Innovative MIOR Process Utilizing Indigenous Reservoir Constituents

By
D. O. Hitzman
A. K. Stepp
D. M. Dennis
L. R. Graumann

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U.S. Department of Energy
Assistant Secretary for Fossil Energy

Virginia Weyland, Project Manager
National Petroleum Technology Office
P.O. Box 3628
Tulsa, OK 74101

Prepared by:
Geo-Microbial Technologies, Inc.
East Main Street
Ochelata, Oklahoma 74051

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ABSTRACT

This research program is directed at improving the knowledge of reservoir ecology and developing practical microbial solutions for improving oil production. The goal is to identify indigenous microbial populations which can produce beneficial metabolic products and develop a methodology to stimulate those select microbes with nutrient amendments to increase oil recovery. This microbial technology has the capability of producing multiple oil-releasing agents.

Experimental laboratory work is underway. Microbial cultures have been isolated from produced water samples. Comparative laboratory studies demonstrating in situ production of microbial products as oil recovery agents were conducted in sand packs with natural field waters with cultures and conditions representative of oil reservoirs. Field pilot studies are underway.

EXECUTIVE SUMMARY

This project is an experimental laboratory study designed to improve the understanding of reservoir ecology, and to establish methods of manipulating indigenous microorganisms that utilize naturally occurring water soluble organic acids to produce beneficial oil recovery agents. The objectives of this research program are to demonstrate in-situ production of oil recovery agents in reservoir waters by indigenous microbial populations, and to enhance and control the content and concentration of the bioproducts by the selective addition of low concentrations of inorganic salts as an alternate electron system.

The research program has been divided into a series of seven tasks that are designed to determine the feasibility of developing a practical and cost effective in-situ microbial system for increasing the effectiveness of oil-recovery agents in oil reservoirs. Research in this program will focus on stimulating in situ microbial products to enhance oil recovery. Experimental work on the project begins in Task 1 with selection of suitable microbial strains and development of test procedures for subsequent studies. Research in Task 2 has developed physical models which have been used to quantify improved oil production in porous media. The objective of Task 3 is to demonstrate that nutrient amendments can be used to selectively stimulate microbes to produce oil-releasing agents. Results from Tasks 1 through 3 were applied to Task 4 for inclusion into an increased oil recovery system. This task has been incorporated in conjunction with the preceding flooding tests. Task 4 tests comprise a significant portion of the test program and involve demonstrating and optimizing the effectiveness of the oil recovery biosystem. Data from experimental work has been correlated and integrated for the effects of the biosystems on oil recovery in Task 5, and reported in a form which could be offered for technology transfer to the oil industry for commercial applications. As results are obtained from the laboratory investigations and are made available to field operations through technology transfer, work in Task 6 has been directed toward applying the new technology to field studies, situations, and operations. This approach provides rapid introduction and evaluation of any system and/or product which is developed by this program, and will allow directly comparable data to be collected. Technical reports have been prepared under Task 7.

The described research project was designed as a three-year experimental study. Work on the project commenced on October 1, 1999 and research projects were initiated as planned at that time. Active experimental projects are now in progress in all Tasks. Samples of produced water have been obtained from actively producing fields and enriched for selective microorganisms. Several promising strains of microbes have been isolated and are currently being used for experimental work. Microcosm scale sand-packed columns were designed and tested for developing selected cultures by nutrient stimulation. Experimental design of flooding regimes is in progress to test the effects of nutrient stimulation on oil recovery in physical models. No problems have been encountered in the project to date. A one-year, no-cost extension was granted on the project to continue collected data on the field projects.

CHAPTER 1
Introduction

It is established that microorganisms can survive and multiply in and under reservoir conditions, and have the potential to significantly influence oil practices and production (credited to Beckman, 1926). It has been proposed that these microorganisms can definitely exert a powerfully positive effect on oil production, especially trapped residual oil (1, 2, 3).

In this investigation, reservoir microflora are deliberately manipulated and controlled by means of specific nutrient amendments to demonstrate increased mobilization and production of oil in laboratory sand packs. This occurs through the dynamic insitu interactions of reservoir oil, water constituents, targeted indigenous microbes, and the microbial metabolic byproducts such as N2 and CO2 gases, surfactants, and solvents derived from nutrient utilization.

It has been shown that the presence of inorganic nutrients can control reservoir ecology, and that adding such nutrients as alternate electron acceptors can stimulate distinct groups of bacteria (4). Several discoveries resulting from this understanding of altered reservoir ecology are of key importance for the present research project:

1. Low concentrations of selected nitrogen salts stimulate populations of indigenous denitrifying microbes,

2. Such expanded denitrifying populations are heterotrophs known to produce copious amounts of oil-mobilizing chemicals and gases at reservoir conditions,

3. These beneficial microbial populations can be established and maintained within the reservoir by various application protocols involving the use of low-cost nitrogen salts.

Although the present research began using so-called light oils, i.e., oil in excess of 20 API gravity, an opportunity to secure oil and water samples from a well known California heavy oil field also presented itself early on in the program. Thus, the line of investigation was expanded in the present research program to include:

1. An increased understanding of the methodology to use low-cost inorganic nutrient amendments that stimulate indigenous beneficial microflora to utilize natural reservoir constituents and cause the release of trapped residual oil, and,

2. To conduct laboratory bench top experiments to determine if trapped 13 API gravity residual oil could similarly be mobilized for production by microbial mechanisms and byproducts that are the result of innovative low-cost nutrient amendments.

The three-year research project began in October 1999 and was subsequently granted a one-year, no-cost extension in order to accommodate the term of an actual light oil recovery field test. This report describes month thirty-seven through month forty-two of the project.

Chapter 2 describes the laboratory experiments, including selection of reservoir microbial strains isolated from oil field brines and other sources, as well as nutrient studies. Design and development of physical models for studying fluid flow is also detailed, as well as sand pack flood results.

The physical models were used to test the concept of controlled microbial ecology for an improved residual oil recovery system. Many long-term sand pack floods have been utilized in this project. The current research effort is now concentrated on oil recovery in sand pack floods, and the results from the oil recovery field trial.

Chapter 3 details the field pilot test currently underway. Chapter 4 describes the work thus far on reports and technology transfer.

CHAPTER 2
Laboratory Experiments

Introduction

Oil reservoirs contain diverse microbial populations, including species introduced during drilling and production activities, and species native to the reservoir environment.

Except in cases of extreme biological constraint (i.e., temperature, salt, etc.), oil reservoirs establish indigenous microbial communities that adapt to the prevailing reservoir conditions. Some microbial species within these complex microbial communities exhibit the metabolic capabilities to produce known oil recovery agents such as gas, surfactants, solvents, and polymers.

The indigenous communities are in dynamic equilibrium with their environment and one another, but can be restructured and manipulated in a directed way to favor production of beneficial products. The calculated addition of inorganic nutrients that serve as alternate electron acceptors stimulate distinct groups of bacteria and alter reservoir ecology. The in situ metabolic activity of these select bacteria results in several bioproducts that effectively release trapped residual oil.

This research program focuses on developing an understanding of a methodology to use low-cost inorganic nutrient amendments that stimulate indigenous microflora to utilize natural reservoir constituents to produce beneficial products. In order to assess effects that the distinct physiological groups have on oil mobilization, it is necessary to develop procedures to measure the multiplicity of effects. Experimental work on the project began with selection of suitable microbial strains and development of test procedures for subsequent studies.

Background

Previous investigations of oilfield waters have endowed us with an extensive culture collection of oilfield microflora. Numerous cultures have been isolated from a wide range of field waters and facilities, including primary production wells and waterflooded fields, ranging from fresh waters to highly saline formation waters, and at various reservoir temperatures.

The cultures have been isolated on varied media, and in particular the standard API acetate-lactate SRB (sulfate reducing bacteria) medium used widely by the oil industry. The collection has been supplemented with isolates from several other environmental sources including activated sewage sludge, polluted marine waters and sediments, naturally attenuated remediation sites, and historically contaminated production sites. Selected cultures from the collection were used as a primary source of inocula for enrichments.

