EVALUATION OF KEY FACTORS AFFECTING SUCCESSFUL OIL PRODUCTION IN THE BAKKEN FORMATION, NORTH DAKOTA

Technology Status Assessment

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1. ***Current State of Technology***

a. Summary of Existing Industry/Sector

The Bakken Formation is known to be an important source rock for oil in the Williston Basin. The formation typically consists of three members, with the upper and lower members being shales and the middle member being dolomitic siltstone and sandstone. Total organic carbon (TOC) within the shales may be as high as 40%, with estimates of total hydrocarbon generation across the entire Bakken Formation ranging from 200 to 400 billion barrels (Lefever and Helms, 2008; USGS, 2008). While the formation is productive in numerous reservoirs throughout Montana and North Dakota, with the Elm Coulee Field in Montana being the most prolific example of Bakken success, many Bakken wells have yielded disappointing results. Though variable productivity within a play is nothing unusual to the petroleum industry, the Bakken play is noteworthy because of the wide variety of approaches and technologies that have been applied with apparently inconsistent, and all too often underachieving, results. Developing a "winning" approach to Bakken exploitation is further complicated by the fact that the typical Bakken well can face significant challenges in all phases of the operation. Drilling, completion, and production problems have been widely reported throughout the play, and even after 20 years of Bakken exploration and production (E&P) activities, there is still little agreement as to what the attributes of a "model" Bakken well might be.

b. Technologies/Tools Being Used

The technologies, tools, and strategies used to exploit the oil resources of any play are largely dependent on the geological and geomechanical characteristics of the target reservoir formation and cap rock. Key geological characteristics include stratigraphy, lithology, and structure.

With respect to stratigraphy, the Bakken Formation in the Williston Basin typically is composed of three members: the Upper, Middle, and Lower Bakken. Lithologically, the Upper and Lower members of the Bakken are dominated by shales rich in organic carbon which act as the source rock for oil reservoirs in the Middle Bakken. The lithology of the Middle Bakken varies widely from clastics (including shales, silts, and sandstones) to carbonates (primarily dolomites), with five distinct lithofacies being identified in the North Dakota portion of the Williston Basin. In general, all of these rocks are characterized by low porosity and permeability (Pitman et al., 2001). With respect to structure, the Williston Basin is characterized by relatively few and subtle structural features (LeFever and Crashell, 1991). The Nesson Anticline in northwestern North Dakota is the dominant tectonic structural feature in the area of North Dakota Bakken productivity, and while the most prolific Bakken reservoirs in North Dakota are not on the Nesson Anticline, it may have some degree of influence on Bakken productivity. Smaller structures that are likely associated with salt collapse features also occur in North Dakota and may also influence the productivity of some Bakken reservoirs (LeFever and LeFever, 1995). These structures may not only serve as traps for oil within the Bakken, but may also exert influence on the stress and strain fields that affect the geomechanical properties of the Bakken. The geomechanical properties of the Bakken are a key component of their ability to serve as productive oil reservoirs, as they will dictate the size, frequency, pattern, and orientation of fracture networks (natural and artificial) at both the micro- and macroscale.

In general, approaches to the selection of exploitation strategies and application of technologies and tools for the drilling, completion, and stimulation of wells in the Bakken play have been largely dictated by knowledge (or lack thereof) of lithology, structure, and geomechanical properties within a localized area. A vast majority of Bakken wells in the last several years have been drilled horizontally into the Middle member where geology is thought to be most favorable (e.g., areas of relatively higher porosity and permeability). Ideally, wells are drilled in a manner that maximizes contact with natural fractures and maximizes drainage from the entire potential "pay" zone. A wide variety of well drilling and

completion techniques have been applied toward the Bakken play, with disparate results and varying degrees of success. For most Bakken wells, the use of hydraulic fracturing (or "frac jobs") is critical to establishing long-term productivity.

c. Benefits and Inadequacies of Current Technology

Current approaches to economically and sustainably produce oil from the Bakken rely heavily, in one way or another, on exploiting natural fracture networks and/or artificially enhancing those networks or creating new ones. The positive aspects of fractures include the fact that they enhance existing porosity and permeability. This is very important in the Bakken because it is typically characterized by low matrix porosity and permeability, and therefore, it is the fracture network that will provide a bulk of the production pathway. This is especially true in the shale lithofacies. Fractures also facilitate or provide a conduit for oil from the reservoir to the borehole, thereby yielding higher production rates. However, the presence of fractures can also lead to borehole stability problems. Careless drilling and completion operations that don't account for the presence and orientation of fractures can increase the potential for damage to microfractures. This can be caused by the use of overbalanced muds, rapid pressure drawdown (producing too much, too fast), and water blocking (this is caused in areas where the Bakken is oil-wet). With these positive and negative aspects of fractures in mind, it is critical that the influence of natural fracture systems, and the geomechanical properties affecting those systems, on the direction of fracture stimulation treatment be considered when designing and executing drilling, completion, and stimulation programs in the Bakken.

