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Innovative MIOR Process Utilizing Indigenous Reservoir Constituents

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DISCLAIMER

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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 known that microorganisms can survive and multiply in and under reservoir conditions, and have the capability to significantly influence oil practices and production (credited to Beckman, 1926). Using such data, it has been proposed that microorganisms can also exert and have a positive effect on oil production (1, 2). Areas being actively studied include the production of biopolymers and biosurfactants by microorganisms, and the injection of these products for viscosity and surface tension modifications. In addition, microorganisms have been tested for their ability to grow in oil reservoirs and by their growth in-situ cause the increased mobilization of oil through various mechanisms and/or products such as CO_2 and other gases, surfactants, organic acids and solvents. Successful field tests employing Microbial Improved Oil Recovery (MIOR) technologies have been reported and more field tests are now in progress (3).

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

- Low concentrations of selected nitrogen salts stimulate populations of indigenous denitrifying microbes,
- Such denitrifying populations are heterotrophs known to produce copious amounts of biopolymers and biosurfactants at reservoir conditions,
- Beneficial microbial populations can be established and maintained within the reservoir by supplying low-cost nitrogen salts.

This line of investigation has been expanded in the present research program to develop 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. The three-year research project began in October 1999. This report describes month thirty-one through month thirty-six of the project. Chapter 2 describes the laboratory experiments, including selection of suitable microbial strains, isolation of cultures from oil field brines and other sources, and nutrient studies. Design and development of physical models for studying fluid flow is also detailed, as well as sand pack flood results. Physical models were used to test the concepts of controlled microbial ecology for creating an improved oil recovery system. Many sand pack floods were completed. Most of the research effort is now concentrated on oil recovery tests.

Chapter 3 details the field pilot tests 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 which adapt to the prevailing reservoir conditions. These complex microbial communities contain the metabolic capabilities to produce known oil recovery agents such as biosurfactants and biopolymers. The indigenous communities are in dynamic equilibrium with their environment, and can be restructured in a directed way to favor production of beneficial products. The presence of inorganic nutrients can control reservoir ecology, and adding inorganic nutrients as alternate electron acceptors can stimulate distinct groups of bacteria. 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 which leads to the biogenic formation of sulfide in reservoirs was pioneered at GMT. These investigations led to the discovery of a novel technology which used 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 which act as an alternate electron acceptor. The technology which has been termed “Biocompetitive Exclusion” is based on the presence of VFA in the reservoir and its preferential use and removal by an indigenous microflora and therefore requires no addition of organisms. The growth of those anaerobic denitrifying microorganisms has the added potential of increasing oil recovery by the production of their metabolic products which can include gases (CO_2 and N_2), biosurfactants, biopolymers, and acids.

This past work which has identified VFA in oil field brines and which has shown its impact on reservoir souring and corrosion has led to the development of technologies which incorporate the VFA in a positive role. These previous experiments, field data, and results can be incorporated directly into this research effort. This research provides strong background information on VFA in reservoir fluids, and will be coupled with the ongoing studies of VFA in oil reservoirs to offer a unique information base for the successful completion of the program.

Experimental

Oil Recovery Tests

Sand pack flooding experiments were conducted to determine the effects of various nutrients and flooding regimes on oil recovery. All experiments were conducted at 120° F (49° C). The sand pack columns were made of plastic, and were 2 inches (5.08 cm) in diameter and 10 feet (3 m) in length.

After saturation with field brine, oil saturation with heavy oil obtained from a California oil field, and waterflooding to residual oil saturation, the packs were inoculated with a microbial consortium. The packs were shut in. Treatment was then begun with various types of nutrients mixed with brine.

Results and Discussion

Oil Recovery Tests

Results are shown in Figures 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.

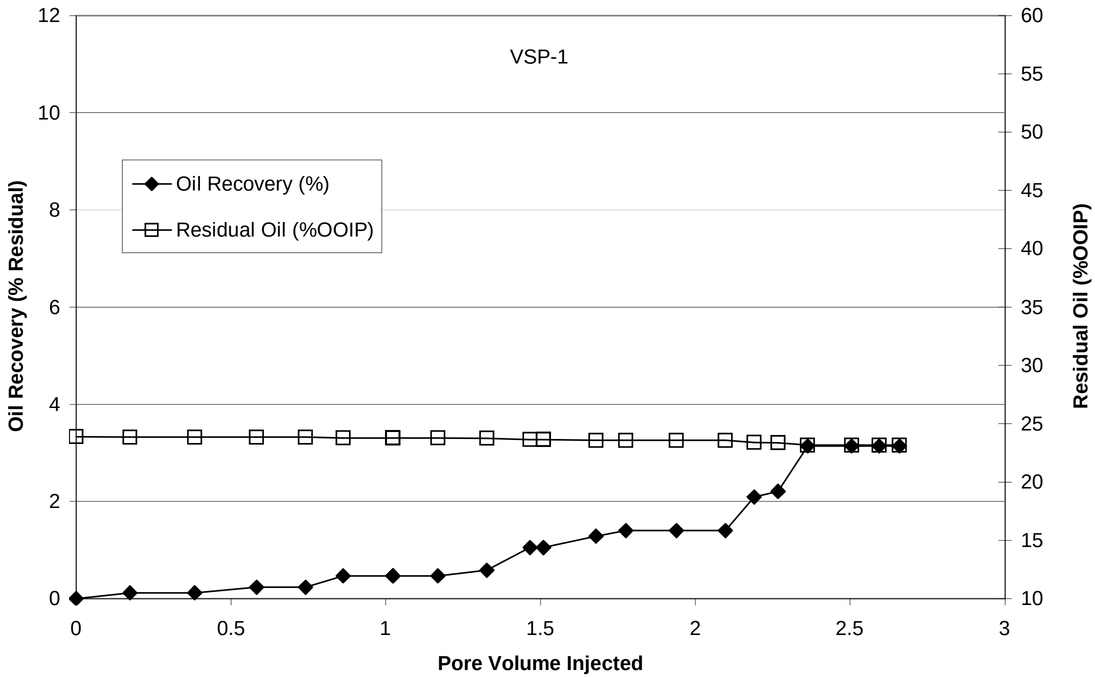

Figure 1. Production with Treatment VSP-1, 100 ppm Maxwell.