The role of VFA as a key component that leads to the biogenic formation of sulfide in reservoirs was pioneered at GMT. These investigations led to the discovery of a novel technology that uses the naturally occurring VFA in a beneficial role to prevent and remove sulfide in the reservoir. This patented technology causes the replacement of the detrimental SRB with a beneficial microbial population by the addition of a proprietary mixture of inorganic salts that act as an alternate electron acceptor.

The technology—termed "BioCompetitive Exclusion"—is based on the presence of VFA in the reservoir and its preferential use and removal by targeted indigenous anaerobic denitrifying bacteria (DNB) when stimulated by the inorganic salt formulae. As such, there is no requirement for the addition of so-called "laboratory" microorganisms. DNB growth and expansion has the added potential of increasing oil recovery by the production of their metabolic products, including gases (N_2 and CO_2), biosurfactants, biosolvents, and biopolymers.

This past work of experiments, field data, and results has identified the critical role of VFA in oil field brines and shown its impact on reservoir souring and corrosion, as well as the potential for increased oil recovery. Such research provides strong background information on VFA in reservoir fluids, and will be coupled with the ongoing studies of VFA and microbial interaction in oil reservoirs to offer a unique information base contributing to the successful completion of the program.

Experimental

Oil Recovery Tests

Repetitive sand pack flooding experiments have been and are being conducted to determine the effects of various nutrients and flooding regimes on oil recovery. All experiments are conducted in the temperature range of 38 to 50 degrees Centigrade. Sand pack columns are made of PVC plastic, and are 2 inches (5.08 cm) in diameter by 10 feet (3 m) in length.

Sand packs are saturated with field brine and "heavy" 13 API gravity oil obtained from a well-known California oil field. After water flooding to residual oil saturation, the packs are inoculated with a microbial consortium that has been isolated from the field brine, then shut in for an incubation period. Water flooding is then resumed with various types of nutrients as amendments.

Results and Discussion

Oil Recovery Tests

Results are shown in Figures VSP 1 – 11. Floods treated with nutrient PE gave the best results of the packs operated in the horizontal position. The pack run in the vertical position with percolator tea also showed good results. Flooding experiments are ongoing to determine which nutrients and which strategies give the best results.

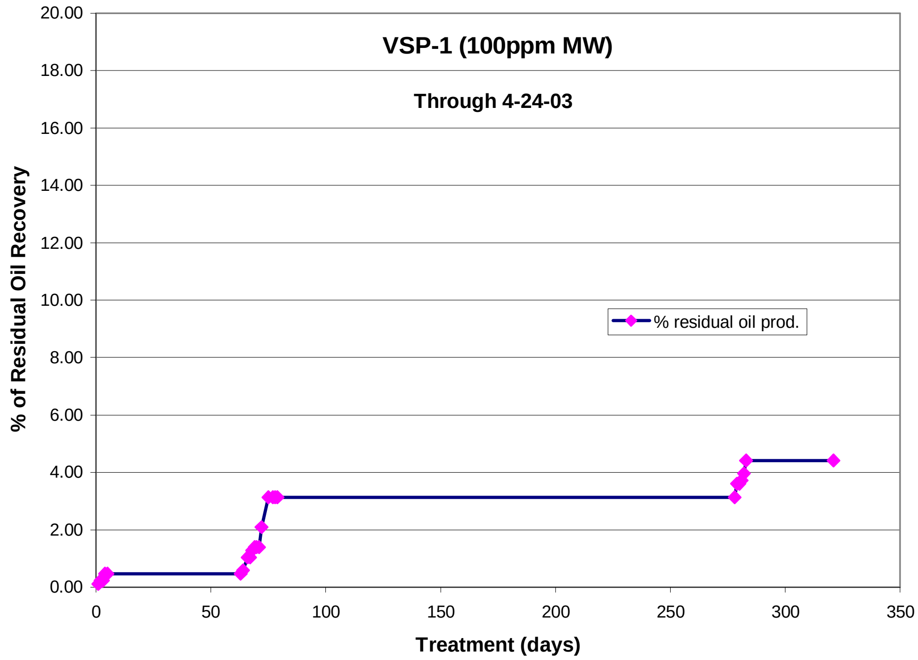

Figure 1. Production with Treatment VSP-1, 100 ppm Maxwell.

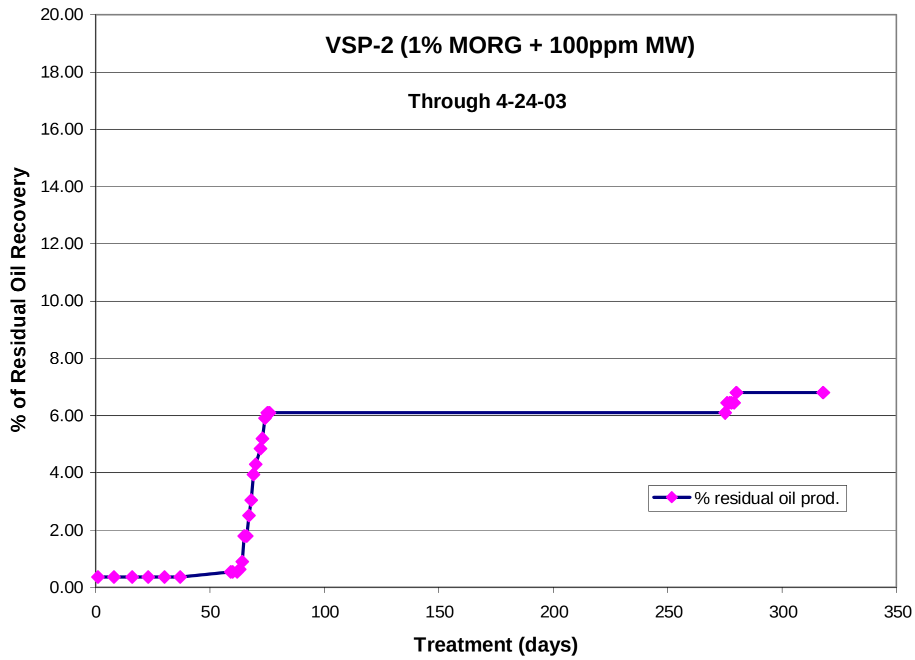

Figure 2. Production with Treatment VSP-2, 1% MORG + 100 ppm Maxwell.

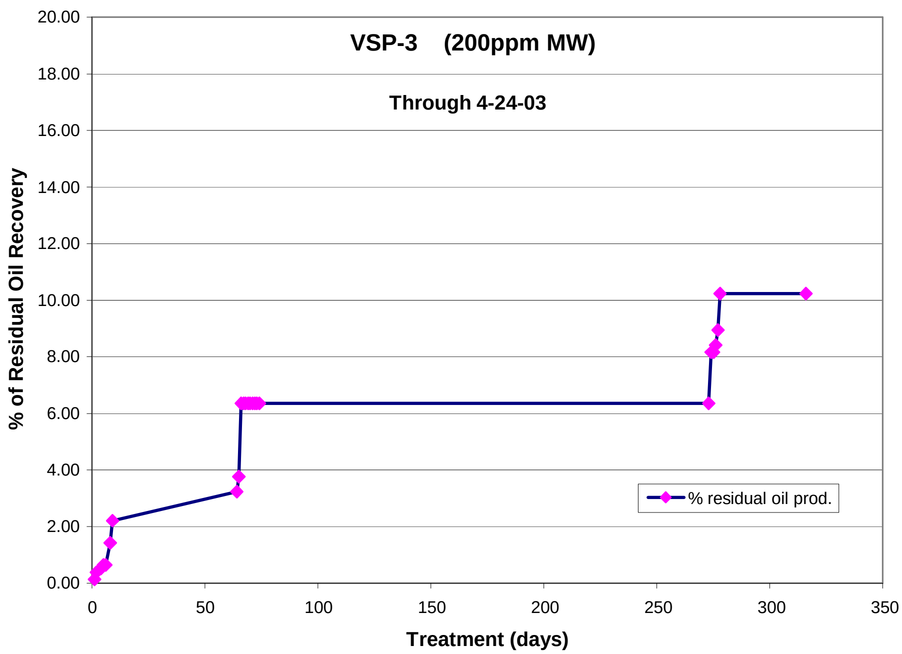

Figure 3. Production with Treatment VSP-3, 200 ppm Maxwell.