2. Development Strategies

a. Why New Technology and Research Is Required

Over the past decades, hundreds of wells have been drilled into the Bakken Formation in a search for oil that has produced widely variable results. The fact that many wells have been very successful, some even producing oil at world-class rates, demonstrates that the Bakken Formation is a tremendous source of oil. Unfortunately, many more wells have seen less successful results. While such inconsistency is not unusual in the world of oil and gas E&P, the deep and tight nature of the Bakken Formation in the Williston Basin make it a very expensive target for E&P. The inconsistency that is associated with the Bakken play, coupled with the high costs associated with Bakken E&P, have limited its exploitation. New research is required because, while it is clear that geologic characteristics and geomechanical properties are the primary factors controlling the sustainable productivity of any given well, the Bakken is extremely heterogeneous with respect to its geological characteristics, and its geomechanical properties are not well understood (Helms and LeFever, 2006) A robust, systematic scientific and engineering research effort can play a vital role in overcoming these challenges and unlocking the vast resource potential of the Bakken Formation in the Williston Basin.

b. Problems to Be Addressed in This Research Project

The research project ("Evaluation of Key Factors Affecting Successful Oil Production in the Bakken Formation, North Dakota") will address the following problems:

- It is difficult to make comparisons between wells because data on key parameters of interest that may impact sustainable oil recovery from the Bakken in North Dakota have not been gathered or managed in any coordinated way. Many such data are known to exist, and it is anticipated that the effective management of such data will facilitate the identification of "winning" strategies for Bakken wells in different geologic/geomechanical regimes.

- The effects of stress and strain fields, particularly their orientation, on macro- and microscale geomechanical properties are not well understood. Seismic and geomechanical studies will be conducted to better understand how the macroscale stress and strain forces associated with geologic structure in central North Dakota may influence the geomechanical properties of Bakken reservoir and seal rocks at the microscale.

- The potential influence of water expulsion from hydrated minerals on Bakken productivity has not been examined. Analytical activities will be conducted to provide previously unavailable insight on this phenomena and its potential to create microfractures.

3. Future

a. What Barriers Shall the Research Overcome

The applicability of results from one Bakken location to another has often been limited and unpredictable. There has been little coordination of research activities. Distribution of information generated by those working in the Bakken play has been relatively infrequent and often limited. This has made it difficult to compare results between locations and identify 1) trends across the play and 2) common threads that may exist between apparently different but successful (or unsuccessful) wells. It is anticipated that the research will make important strides in overcoming these barriers.

Robust dynamic geomechanical and geochemical simulations are needed to predict the mechanical integrity of Bakken reservoir and seal rocks, design and simulate hydrofracture operations, and address wellbore stability problems. There is currently a lack of these simulations in the public domain, which limits the ability of many independent operators and other stakeholders to address these issues. It is anticipated that the research project will provide operators and other stakeholders with fresh insight regarding the roles that geologic structure and geomechanics play in the design and operation of a successful Bakken well in North Dakota.

b. Impact on the U.S. Domestic Gas Supply Industry

The Bakken Formation in the Williston Basin is seen by many as holding a world-class prize, with many billions of barrels of oil in place. The development of this valuable resource is plagued by a myriad of challenges, many of which are addressed at some level by this research project. The size of the resource and record-high oil prices have led to an increased interest in the Bakken play by domestic oil and gas E&P companies. Improved success rates when drilling Bakken wells can lead to increased domestic proven reserves and a stronger U.S. domestic oil and gas industry. Furthermore, existing and new companies commonly have staff with limited or no knowledge of the Bakken play. These companies rely on information from the current literature and the state and federal governments to quickly answer their questions. This research project will provide additional insight and understanding to the companies working to effectively exploit the resources of the Bakken and provide the United States with a secure and affordable source of oil.

c. Deliverables (Tools, Methods, Instrumentation, Products, etc.)

Deliverables will include the following:

- A database of key geological, drilling, completion, and stimulation parameters affecting Bakken productivity in key areas of North Dakota.

- A database of geomechanical properties affecting Bakken productivity.

- A petrophysical model of a Bakken reservoir that includes previously unavailable insight on stress and strain orientation and other geomechanical parameters.

- Technical reports on the progress and results of each of the technical activities conducted over the course of the project and the implications of those results on current and future Bakken E&P efforts.

4. References

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