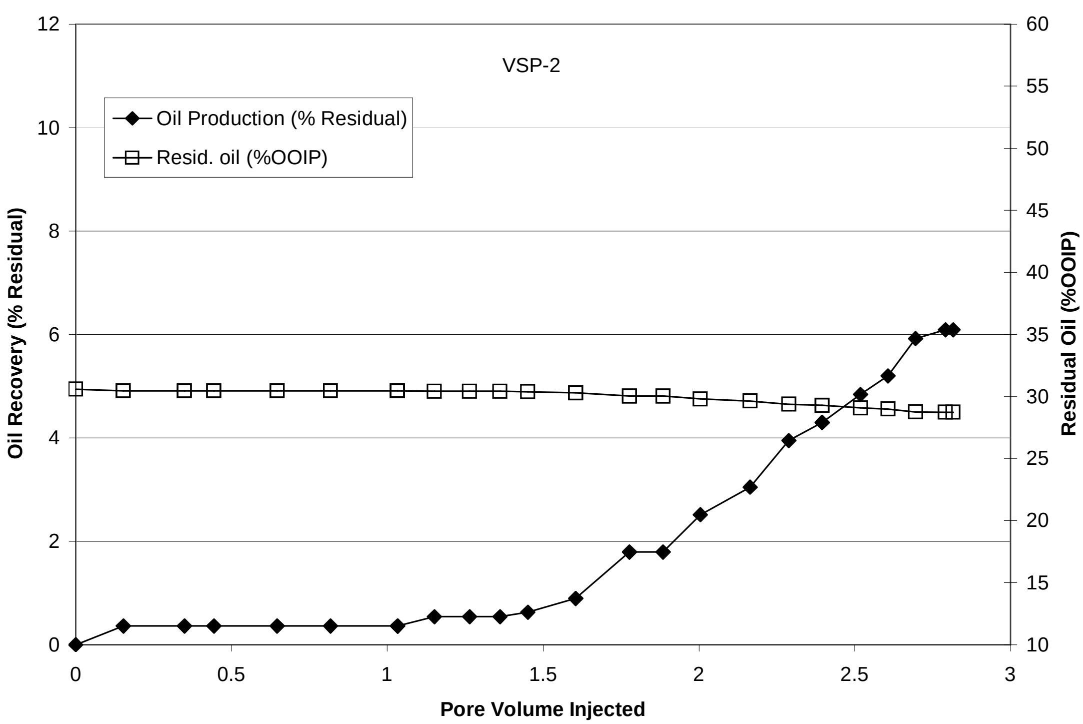

Figure 2. Production with Treatment VSP-2, 1% MORG + 100 ppm Maxwell.

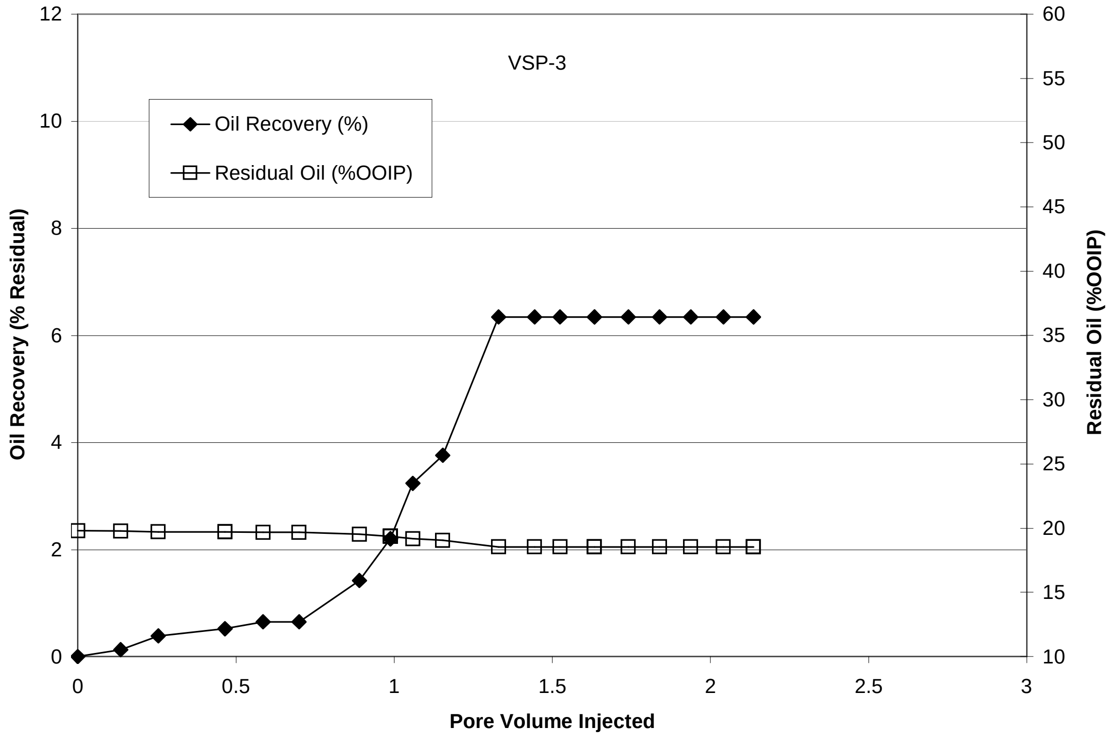

Figure 3. Production with Treatment VSP-3, 200 ppm Maxwell.

