Energy & Environmental Research Center
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October 29, 2021

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
600 East Boulevard Avenue, Department 405
State Capitol, 14th Floor
Bismarck, ND 58505-0840

Dear Ms. Fine:

Subject: Quarterly Progress Report for the Period of July 1 – September 30, 2021, "Bakken Production Optimization Program 3.0"; Contract No. G-051-98; EERC Fund 24568

Attached please find the Energy & Environmental Research Center (EERC) Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5287 or by e-mail at jsorensen@undeerc.org.

Sincerely,

DocuSigned by:
James Sorensen
0671D00C8437443...

James A. Sorensen
Director of Subsurface R&D

JAS/kal

Attachment

c/att: Brent Brannan, North Dakota Industrial Commission

BAKKEN PRODUCTION OPTIMIZATION PROGRAM

Quarterly Progress Report

(for the period July 1 – September 30, 2021)

Prepared for:

North Dakota Industrial Commission

Partners of the Bakken Production Optimization Program (BPOP) Consortium
- ConocoPhillips
- Hess Corporation
- Liberty Resources LLC
- Marathon Oil Company
- Oasis Petroleum
- Petro-Hunt, L.L.C.
- WPX Energy
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October 29, 2021

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TABLE OF CONTENTS

LIST OF TABLES

BAKKEN PRODUCTION OPTIMIZATION PROGRAM

EXECUTIVE SUMMARY

The Bakken Production Optimization Program (BPOP) was established to facilitate Bakken petroleum system (BPS) oil recovery while simultaneously reducing the environmental footprint of oil and gas development. This program is administered by the Energy & Environmental Research Center (EERC), with funding from the North Dakota Industrial Commission (NDIC) Oil and Gas Research Program and the North Dakota petroleum industry. Through BPOP, the EERC is working closely with a consortium of industry partners and the state to address emerging opportunities and challenges related to Bakken development. This progress report presents an overview of BPOP activities from July 1 through September 30, 2021.

Well economics were studied to identify opportunities to improve financial performance of Bakken wells. Cases are compared using a break-even cost metric. Three cases were considered using production data from wells with type-curves that represent a low, medium, and high break-even oil price. The inputs used for the economic analysis include lease operating expenses for maintenance, electricity, saltwater disposal, maintenance water, and chemicals. Progress was achieved advancing two projects: 1) application of flared gas injection in production wells and 2) transient multiphase flow of undulating horizontal wells.

Discussions were held with a BPOP partner that is providing EERC researchers with access to a BPS well for the purpose of temporal fluid collection and analysis. Oil and fluid fingerprinting techniques continued to be optimized, including hydrocarbon and residual salt extraction methods. Samples of oil from various petroleum systems were analyzed. Optimal conditions were tested on several rock samples.

The data analytics effort focused on two activities: 1) completion optimization calculations on a drill spacing unit (DSU) level, which incorporated DSU development intensity metrics and well geospatial information and 2) comparison of the first 6- or 9-month production volumes and the best 6- or 9-month production volumes using a sliding window.

A webinar entitled “Cyclic CO_2 Enhanced Oil Recovery in the Bakken Production System – Opportunities, Potential, and Challenges” was presented to BPOP partners on August 31, 2021.

The enhanced oil recovery pilot test at BPOP partner company Liberty Resources’ East Nesson site was approved by the NDIC Oil and Gas Division. Modeling and simulation efforts by the EERC and project partners continued in support of planning efforts. The site was commissioned, including installation of pilot partner EOR ETC, LLC’s coinjection skid. The two-phase fluid injection EOR pilot successfully began on September 10, 2021.

Activities next quarter will include a webinar presentation on the design, permitting, and execution of the injection phase of the East Nesson EOR pilot test, as well as a webinar presentation on the results of a comparative study on the effectiveness of 3-mile laterals.

BAKKEN PRODUCTION OPTIMIZATION PROGRAM

INTRODUCTION

The Bakken Production Optimization Program (BPOP) was established to facilitate Bakken petroleum system (BPS) oil recovery while simultaneously reducing the environmental footprint of oil and gas development. This program is administered by the Energy & Environmental Research Center (EERC), with funding from the North Dakota Industrial Commission (NDIC) Oil and Gas Research Program (OGRP) and the North Dakota petroleum industry. Through BPOP, the EERC is working closely with a consortium of industry partners and the state to address emerging opportunities and challenges related to Bakken development.