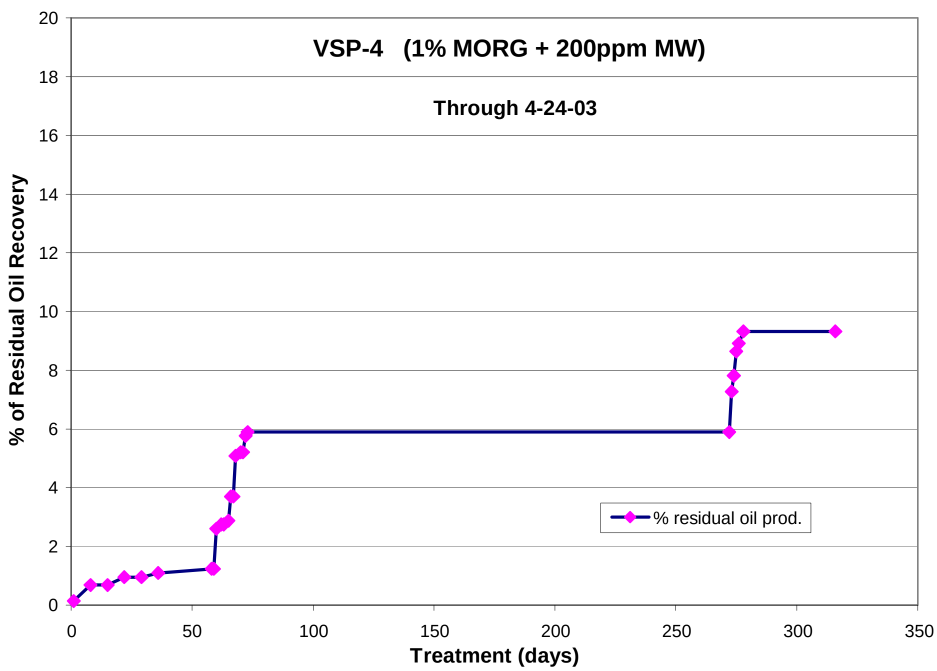

Figure 4. Production with Treatment VSP-4, 1% MORG + 200 ppm Maxwell.

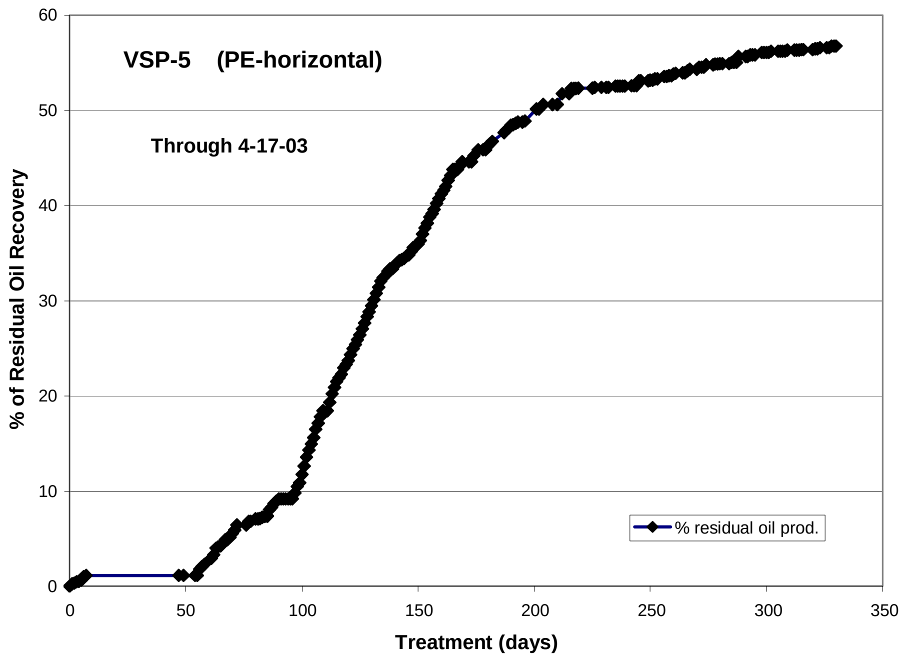

Figure 5. Production with Treatment VSP-5, Nutrient PE.

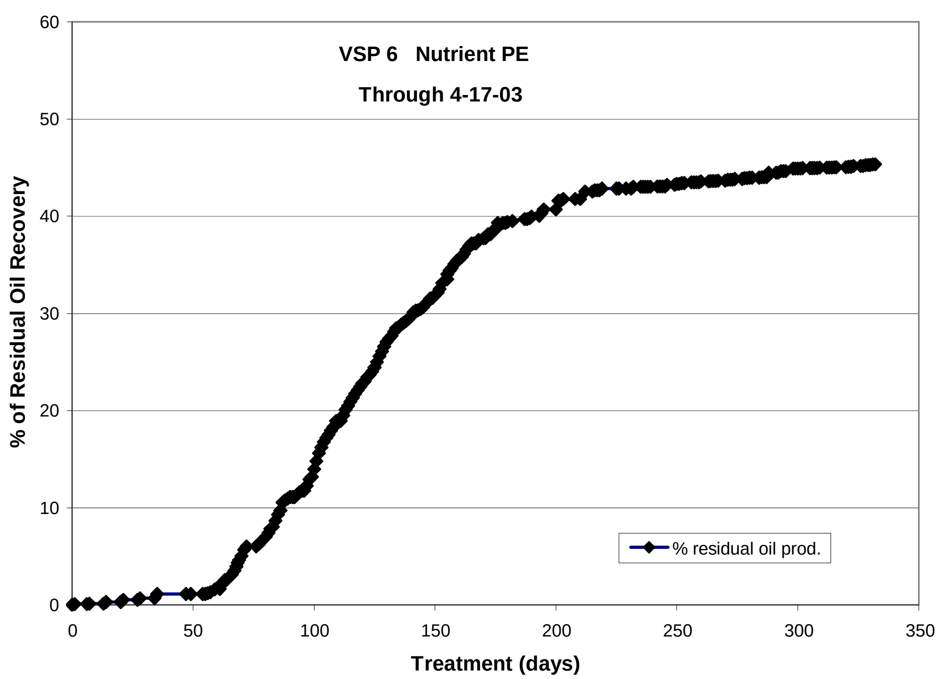

Figure 6. Production with Treatment VSP-6, Nutrient PE.

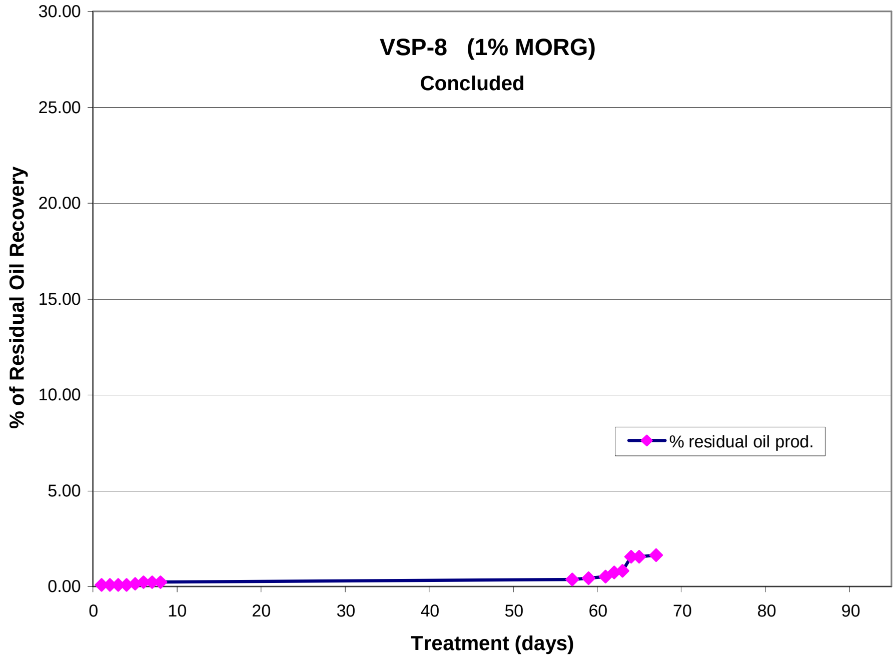

Figure 7. Production with Treatment VSP-8, 1% MORG.

