Energy & Environmental Research Center
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April 28, 2023

Mr. Reice Haase
Deputy Executive Director
North Dakota Industrial Commission
600 East Boulevard Avenue, Department 405
State Capitol, 14th Floor
Bismarck, ND 58505-0840

Dear Mr. Haase:

Subject: Quarterly Progress Report for the Period of January 1 – March 31, 2023, "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 email at jsorensen@undeerc.org.

Sincerely,

DocuSigned by:
James Sorensen
0671D00C8437443...

James A. Sorensen
Director of Subsurface R&D

JAS/rlo

Attachment

c/att: Brent Brannan, North Dakota Industrial Commission
Karen Tyler, North Dakota Industrial Commission

BAKKEN PRODUCTION OPTIMIZATION PROGRAM

Overall Project Period of Performance: May 1, 2020 - April 30, 2023

Quarterly Progress Report

(For the period January 1 – March 31, 2023)

Prepared for:

North Dakota Industrial Commission

Partners of the Bakken Production Optimization Program (BPOP) Consortium
- Computer Modelling Group
- Chord Energy
- ConocoPhillips
- Devon Energy Corporation
- ExxonMobil
- Hess Corporation
- Liberty Resources LLC
- Marathon Oil Company
- Petro-Hunt, L.L.C.
- XTO Energy, Inc.

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April 28, 2023

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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 (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. This progress report presents an overview of BPOP activities from January1, 2023, through March 31, 2023.

Results and information were shared on various topics this quarter. An abstract entitled "Laboratory Simulations of H_2S Generation in the Bakken Petroleum System" was accepted by the 2023 Unconventional Resources Technology Conference (URTeC), and a paper was prepared for publication. An abstract entitled "Investigation of H_2S Presence in the Bakken Production" was submitted to the 2023 American Association of Petroleum Geologists (AAPG) Rocky Mountain Section meeting. Additionally, a report entitled "Fluid Fingerprinting in Reservoirs and Source Rocks Collected at the Study Well, Williston Basin, North Dakota" will be prepared and delivered to BPOP members in the second quarter of 2023.

Polar Bear^{SM} project development has continued this quarter. This project will assist in developing and demonstrating a technology that can reduce flaring, achieving attractive economics while adapting to the unique circumstances of the remaining flaring in the basin. During this quarter, the EERC completed an investigation of irregular flow in horizontal wells. A multiphase transient flow model was used to study this behavior and provide insights that may lead to improvements in production efficiency. Presently, the work is being reviewed internally, and a webinar will be scheduled to share results.

As a part of the BPOP fluids characterization study, the EERC research team continued to investigate the potential mechanisms of souring in Bakken wells related to thermochemical sulfur reduction (TSR), bacterial sulfur reduction (BSR), generation of H_2S by the source rock, and a process involving fracking fluids. During the reporting period, the EERC focused efforts primarily on simulating the TSR process at various temperatures in addition to testing anhydrites, reservoir rock, source rock, brine, and fracking fluid. Only traces of H_2S were detected during a series of experiments, and additional work is planned to simulate the process of souring in a lab environment. Souring well information has been provided by BPOP members, and locations for the sampling program have been decided. H_2S samples for the isotope analysis were collected at approximately 40 wells. Well and production data were collected from the focus area, and an initial discussion with a completion optimization developer took place.

In response to feedback from BPOP partners and the North Dakota OGRP, the completion and production data analytics team investigated parent–child well interactions, Bakken core area expansion, and gas/water production forecasts for the BPS. Monthly production data for nearly 16,000 producing wells in the Bakken were used to evaluate historical trends in oil, gas, and water production. Gas/oil ratio (GOR) and water/oil ratio (WOR) trends were used to forecast the next decade of gas and water production based on forecasted well count and oil rate performance over the next decade. A draft presentation was developed and is undergoing internal review.

In support of a potential second enhanced oil recovery (EOR) injection cycle at the East Nesson pilot site, the EERC continues simulation analysis of water alternating gas (WAG) injection scenarios. In addition, the EERC is utilizing a recalibrated model to optimize the design for the possible second injection cycle. The optimization is designed for fewer injection cycles (fewer conversion from water to gas injections), shorter injection duration, and a lower volume of water to be injected to reduce the handling of the produced water disposal after the well is put back on production following the second injection cycle.

The EERC received approval for a no-cost time extension for the BPOP 3.0 project to modify the end date of this agreement from April 30, 2023, to August 31, 2023. The extension is necessary to account for recent delays caused by a combination of factors in the execution of field-based efforts. The additional time requested will allow for the data and lessons learned from those activities to be adequately incorporated into the final BPOP 3.0 products.

Preparation for the BPOP 4.0 proposal was initiated and will be submitted to NDIC by June 1, 2023, for consideration under the OGRP.