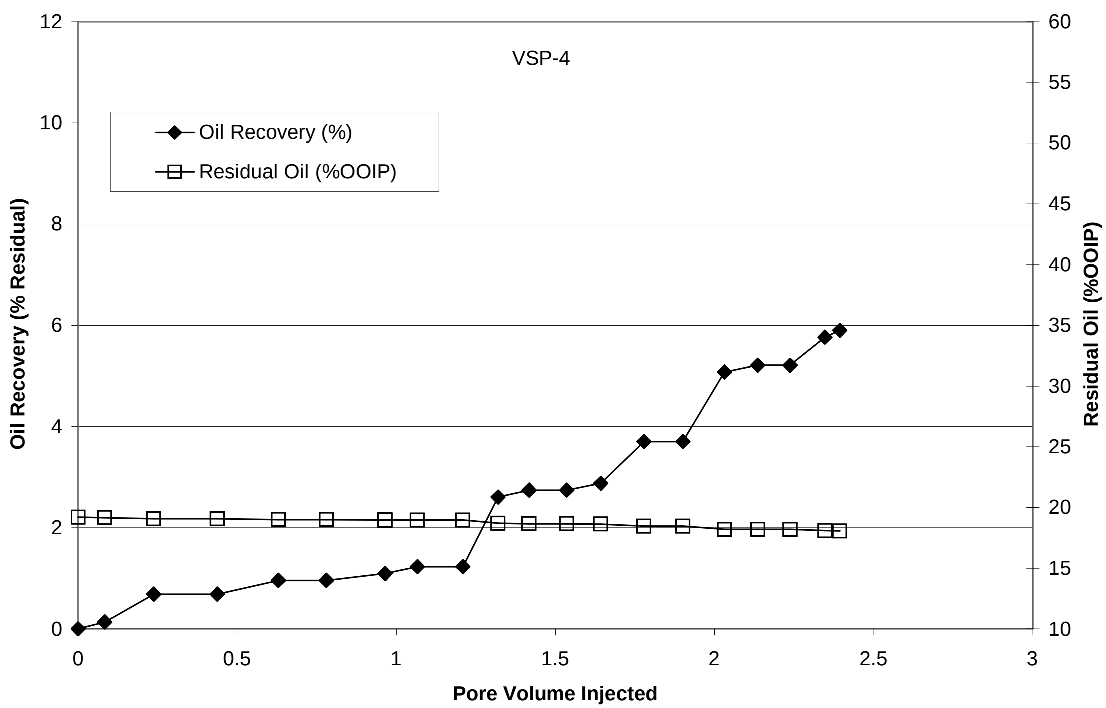

Figure 4. Production with Treatment VSP-4, 1% MORG + 200 ppm Maxwell.

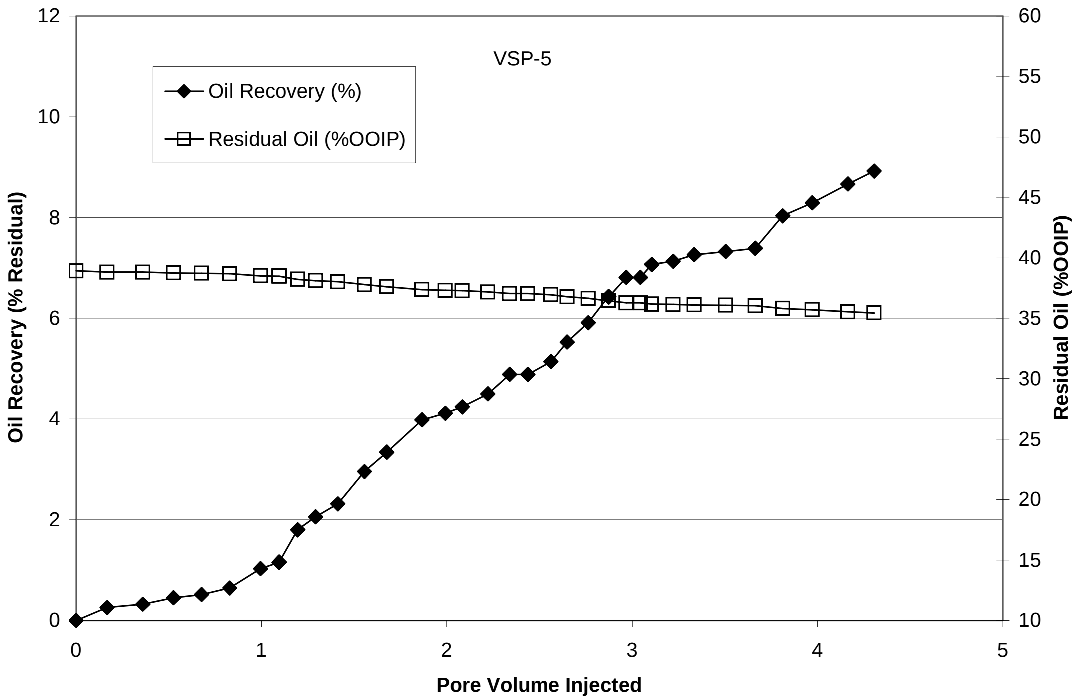

Figure 5. Production with Treatment VSP-5, Nutrient PE.