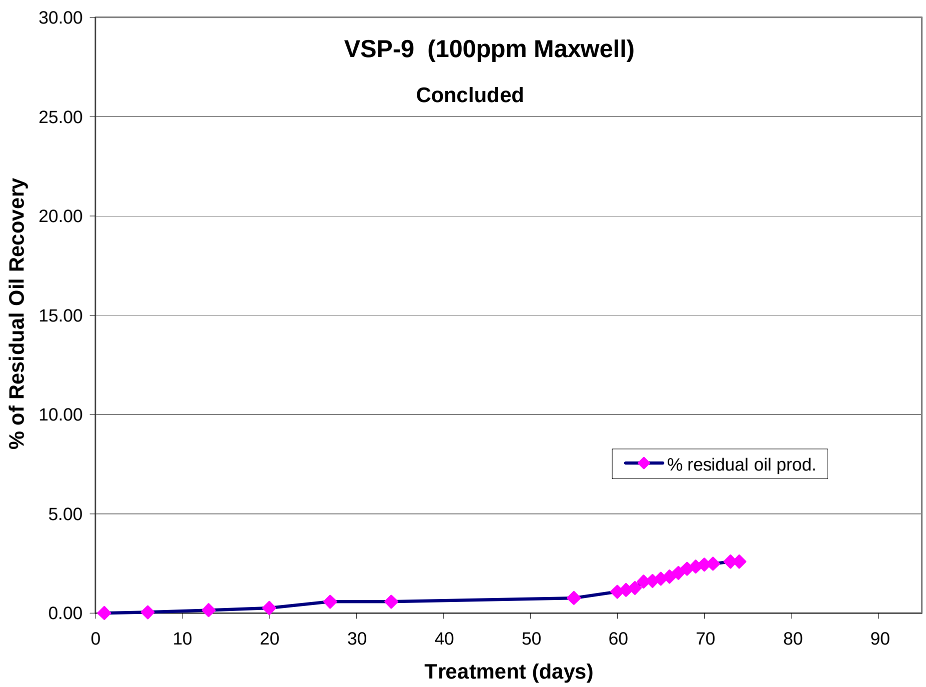

Figure 8. Treatment with Production VSP-9, 100 ppm Maxwell.

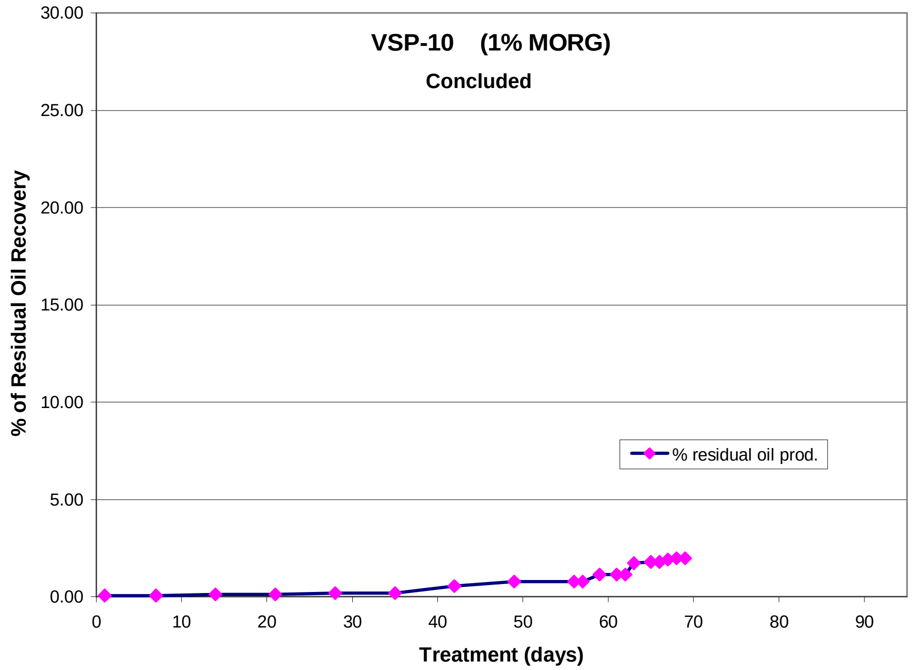

Figure 9. Production with Treatment VSP-10, 1% MORG.

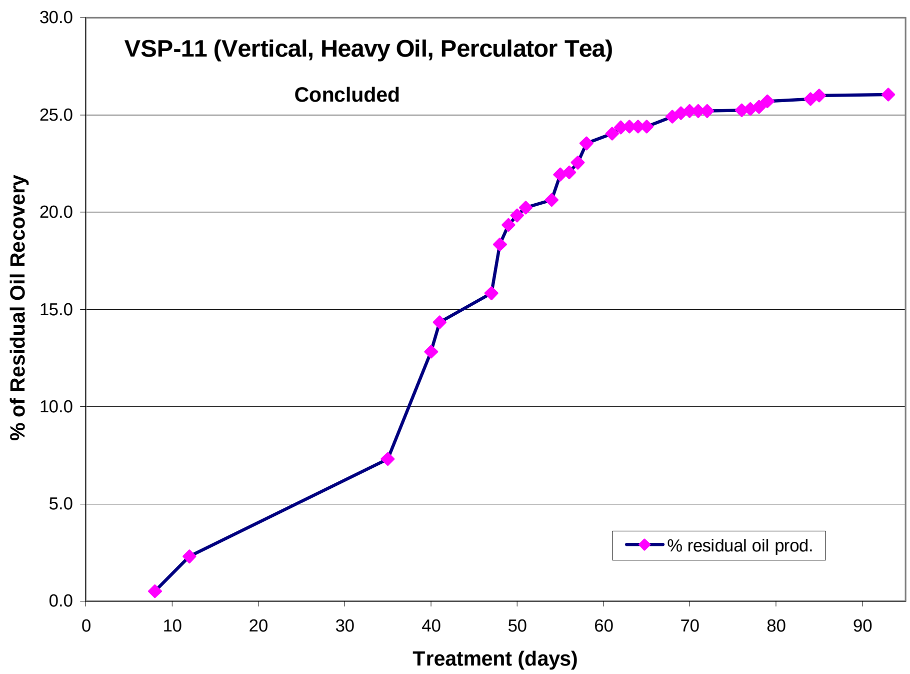

Figure 10. VSP-11 Vertical, Tulare Heavy Oil, Percolator Tea treatment

CHAPTER 3
Field Evaluation of New Technology/Products

Introduction

As results are obtained from the laboratory investigations and made available to field operations through technology transfer, some of the findings have been offered and applied to field studies, situations, and operations. As the laboratory results are incorporated into pilot field projects, these field operations are being closely followed and monitored. The identifications of such fields and participation of the operators will provide additional feedback data from such projects. These pilot field evaluations are being conducted in conjunction with ongoing projects whenever possible. By utilizing such ongoing projects, the requirements for collection of baseline data, flood responses, field operations, etc. will be minimized. A pilot study has been implemented with operator assistance. This approach has allowed rapid introduction and evaluation of systems/products that have been developed by this program and provides directly comparable data. This method of field testing offers a low cost and easily approved and operated system to introduce the technology/products which have been developed in this research program.

Pilot Field Tests

The project is in the Weyburn Field area for Nexen Company. Weyburn is in southeast Saskatchewan and the production is Mississippian coming from dolomitic limestone. The wells are being treated with Max-Well amendments. Results thus far are shown in Figures 11 – 22. The project has shown a dramatic improvement in oil recovery above the established decline curve (more than two years of baseline production data used for decline curve). Charts depict combined production of the eleven (11) waterflooded production wells involved in the project, and the individual wells. This oil recovery field project has now been concluded.