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

During this reporting quarter, research activities were advanced with continued support from partners.

Process Optimization

The present challenges facing the Williston Basin include maintaining a high level of production with minimal environmental impact and competing for investment. Activities that achieve this goal will grow Tier 1 and Tier 2 acreage, change the economics for Tier 3, and produce a cleaner barrel of oil. BPOP is systematically analyzing trends; working with BPOP operators; and defining challenges to improve process efficiency, identify technology, and provide operational solutions through process modeling and system design. Through BPOP, the EERC continues to serve operators, the state, and the North Dakota Petroleum Council to address challenges such as flaring, production efficiency, and emissions.

During this quarter, the EERC completed an investigation of irregular flow in horizontal wells. The terms heel and toe are typically used to refer to ends of a horizontal well. The heel being the transition from vertical to horizontal and the toe referring to where the horizontal section terminates. Geologic markers, either well logs or cuttings, are used as a guide to steer the horizontal trajectory. The subsurface stratigraphy will determine if a well is drilled toe down or toe up following a target (i.e., a gamma signature in the middle Bakken.) It is common for a horizontal well to be steered up and down during drilling, resulting in trajectory undulation. These undulations in the horizontal well's trajectory cause hydraulic phenomena for multiphase fluids that create unsteady production at the surface. A multiphase transient flow model was used to study this behavior and provide insights that may lead to improvements in production efficiency. Presently, the work is being reviewed internally, and a webinar will be scheduled to share results.

Flare Reduction Through *Polar Bear*^{SM}

Polar Bear is a name the EERC is using to refer to new technology that is being developed to address the remaining flared gas in North Dakota. The polar bear is an icon of adaptability, robustness, and environmental sensitivity. Presently, North Dakota is capturing 95% of produced gas. Although only 5% flaring is the number one contributor to carbon intensity in North Dakota's upstream oil and gas business, achieving zero flaring is essential to producing the cleanest barrel of oil in the nation. This project is developing and demonstrating a technology that can achieve attractive economics while adapting to the unique circumstances of the remaining flaring in the basin.

Achievements for this project include the following:

- A license agreement has been established between the EERC and Equinor.
- Two patents have been issued by the U.S. Patent and Trade Office (USPTO).
  - Two patent applications are under consideration, and notification of approval has been provided for one.
- A joint development agreement has been signed between the EERC and Steffes Corporation.
- Nondisclosure agreements have been signed with four BPOP partners regarding prototype demonstration.
- Laboratory testing has been completed with new innovative compressors and a prototype constructed.
- Equation-of-state modeling has been completed.
- Process control has been tested, and field testing has been scheduled.

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 program tasks.

Access to multiple BPS wells for the purpose of temporal fluid collection and analysis was provided by a BPOP partner. Temporal fluid sample collection activities for a newly producing well and its associated parent well at the same location, in the southeast portion of the North Dakota BPS, were initiated in mid-September 2021 and continued throughout this quarter. The produced fluids samples collected included gas, water, and oil, which are being analyzed in EERC laboratories. Access to a second location in the northwestern portion of the North Dakota BPS containing multiple new wells with associated core available was also secured. The third round of sample collection was performed on two of these wells in January 2023 and will continue quarterly with the inclusion of additional wells in subsequent sampling events. Sample collection and analyses for these wells will include both oil and produced water as well as sulfur speciation of the H_2S component of the produced gas. This specific effort will support the current BPOP H_2S study. The core from a well associated with the wells of the same pad was reviewed and evaluated, with sub-core samples from multiple locations being collected. These sub-core samples represent multiple formations and multiple facies within these formations that extend above and below the BPS. Salt and hydrocarbon extraction was conducted on each sample to enhance the understanding of fluid compositions throughout the BPS and adjacent formations. These data will be compared and contrasted with data on fluid samples taken from the associated producing wells and will enhance the BPS fluids database managed at the EERC. The extracted salt and hydrocarbon fluid data for corresponding formations between each of the two locations will be compared and contrasted to help verify fingerprinting methods.

A pilot project, based on one study well, tested fingerprinting techniques for produced fluids (oil and water) and rock extracts from the BPS. The concentration of strontium (Sr) and $^{87}Sr/^{86}Sr$ isotope ratio in produced water samples indicated that the Three Forks (TF) was the source of produced water in the Bakken well selected for the study. The correlation of Sr isotopes in produced water and Bakken/TF residual salts in the second investigated well did not provide a conclusive interpretation, even though TF isotope signatures matched in two wells. The research team concluded that an additional marker or indicator needs to be found to improve the fingerprinting technique and make interpretations stronger.

A report entitled “Fluid Fingerprinting in Reservoirs and Source Rocks Collected at the Study Well, Williston Basin, North Dakota” was completed and will be delivered to BPOP members in April of 2023.