The goals of BPOP are to:

- Provide the state and industry with science-based insight to maintain the economic and environmental sustainability of the Bakken play in North Dakota.
- Provide stakeholders with the knowledge needed to plan and implement innovative development strategies that will take the Bakken into the next decade and help achieve the Governor's goal of 2 million barrels per day of North Dakota oil production.

The anticipated ongoing outputs of BPOP are 1) increased well productivity and economic output of North Dakota's oil and gas resources; 2) decreased environmental impacts of wellsite operations; and 3) guidance to stakeholders regarding optimal, prudent development of North Dakota's Bakken petroleum resources.

ACCOMPLISHMENTS DURING REPORTING PERIOD

Efforts continued this quarter to advance the research activities with continued interest from partners.

Process Optimization

Processing produced fluids from the well to market, although simple when described in a basic flow diagram, is complicated by dynamic and variable production rates and fluids composition, extreme climate, complex business and financial models, and evolving regulations. By working with BPOP partners, the EERC can systematically analyze trends by assimilating data and information from multiple operators, assist in defining the challenges to improved process efficiency, and identify technological and operational solutions through process modeling and system design. Through BPOP, the EERC will continue to serve existing and new North Dakota Petroleum Council task force groups established to address challenges such as flaring, vapor pressure compliance, and emissions.

Well economics were studied in the previous quarter to identify opportunities to improve financial performance of Bakken wells. Cases are compared using a break-even cost metric. Three cases were considered using production data from wells with type-curves that represent a low, medium, and high break-even oil price of $21, $45, and $89 per bbl, respectively. The inputs used for the economic analysis include lease operating expenses (LOEs) for maintenance, electricity, saltwater disposal (SWD), maintenance water, and chemicals. The analysis considers adjustments to freshwater used for maintenance and anticipated changes to oil and produced water volumes. The findings indicate that existing wells could benefit by reducing costs in the following two areas: 1) costs associated with disposal of produced water and 2) costs associated with reducing maintenance water, which increases oil revenue. Additionally, a 20% reduction in drilling and well costs is examined considering new wells developed in non-core acreage and assuming the expected reservoir potential remains unchanged. The potential impact to well economics was examined if all three strategies are executed. While the assumption is that production performance may be constrained, economic well performance can be improved by reducing development costs, improving efficiency of maintenance water, and decreasing SWD costs.

Progress was achieved advancing two projects: 1) application of flared gas injection in production wells and 2) transient multiphase flow of undulating horizontal wells. A geologic model has been developed for the first project, and initial modeling results have been completed for the second project. The characteristics of slugging flow behavior have been captured with transient flow modeling and cases have been compared between an undulating horizontal well and a straight well. Results are promising and details will be reported in the next quarter.

Fluids Characterization

The optimization of crude oil production in North Dakota requires an accurate understanding of the fluids being produced. Crude oil, associated gas, and produced water are complex mixtures, and their chemical and physical properties can vary geographically and over the life of a single well. Over the first 6 years of BPOP, extensive fluids data have been acquired, and a database of fluids information has been created. The EERC will continue to maintain and expand this valuable database and coordinate data gathering, sampling, and analysis activities to support all the program tasks.

Discussions were held with a BPOP partner that is providing EERC researchers with access to a BPS well for the purpose of temporal fluid collection and analysis. Potential analyses on core samples from the well were also discussed.

The research team worked on optimization of the hydrocarbon extraction method from core (source rocks, reservoir) using a sonication technique. The extraction method was tuned and tested on Bakken rock. The whole oil gas chromatography method was tuned for the purpose of oil fingerprinting. Various experimental conditions were tested including duration of the leaching process, amount of sample and solvent, and particle sizes of crushed rock. Optimal conditions of the extraction were calculated and tested on several rock samples.

Well Completion Optimization

Over the reporting period, the EERC data analytics effort focused on two activities: 1) completion optimization calculations on a drill spacing unit (DSU) level and 2) comparison of the first 6- or 9-month production volumes and the best 6- or 9-month production volumes.

DSU completion optimization: New research in this area is based on an expanded and updated database of over 14,000 wells, encompassing a broader extent of the BPS and including additional completion parameters that were not available in the previous study. A revised geospatial analysis was conducted to label the wells with a unique DSU identification that includes both 1280- and 2560-acre DSUs. The data analytics incorporated DSU development intensity metrics and well geospatial information to better account for these factors in estimating the effects of completion practices on well performance. The work is still in progress, but initial rounds of calculations demonstrated promising results that require in-depth interpretations and further elaboration.