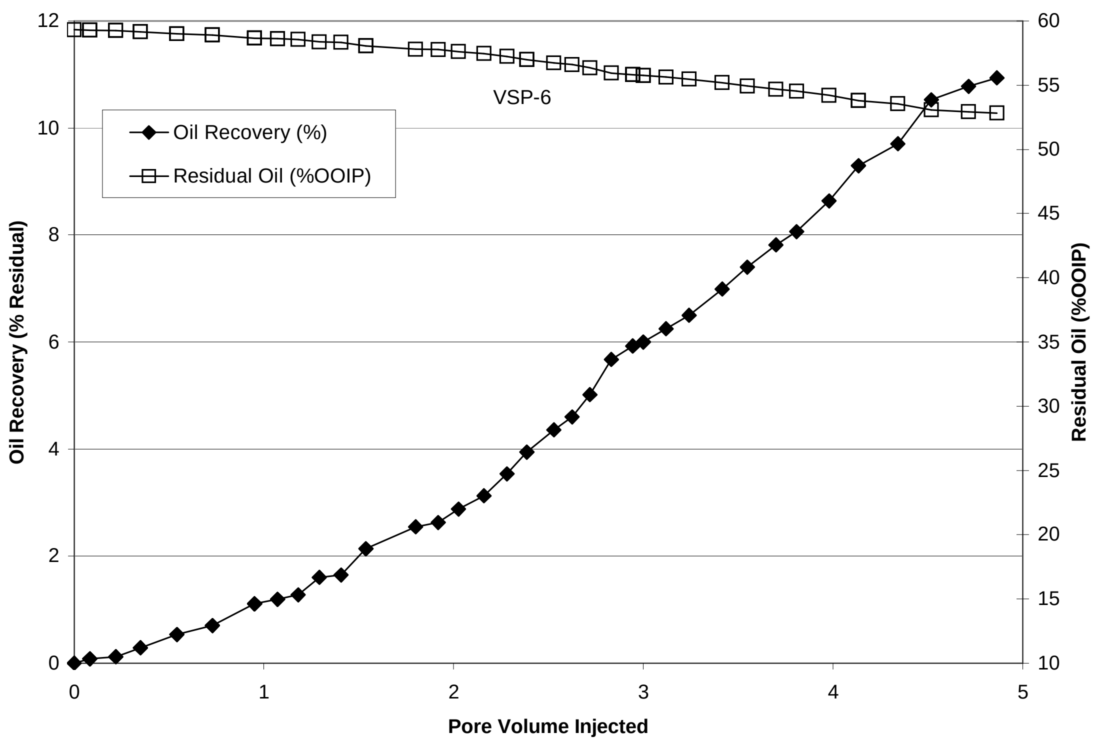

Figure 6. Production with Treatment VSP-6, Nutrient PE.

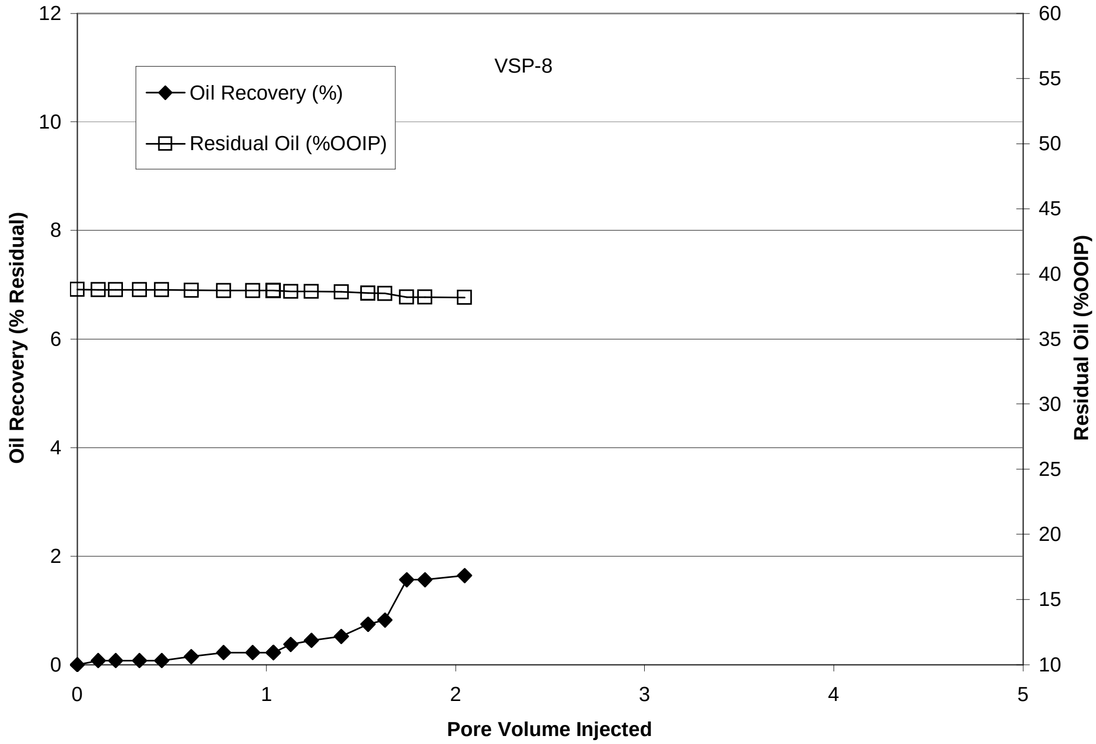

Figure 7. Production with Treatment VSP-8, 1% MORG.

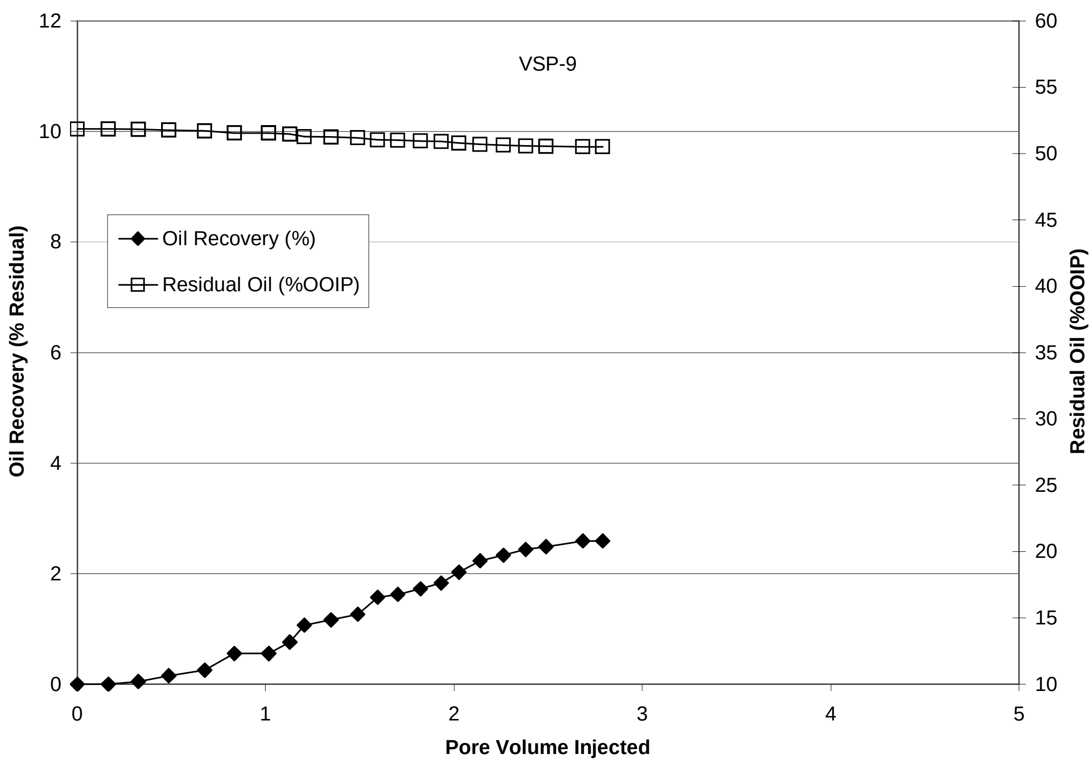

Figure 8. Treatment with Production VSP-9, 100 ppm Maxwell.