H_2S Study

The EERC research team continued to investigate potential mechanisms of souring in Bakken wells related to thermochemical sulfur reduction (TSR), bacterial sulfur reduction (BSR), generation of H_2S by the source rock, and a process involving fracking fluids. During the reporting period, the research team was focused primarily on simulation of the TSR process at various temperatures and using anhydrites, reservoir rock, source rock, brine, and fracking fluid. Unfortunately, only traces of H_2S were detected during a series of experiments, and additional work must be done to simulate the process of souring in a lab environment. Even though the goal

of experiments was not achieved, the research team acquired new experience and knowledge of experimental settings, required materials, procedures, and learned lessons from the challenging high-temperature/pressure tests. Laboratory simulations will be continued to investigate souring mechanisms in the Bakken and will consider published results of other research groups and use newly acquired experimental experience.

The EERC research team continued sampling activities for the purpose of the study. All BPOP members provided information on their sour wells, and locations for the sampling program have been decided. H_2S samples for the isotope analysis were collected at approximately 40 wells. Oil, water, and anhydrite samples were sampled for the elemental analysis and S isotope measurements. These data points will be used in the final interpretation of H_2S origin based on δS^{34}. The research team has started the evaluation of the well completion optimization technology applied by a Bakken operator on 11 producing wells to reduce the risk of souring. Well and production data were collected from the focus area, and an initial discussion with completion optimization developer took place.

An abstract entitled "Laboratory Simulations of H_2S Generation in the Bakken Petroleum System" was accepted by the 2023 Unconventional Resources Technology Conference (URTeC), and a paper was prepared for publication. An abstract entitled "Investigation of H_2S Presence in the Bakken Production" was submitted to the 2023 American Association of Petroleum Geologists (AAPG) Rocky Mountain Section meeting.

Completion and Production Data Analytics

Year 1 and 2 Activities

Activities initiated in Years 1 and 2 continued as follows.

Bakken Well Refracturing

The original Bakken well-refracturing work (Version 1 – Dalkhaa and others, 2019) and first update (Version 2 – Dalkhaa and others, 2020) were updated to capture additional refractured wells and production data (Version 3). A total of 69 additional refractured wells were identified and added to the Version 2 refracturing database. The updated database includes 341 refractured wells from the North Dakota portion of the Bakken that were refractured as of October 2021, which constitutes the data set used in the present study (Version 3 Refrac Master Database). The main objectives of Version 3 are to:

- Update the EERC master database of wells that have been refractured in the North Dakota portion of the BPS by identifying wells that have been refractured since Version 2.

- Revise the evaluation of production performance of the refractured wells that were previously identified in the Version 2 update.

- Update the analysis of the impact of fracture hits from refracturing or the influence of the refractured well on nearby offset wells.

- Update the economic modeling for refractured wells using a stochastic modeling approach coupled with decision tree modeling for different forecasted production scenarios.

- Evaluate relationships between refractured performance and geographic location in the Bakken, geological cluster within the Bakken, or well completion features.

- Assess the potential economic impact of a broad refracturing program applied throughout the BPS.

A draft report, Refracturing in the Bakken – An Updated Analysis of Data from 341 Wells Across North Dakota, was completed and is under EERC senior management review. The report will be finalized and released in the following quarter.

Year 3 Activities

In response to feedback from BPOP partners and the North Dakota OGRP, the data analytics team investigated parent–child well interactions, Bakken core area expansion, and gas/water production forecasts for the BPS. An updated database of well completion and production data obtained from Enverus's DrillingInfo was cleaned and checked for outliers and is being used for all Year 3 data analytics work. Progress on the Year 3 analysis plan over the reporting period was as follows.

Parent–Child Well Interactions

A draft report entitled "Data-Driven Analysis of Parent–Child Interactions in the Bakken" was completed and is under senior management review. The report will be finalized and released in the following quarter. The work investigated parent–child well interactions in the Bakken and identified key drivers using machine learning.

Bakken Core Area Expansion

A draft report entitled "A Data-Driven Analysis of Bakken Core Area Expansion and Implications for Future Development Potential" was completed and is under senior management review. The report will be finalized and released in the following quarter. The work investigated recent core area development, classified wells by their productivity, and used the classifications to delineate the core area in the Bakken. In addition, the work identified key drivers for the recent Bakken core expansion and analyzed potential remaining development opportunities in the Bakken.

Gas and Water Production Forecasts

Monthly production data for nearly 16,000 producing wells in the Bakken were used to evaluate historical trends in oil, gas, and water production. Gas/oil ratio (GOR) and water/oil ratio (WOR) trends were used to forecast the next decade of gas and water production based on forecasted well count and oil rate performance over the next decade. A draft presentation was developed and is undergoing internal review.