Comparison of well performance indicators: The goal of this effort is to improve the strength of the statistical model and overall depth of interpretations. In past efforts, the EERC team preprocessed the publicly available data and removed outliers and anomalies from the data set used in multilevel regression modeling. A potential source of model error is the response variable or indicator of well performance. In previous work, the EERC used the first 6-month production volumes as the response variable to represent production performance. However, discussions with oil and gas operators indicated that, in some instances, the initial oil production was curtailed for various technical and nontechnical reasons and the first 6-month production volume may, therefore, not adequately represent well performance. The goal of the analysis this quarter was to compare well performance indicators based on the first months of production and maximum production values calculated using a sliding window. The sliding window approach to identify the maximum values for 6 or 9 months of cumulative production can be a better alternative to the first 6 or 9 months of cumulative production for representing well production. Despite the high correlation coefficients between these two performance indicators, thousands of wells showed that the best 6 or 9 months of cumulative production was 10% or more greater than the first 6 or 9 months of cumulative production. These differences are more pronounced in poorly performing wells with the first 6-month production volume of less than 60,000 bbl. Future work may explore the sliding window approach and the best 6 or 9 months of cumulative production as the response variable.

Enhanced Oil Recovery

A webinar entitled “Cyclic CO_2 Enhanced Oil Recovery in the Bakken Production System – Opportunities, Potential, and Challenges” was presented to BPOP partners on August 31, 2021. This presentation provided a summary of findings and conclusions derived from several ongoing Bakken EOR (enhanced oil recovery) studies conducted through BPOP. A survey of the nine known BPS EOR injection tests and field pilots conducted in the North Dakota and Montana portions of the Williston Basin was discussed. Considerations for CO_2 and

rich gas application for Bakken EOR were provided, and the potential impact of CO_2 EOR on North Dakota Bakken oil production was explored for several potential development scenarios using spreadsheet forecasting. Several knowledge gaps and potential advancements were enumerated that could improve the design, implementation, deployment, and forecasting of Bakken EOR. Methods for detecting and characterizing short circuiting of injected gas between horizontal wells and other conformance issues associated with multiwell cyclic huff 'n' puff were discussed. The presentation slide deck was uploaded to the BPOP website and is available to BPOP partners.

BPOP partner company Liberty Resources (Liberty) continued to develop plans for an EOR pilot test at the East Nesson site and includes EOR ETC, LLC (EOR ETC) as a pilot partner. EERC personnel conducted activities to support those planning efforts. Weekly and biweekly project meetings have been ongoing to update the project partners on the pilot planning, execution, and operation and the modeling and simulation work throughout the quarter.

A comprehensive sensitivity analysis was performed to evaluate the impacts of different operational design parameters (injection gas and water rates, number of cycles, and soaking the injected fluid before producing) on the performance of two phases of coinjection (water and rich gas) to assist in designing the pilot test at the pilot site. The performance metrics evaluated include the cumulative oil produced, incremental oil production, oil recovery factor, and incremental oil recovery ratios. These performance metrics were assessed for both short and long terms to determine the effectives of the number of injection cycles.

An update on the modeling of pressure, temperature, and volume (PVT) data was carried out by Computer Modelling Group, a project partner, to further tune the existing equation of state fluid model with the laboratory measured minimum miscibility pressure of the rich gas to be injected. During this round of the model calibration, the composition of the injected rich gas was also updated in the simulation model, based on the latest gas composition analysis.

The application of Liberty Resources Management Co., LLC, for an order granting temporary authority to use the Haley 158-93-29-32-10MBH well (File No. 35883) located in a spacing unit comprising Sections 29, 30, 31, and 32, T.158N., R.93W., Mountrail County, North Dakota, as an injection well for an EOR pilot operation in the East Tioga-Bakken Pool, was approved by the NDIC Oil & Gas Division (Hearing Case No. 28830).

The pilot test of two-phase fluid injection EOR at the East Nesson site was commissioned, including installation of pilot partner EOR ETC's coinjection skid. The injection successfully began on September 10, 2021. Continuous and periodic data collected from the reservoir surveillance program put in place are being monitored, processed, and visualized to evaluate the performance of the ongoing pilot test at the site.

Program Management and Development

The project team continued to engage partners to guide the activities to meet partner needs. Planning was initiated for a BPOP partner meeting.