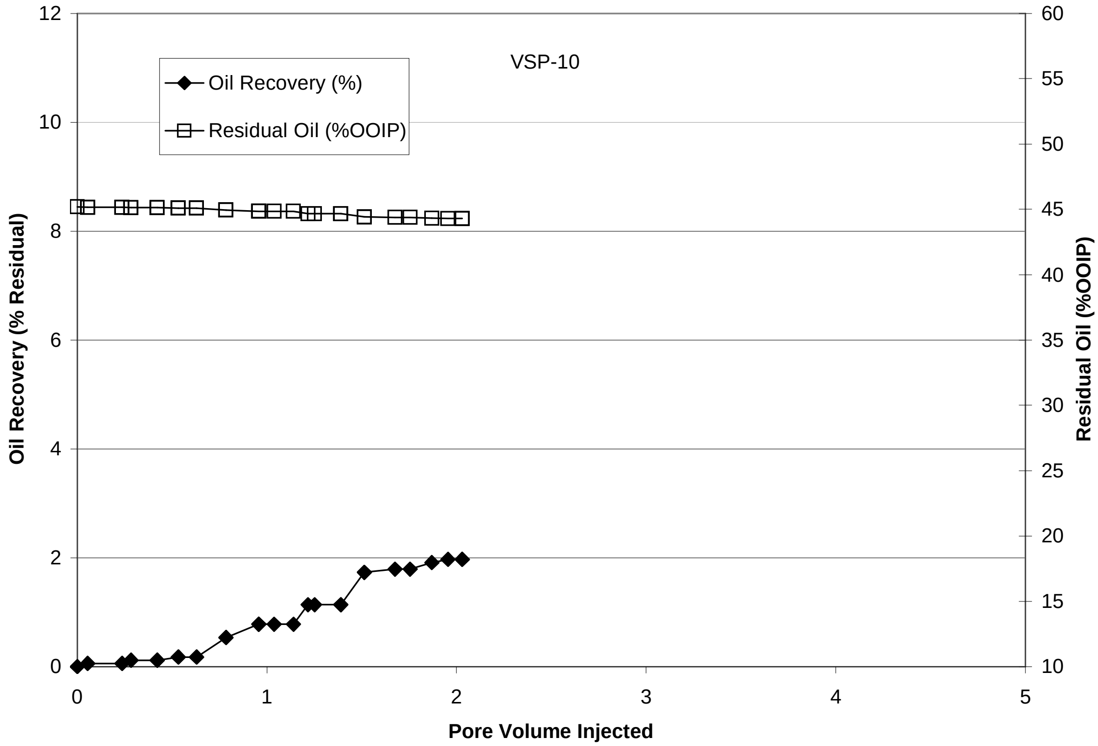

Figure 9. Production with Treatment VSP-10, 1% MORG.

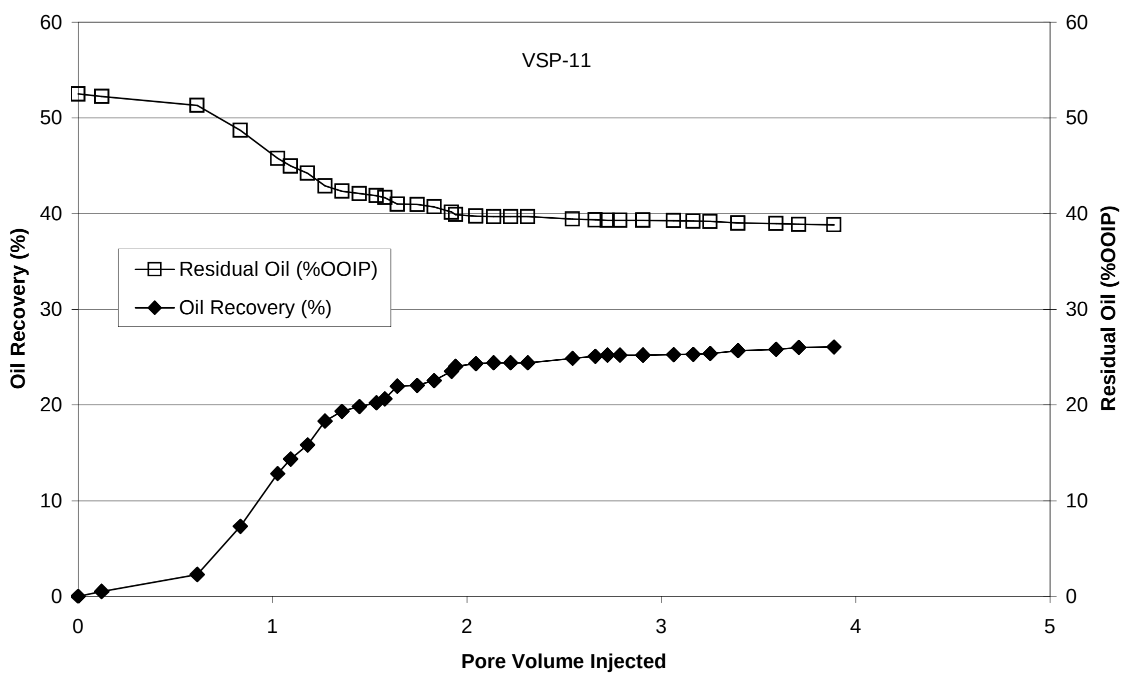

Figure 10. VSP-11 Vertical, Tulare Heavy Oil, Percolator Tea treatment.