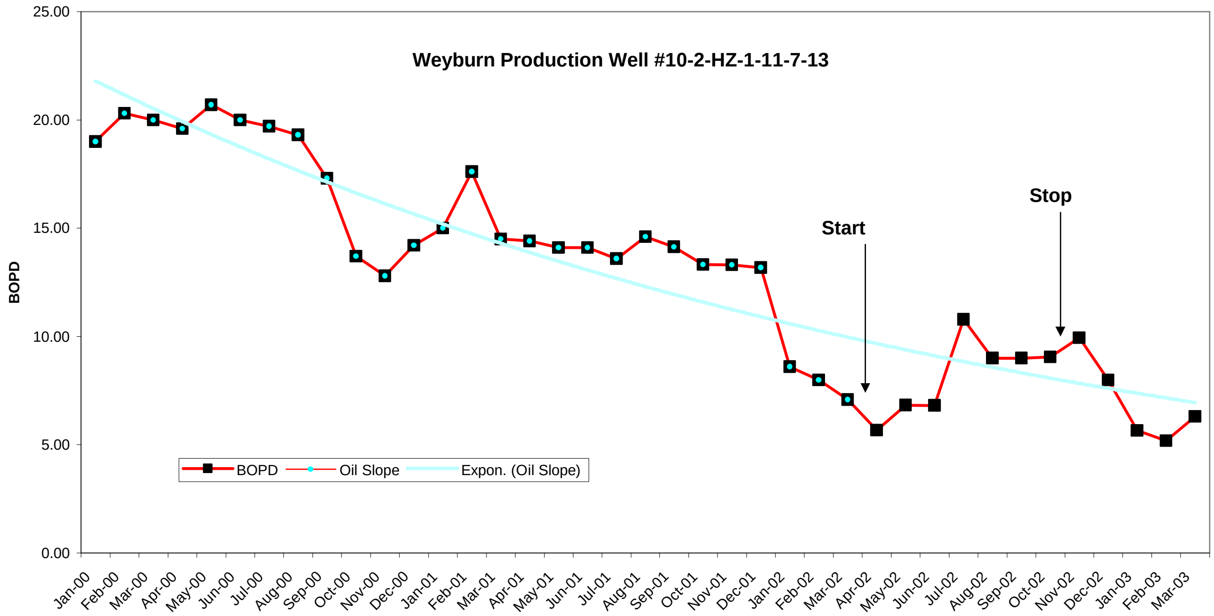

Figure 11. Weyburn 10-2-HZ-1-11-7-13.

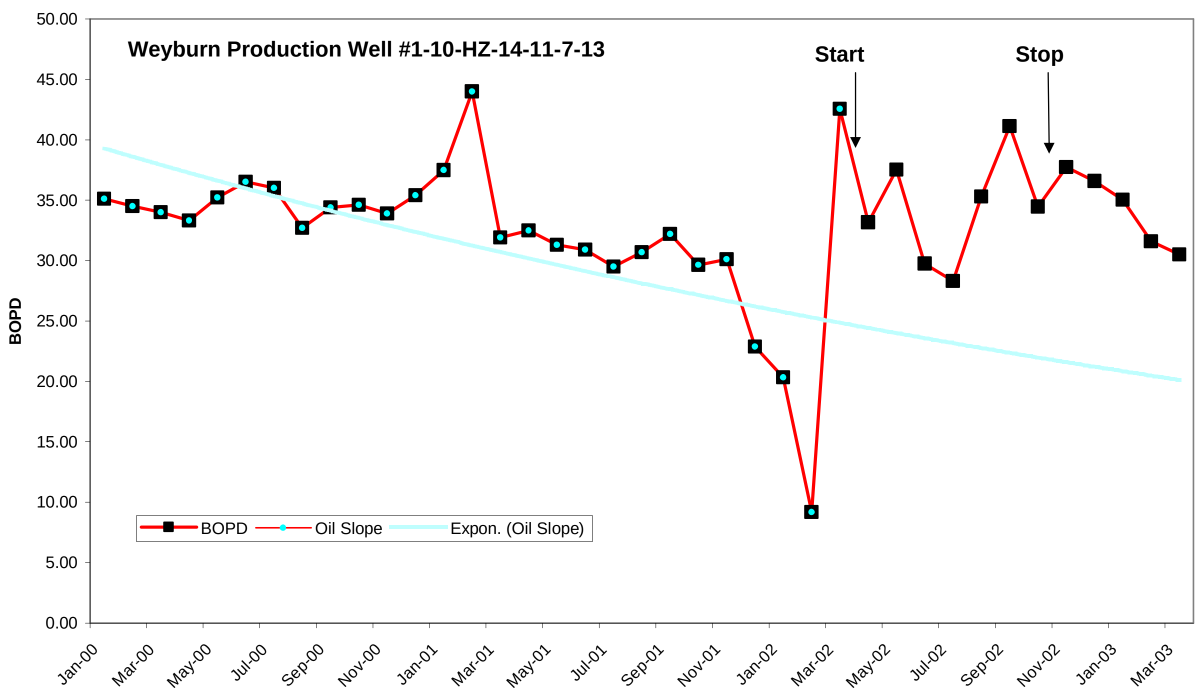

Figure 12. Weyburn 1-10-HZ-14-11-7-13.

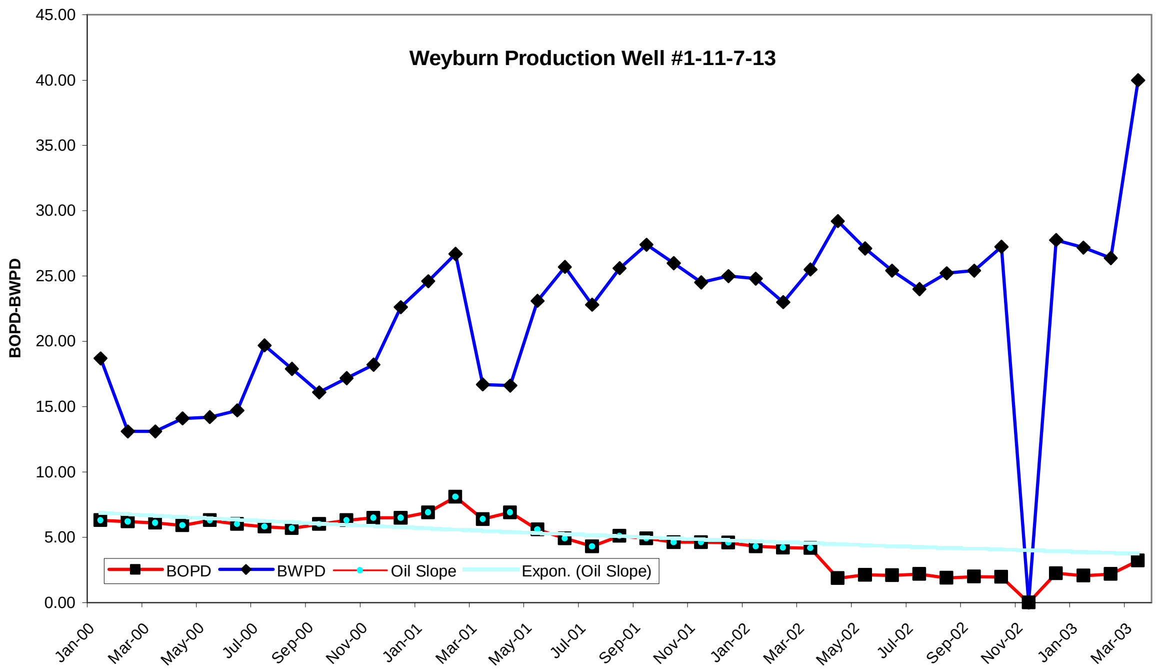

Figure 13. Weyburn 1-11-7-13.