PARTNERSHIP AND FINANCIAL INFORMATION

The original budget as proposed to NDIC OGRP is $12,000,000, as shown in Table 1.

Table 1. BPOP – Original Budget

Sponsors	Budget
NDIC Share – Cash	$6,000,000
Industry Share – Cash	$500,000
Liberty – In-Kind	$4,000,000
DOE – Cash	$1,500,000
Total	**$12,000,000**

Table 2 presents a revised expected budget based on the allocation of cost share secured by the EERC. Expenses to date are also listed in Table 2.

Table 2. BPOP – Expected Budget and Expenses to Date

Sponsors	Expected Budget	Actual Expenses as of 9/30/2021	Balance
NDIC Share – Cash	$6,000,000	$1,987,730	$4,012,270
Industry Share – Cash	$500,000	$177,622	$322,378
Oasis – In-Kind	$2,109,144	$2,109,144	$0
DOE – Cash	$1,500,000	$1,146,157	$353,843
Liberty Resources – In-Kind	$1,159,961	$1,159,961	$0
EOR ETC – In-Kind	$110,000	$0	$110,000
Industry – TBD	$620,895	$0	$620,895
Total	**$12,000,000**	**$6,580,614**	**$5,419,386**

FUTURE ACTIVITIES

Process Optimization

Activities next quarter include the continued engagement with BPOP partners to advance concepts to improve economic well performance. Given the recent developments with 3-mile lateral completions, an investigation on past and present well development and performance will be completed. A webinar on the results of the examination of 3-mile laterals will be presented to the BPOP membership on November 16, 2021.

Fluids Characterization

The priority of future activities will continue to be engagement with industry partners to better understand their needs related to Bakken production issues and practices and to expand the geographical extent of the sampling and analysis effort. Temporal fluid collection and analysis from a BPS well with access provided by a BPOP partner will be initiated. Core samples from the well are anticipated to be provided to the EERC next quarter. Analysis of the fluid and rock samples will be coupled with the fluid fingerprinting work to understand composition changes in oil and water chemistry over time.

In addition to the ongoing oil fingerprinting methods, a water fingerprinting method based on characterization of residual salt extracts from formation samples will be applied to core samples representing different portions of the Bakken and Three Forks reservoirs. Better understanding the formation fluid chemistry (including cation/anion chemistries and strontium isotope composition) from different portions of the BPS, as well as from formations overlying and underlying the BPS, will allow for better identification of the formations that are contributing to water generation in BPS wells and to what extent. Historical water chemistry data and information generated by the EERC laboratory will continue to be compiled and used to identify compositional differences in water samples produced from various reservoirs.

EERC efforts will continue to improve the oil fingerprinting analytical techniques using high-resolution gas chromatography and mass spectrometry and expand the applications to benefit current and future Bakken system research activities. A detailed geochemical analysis of separated saturate and aromatic fractions using a selected ions method (SIM) will be performed on a representative collection of approximately 40 organic extracts of Bakken source rock and reservoirs and samples of oil. The analyses using optimized the SIM mode will improve method resolution, identify informative compounds, and provide geochemical data that will be used in problem solving.

Well Completion Optimization

Future work will focus on improvement of completion optimization calculations and interpretations at the DSU level. Initial results of statistical modeling based on the improved and updated data set will be revised and provide more in-depth interpretations that can be used in operational optimization. Another activity will be an update to the re-frac study, which was originally completed in 2018. An updated data set will be used, and the study will focus on both technical and commercial aspects of technologies improving oil recovery.

Enhanced Oil Recovery

EERC engineers will visit the East Nesson site to observe the ongoing pilot operation. The first cycle injection of the pilot test is scheduled to be completed on October 11, 2021, and the subsequent production phase will begin within a day or two of the end of injection.

The pilot injection data will be integrated into the existing simulation model for model and pilot data comparison and for improving the model prediction accuracy, if needed, through a history-matching process.

An economic analysis of the pilot test will be conducted. The results from the techno-economic analyses will be scaled up to understand the impact of a larger-scale implementation of the two-phase coinjection EOR process for the Bakken play.

An update on the design, permitting, and execution of the injection phase of the project will be presented in a webinar to the BPOP membership in late November 2021. A journal paper will be developed detailing the findings and lessons learned from the various studies conducted during the project.

Program Management and Development

Additional research activity ideas will be discussed with project partners. Planning will continue for a BPOP partner meeting.