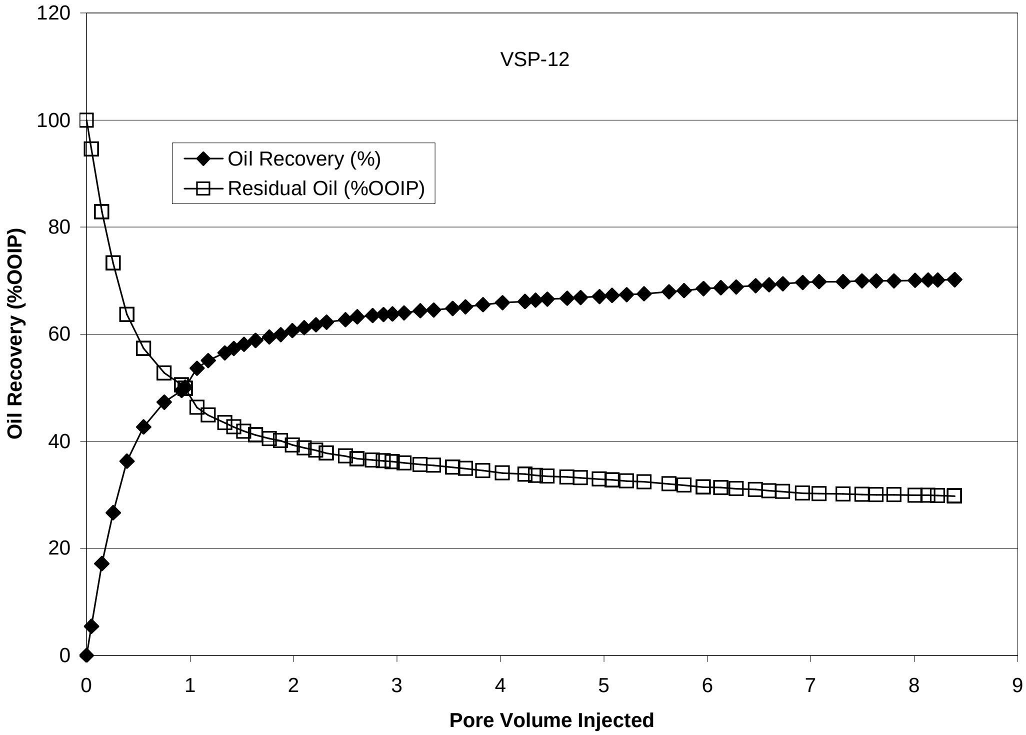

Figure 11. VSP-12 Vertical, Tulare Heavy Oil, 100ppm MW intermittent treatment on OOIP.

CHAPTER 3
Field Evaluation of New Technology/Products

Introduction

As results have been obtained from the laboratory investigations and are 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. Weyburn is in southeast Saskatchewan and the production is Mississippian coming from dolomitic limestone. The wells are being treated with Max-Well. Results thus far are shown in Figures 12 – 22. The project as a whole has shown an improvement in oil recovery above the decline curve. Seven of ten wells are producing at levels above the decline curve. The project is still ongoing.

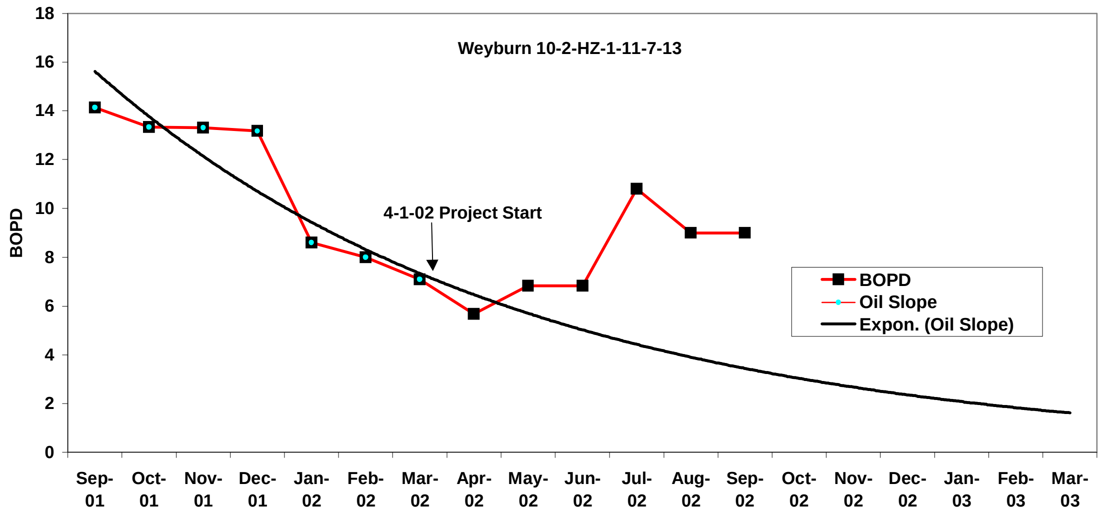

Figure 12. Weyburn 10-2-HZ-1-11-7-13.

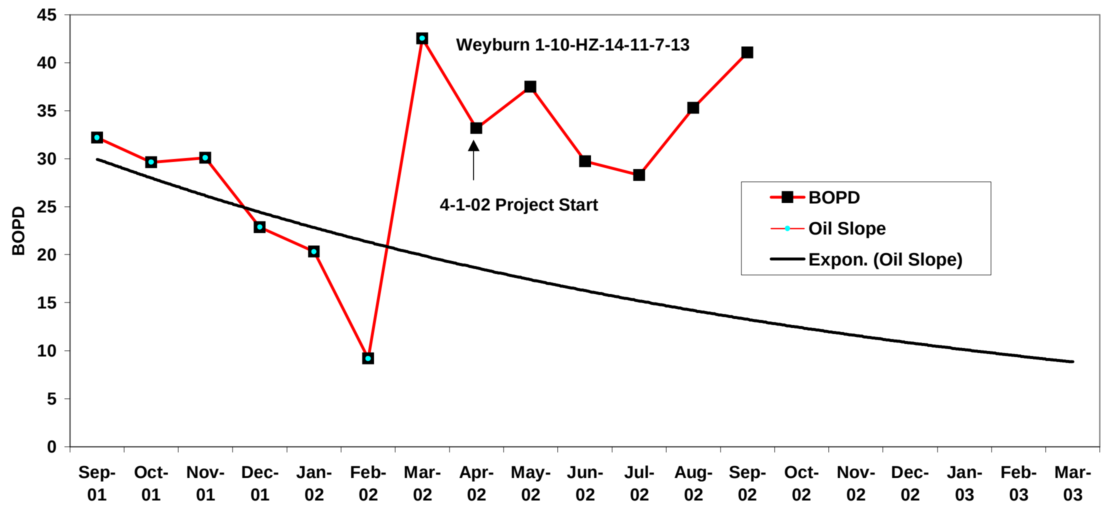

Figure 13. Weyburn 1-10-HZ-14-11-7-13.