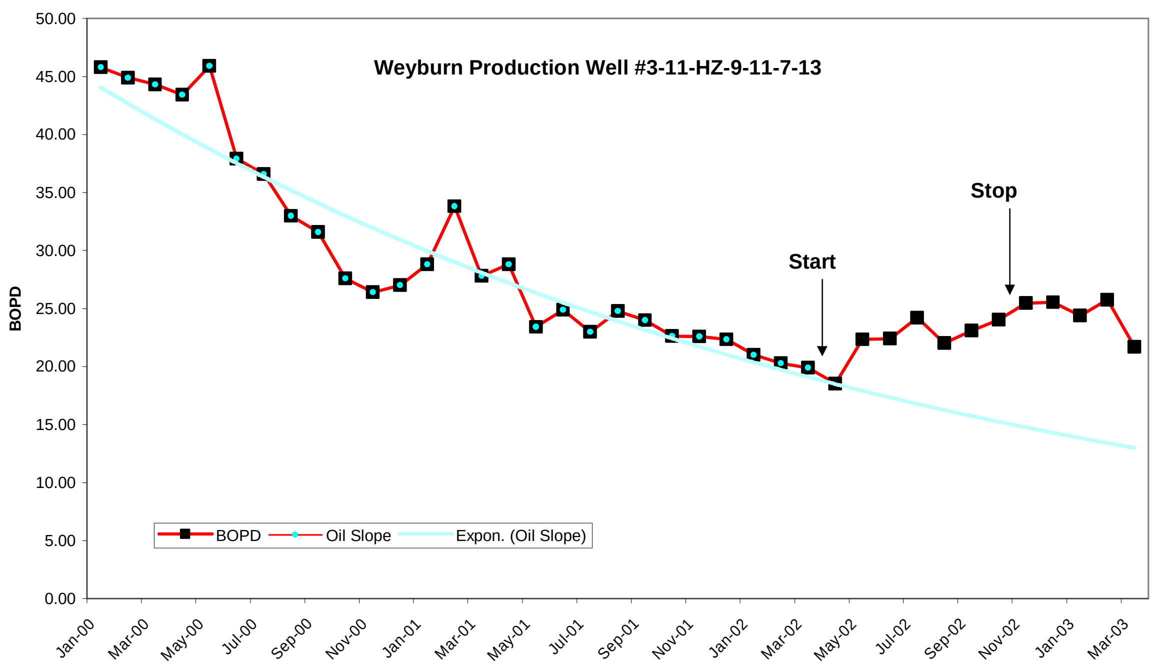

Figure 14. Weyburn 3-11-HZ-9-11-7-13.

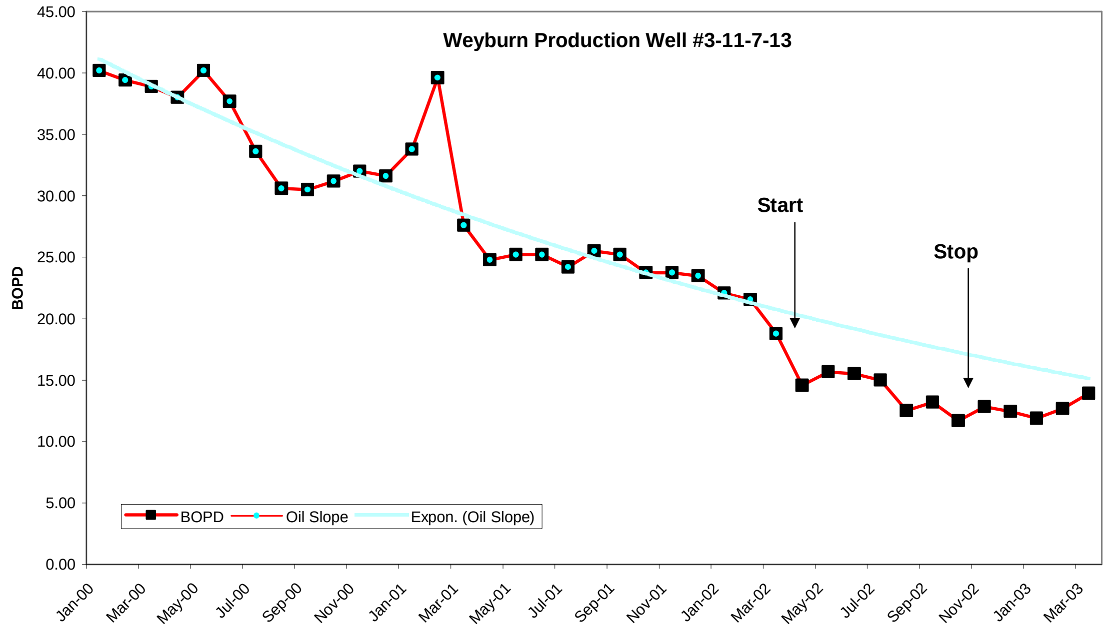

Figure 15. Weyburn 3-11-7-13.

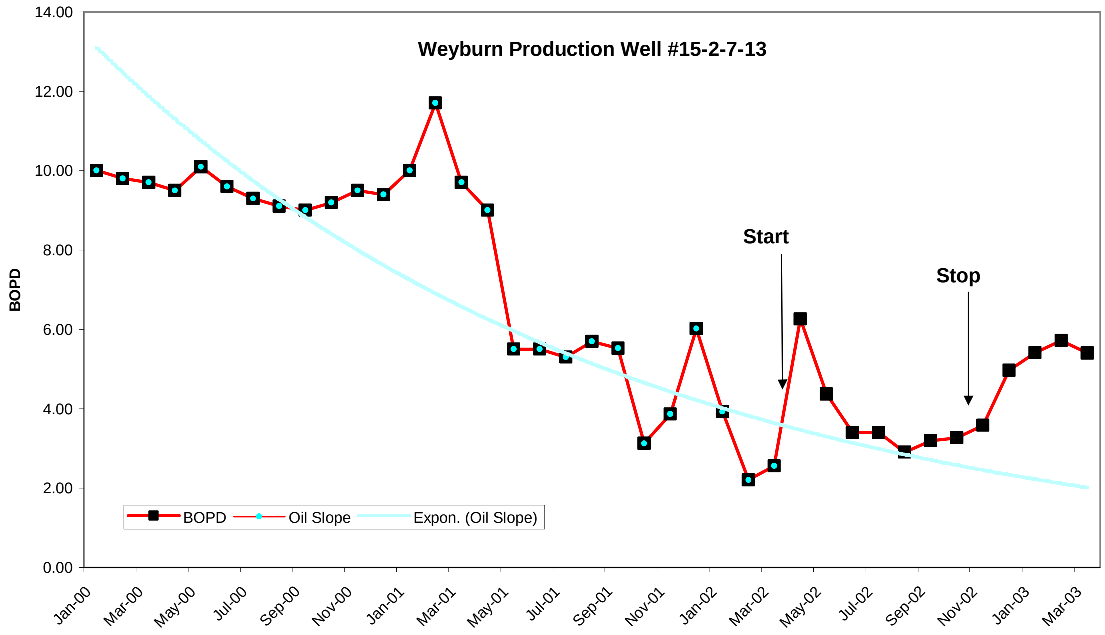

Figure 16. Weyburn 15-2-7-13.

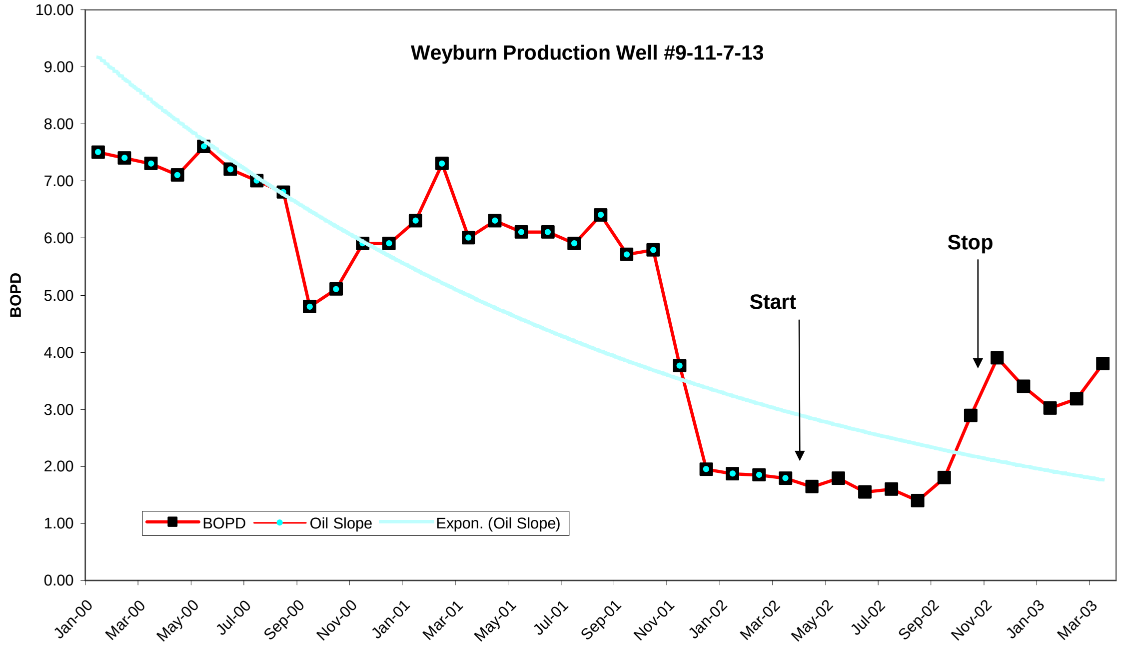

Figure 17. Weyburn 9-11-7-13.