Enhanced Oil Recovery

Continuous and periodic data from the East Nesson pilot site (as part of the reservoir surveillance program) are still being collected, processed, and analyzed to continue to evaluate the performance of the co-injection pilot. Weekly and biweekly project meetings have been ongoing to update the project partners on the pilot planning, execution, operation, modeling, and simulation work throughout the quarter.

As part of a possible second EOR injection cycle at the East Nesson site, a simulation analysis of water alternating gas (WAG) injection scenarios has continued in this quarter to help design the second injection cycle. Planning includes considering the operational constraints (i.e., the produced rich gas availability), gas compression capacity, and production facility capacity. Testing of the produced water from the area is being considered for the possible next WAG injection. The effect of the produced water salinity on the performance of the coinjected surfactant was investigated in the previous quarter and continued into this quarter.

During this quarter, the simulation model was recalibrated, following a transition to the newest version of the simulation software available from the prior version. Updated data have become available since the previous model calibration was performed; therefore, the EERC integrated additional production data (through March 2023) into the simulation. Using this newly recalibrated model, the reevaluation of WAG cases is currently being conducted to optimize the design for the possible second injection cycle. The optimization is designed for fewer injection cycles (fewer conversions from water to gas injections), shorter injection duration, and lower volume of water to be injected to reduce the handling of the produced water disposal after the well is put back on production following the second injection cycle. In addition, lower water injection rates are part of the consideration in the optimization simulation, based on a possible injection facility restriction that might occur.

Program Management and Development

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

Continued to improve the administrative functions of the website product database, which will increase the overall function of the website and enhance the product upload process in the future.

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 Resources – In-Kind	$4,000,000
DOE* – Cash	$1,500,000
Total	**$12,000,000**

* U.S. Department of Energy.

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 3/31/2023	Balance
NDIC Share – Cash	$6,000,000	$5,047,226	$952,774
Industry Share* – Cash	$1,700,000	$1,017,996	$682,004
Chord Energy** – In-Kind	$2,109,144	$2,109,144	$0
DOE – Cash	$1,499,501	$1,499,501	$0
Liberty Resources – In-Kind	$1,440,471	$1,440,471	$0
EOR ETC – In-kind	$20,400	$20,400	$0
CMG*** – In-kind	$28,500	$28,500	$0
Total	**$12,798,016**	**$11,163,238**	**$1,634,778**

* Industry cash cost share has been provided by Hess Corporation, Petro-Hunt LLC, XTO Energy Inc., Devon Energy Corporation, ConocoPhillips, and Marathon Oil Company.
** Formally known as Oasis.
*** Computer Modelling Group.

FUTURE ACTIVITIES

Process Optimization

Activities next quarter will include continued engagement with BPOP partners to produce webinars on topics of interest.

Polar Bear

Activities next quarter will include moving equipment to the field and continued compressor supplier development.

Fluids Characterization

Fluid sample collection on the new well in the southeastern portion of the BPS will continue quarterly for the next 12–18 months, depending on results obtained and well access availability. The EERC has also initiated sample collection on a newly established group of wells on a pad with relatively fresh core availability. These wells will continue to be sampled quarterly over the next several months. The location of these wells and associated core is in a new area of the BPS (north central) and will provide increased spatial representation to the EERC-constructed database. Results of fluid analysis conducted on the samples from all of these wells will be compared to data derived from analysis of samples obtained from fluid extraction from the appropriate cores. Similar sample collection and analytical approaches will be applied to other new wells with current BPOP partners as opportunities are identified.

The pilot fingerprinting work will be continued using rock and fluid samples. The results of the laboratory work on samples from the second well selected for the study will be compared to the data from the study well, and recommendations for the next phase of the research project will be formulated. The focus of the research will be unique indicators in produced water and residual salts extracted from rocks.

H_2S Study

The EERC team will continue the sampling program, including collection of H_2S, oil, and water from the sour wells identified by the BPOP members. The focus will be on the H_2S samples collected at well sites and measurement S isotope composition. Completion optimization technology reducing souring in wells will be further investigated.

Completion and Production Data Analytics

Year 2 activities will continue into the next reporting period and focus on finalizing the Bakken well refracturing report (Version 3).

Year 3 activities will continue into the next reporting period, focusing on finalizing the reports for the parent–child well interactions and Bakken core expansion. The gas and water production forecast presentation will be reviewed internally and then presented to our BPOP members.

Enhanced Oil Recovery

The optimization simulation of WAG injection will continue in support of design and implementation of the possible second injection cycle that might occur in the third quarter of 2023.

Program Management and Development

Preparation for the BPOP 4.0 proposal will continue and once finalized, will be submitted to NDIC OGRP for consideration. The no-cost time extension for the BPOP 3.0 project to modify the end date of this agreement from April 30, 2023, to August 31, 2023 was approved.