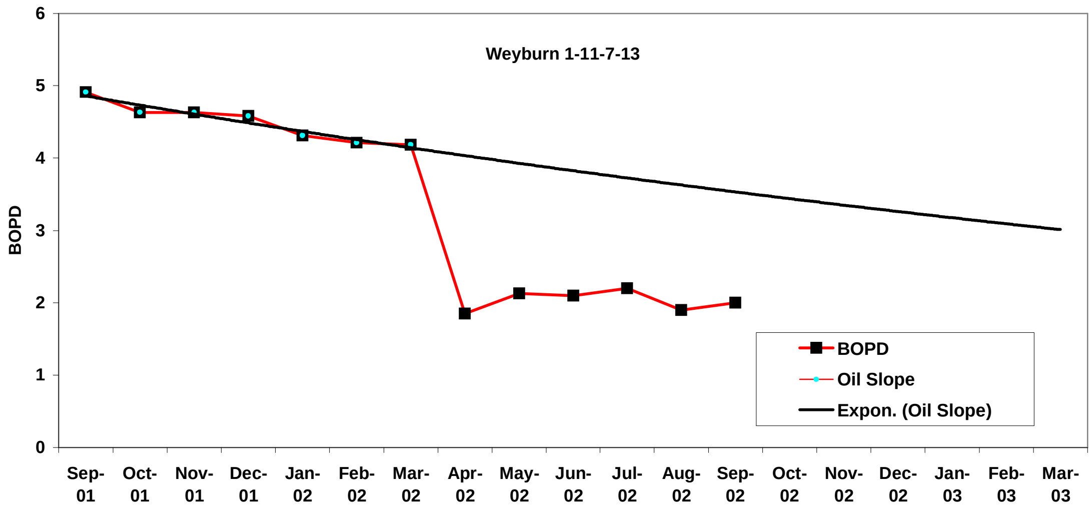

Figure 14. Weyburn 1-11-7-13.

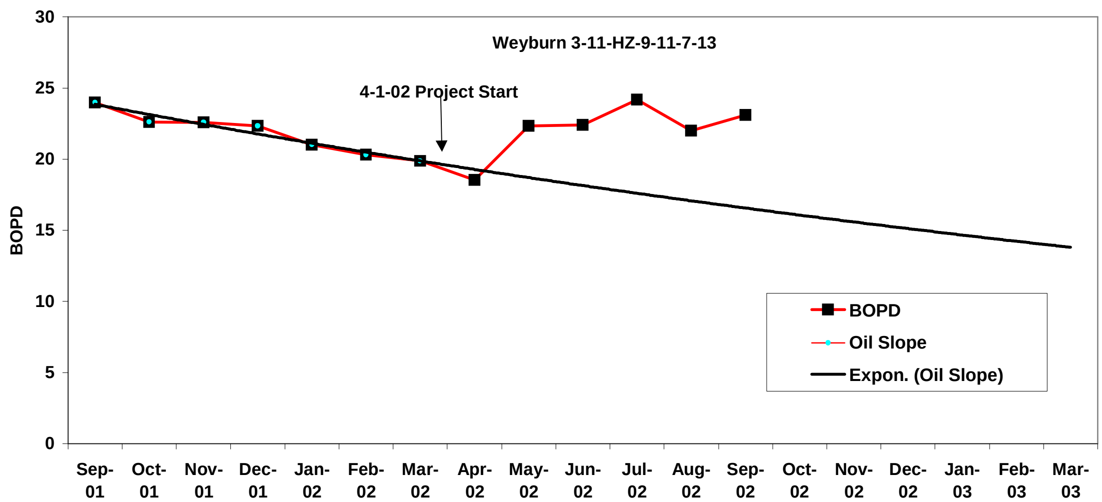

Figure 15. Weyburn 3-11-HZ-9-11-7-13.

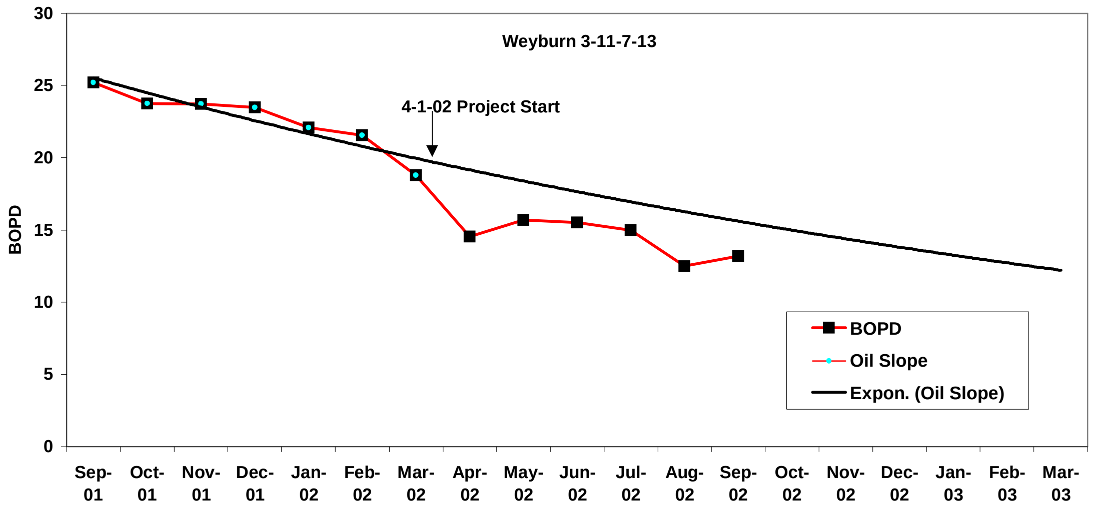

Figure 16. Weyburn 3-11-7-13.