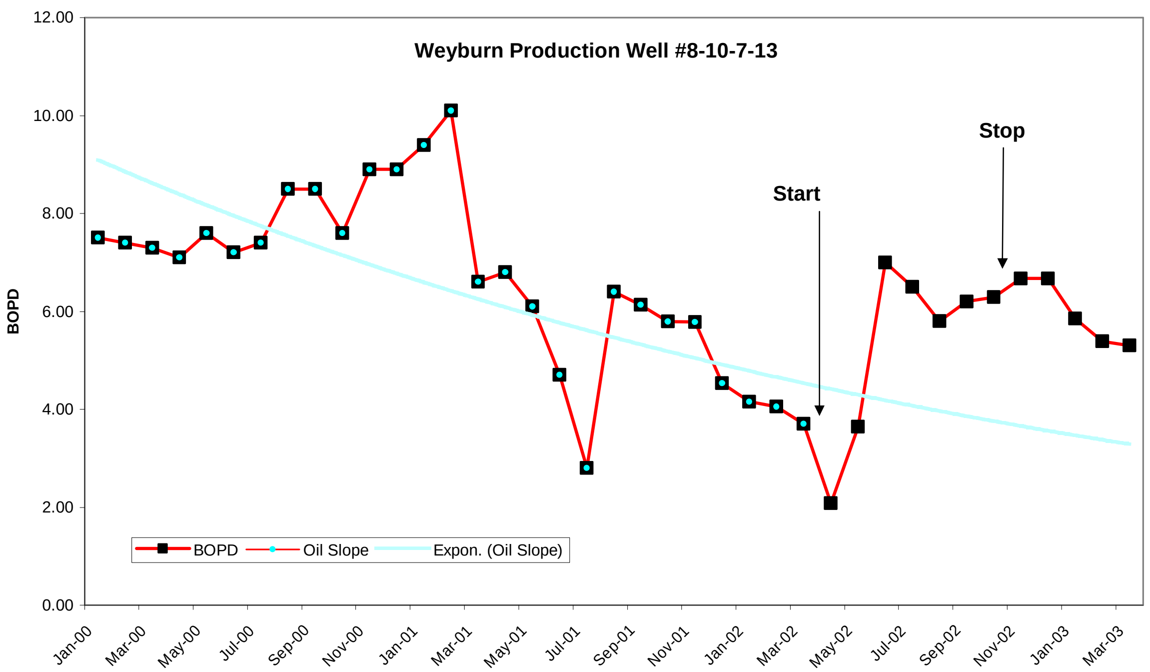

Figure 18. Weyburn 8-10-7-13.

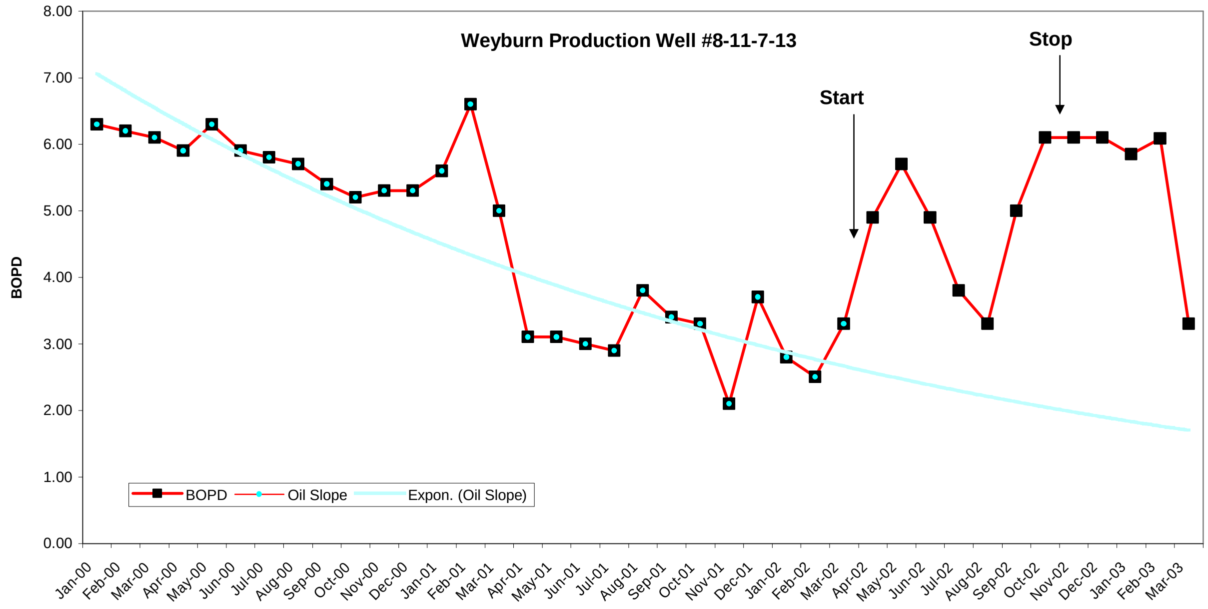

Figure 19. Weyburn 8-11-7-13.

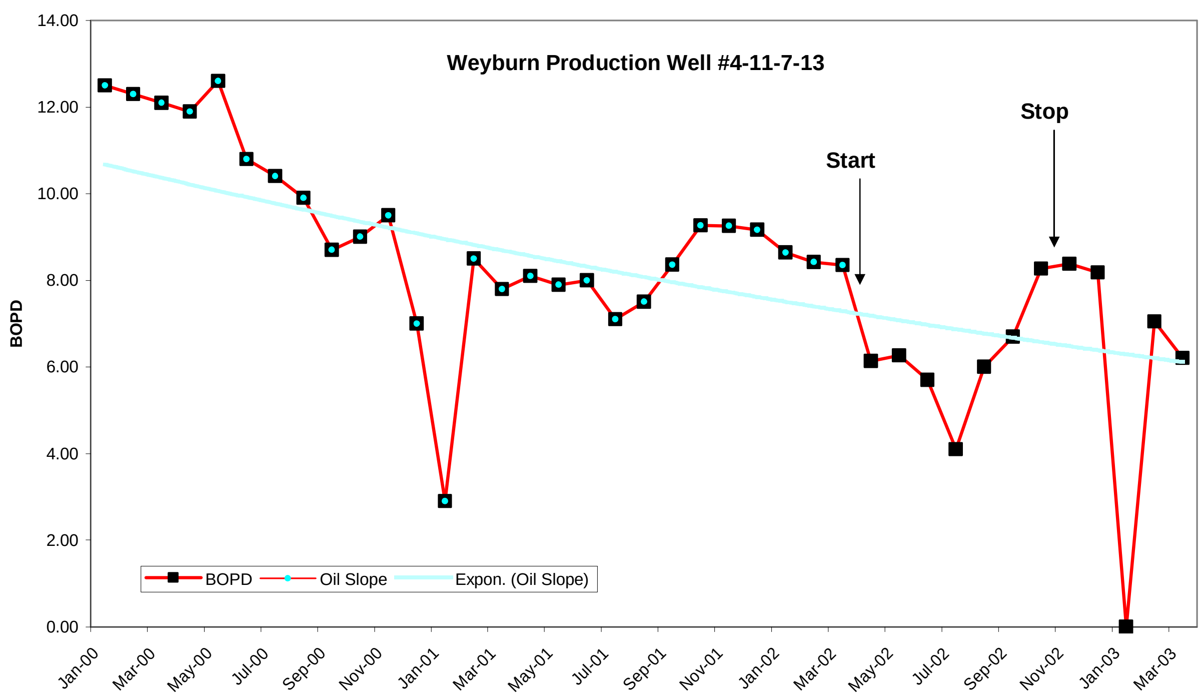

Figure 20. Weyburn 4-11-7-13.

