODUCTS

Activities conducted during this reporting period resulted in one product, listed as follows:

- An abstract was submitted to be considered for a presentation at the 2016 URTeC in San Antonio, Texas, in July 2016.

CHANGES/PROBLEMS

No problems were experienced during the reporting period, and no changes or deviations from the formal statement of work were necessary.

APPROACH CHANGES

The research approach has not changed during this reporting period.

PERFORMANCE VARIANCES

There were no performance variances during this reporting period.

TECHNOLOGY TRANSFER

One technology transfer activity was conducted during the quarter. A WebEx presentation and meeting was conducted on November 16. While the WebEx covered topics and results from both this project and another complementary DOE-funded Bakken-related project, much of the WebEx focused on the results of the advanced SEM and micro-CT activities generated under Task 3. The WebEx include representatives of all of the partners in this project, as well as representatives from Hess, Continental, ExxonMobil, Schlumberger, and Kinder Morgan.