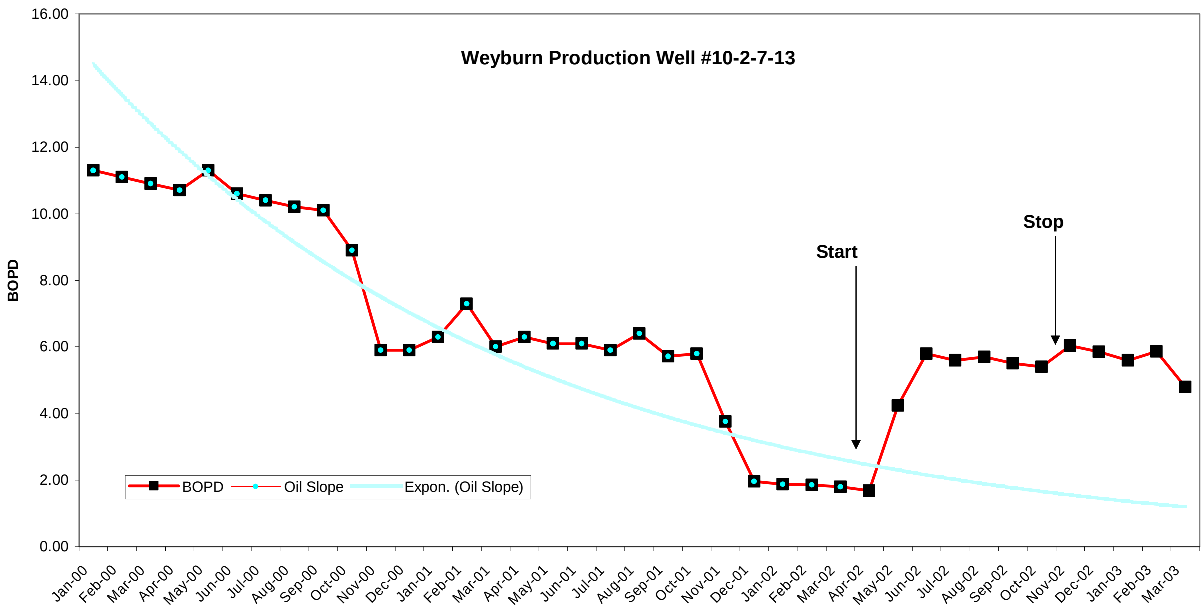

Figure 21. Weyburn 10-2-7-13.

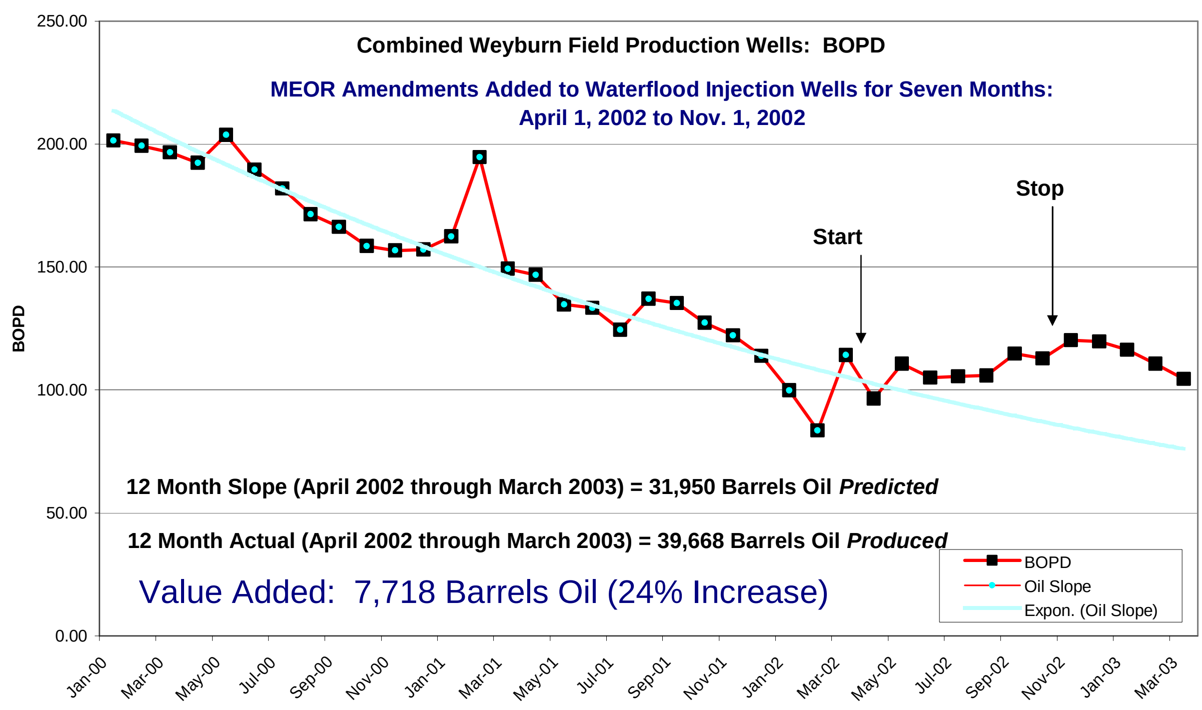

Figure 22. All Weyburn Production Wells.

CHAPTER 4
Reports and Technology Transfer

Introduction

Reports have been issued semiannually, and will also be published in a final comprehensive report. Reports will be issued and offered to industry.

The sixth Semi-Annual report was delivered on schedule.

Presentations and publications

Hitzman, D. O. and S. A. Bailey. 2000. Innovative MIOR Process Utilizing Indigenous Reservoir Constituents. DOE Semi-Annual Report, January 2000.

Hitzman, D. O., S. A. Bailey, and A. K. Stepp. 2000. Innovative MIOR Process Utilizing Indigenous Reservoir Constituents. DOE Semi-Annual Report, July 2000.

A presentation on the project was made at the Oil Technology Program Contractor Review Meeting in Denver in June 2000 by Scott Bailey.

Hitzman, D. O. and A. K. Stepp. 2001. Innovative MIOR Process Utilizing Indigenous Reservoir Constituents. DOE Semi-Annual Report, January 2001.

Hitzman, D. O., A. K. Stepp, D. M. Dennis, and L. R. Graumann. 2001. Innovative MIOR Process Utilizing Indigenous Reservoir Constituents. DOE Semi-Annual Report, October 2001.

Hitzman, D. O., A. K. Stepp, D. M. Dennis, and L. R. Graumann. 2002. Innovative MIOR Process Utilizing Indigenous Reservoir Constituents. DOE Semi-Annual Report, April 2002.

Hitzman, D. O., A. K. Stepp, D. M. Dennis, and L. R. Graumann. 2002. Innovative MIOR Process Utilizing Indigenous Reservoir Constituents. DOE Semi-Annual Report, October 2002.

Dennis, D.M.. 2003. Presentation to Canadian Oil & Gas Industry, March 2003, Calgary, Alberta.

Presentations as part of GMT Exhibit Booth

Society of Geophysicists (SEG) Annual Convention, October 31-November 5, 1999, Houston.

GEO 2000, Middle East Oil and Gas Exposition, March 27-29, 2000, Bahrain.

Society of Petroleum Engineers (SPE) DOE Improved Oil Recovery Symposium, April 2-5, 2000, Tulsa.

American Association of Petroleum Geologists (AAPG) Annual Convention, April 16-19, 2000, New Orleans.

NAPE (North American Prospect Exposition), January 31-February 1, 2001, Houston.

AAPG, March 9-13, 2001, Dallas.

SPE, March 24-27, 2001, Oklahoma City.

Oklahoma Geological Survey, May 8-9, 2001, Oklahoma City.

AAPG Annual Convention, June 2-7, 2001, Denver.

CSPG (Canadian Society for Petroleum Geologists), Annual Convention, June 16-20, 2001, Calgary.

SEG Annual Convention, September 9-12, 2001, New Orleans.

AAPG East Section Meeting, September 23-25, 2001, Kalamazoo, Michigan.

NAPE, January 29-31, 2002, Houston.

AAPG Annual Convention, March 10-13, 2002, Houston.

Kansas Geological Society, March 28, 2002, Wichita, KS.

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