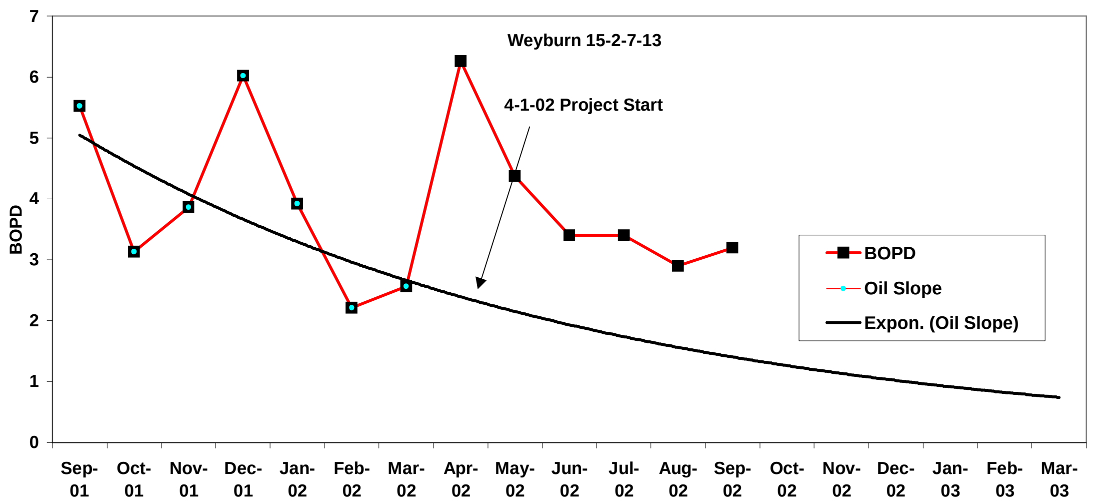

Figure 17. Weyburn 15-2-7-13.

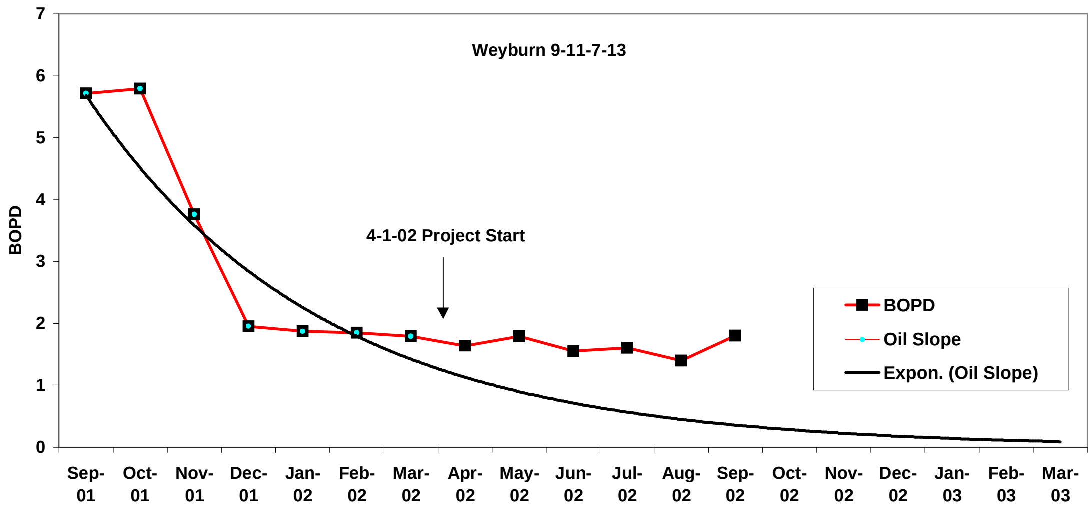

Figure 18. Weyburn 9-11-7-13.

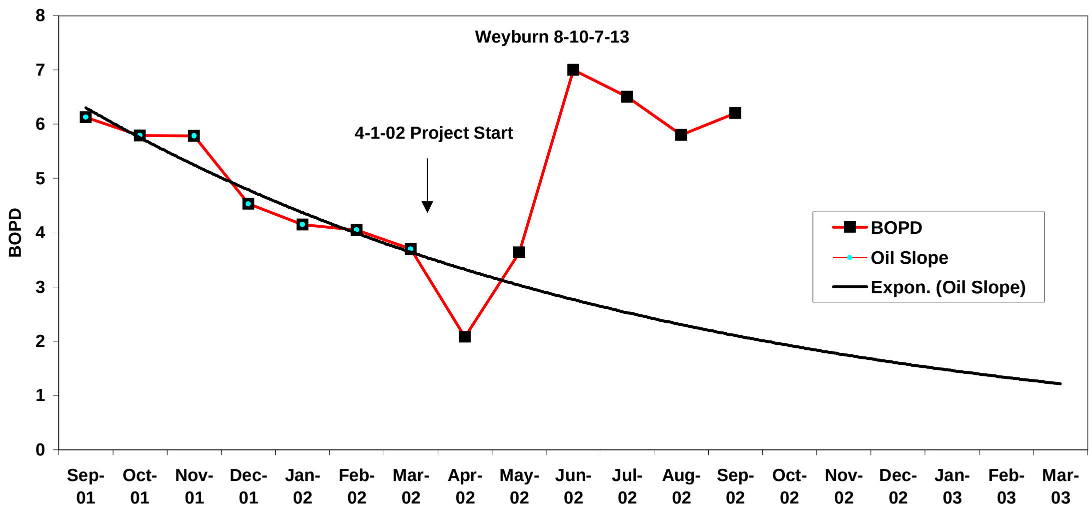

Figure 19. Weyburn 8-10-7-13.

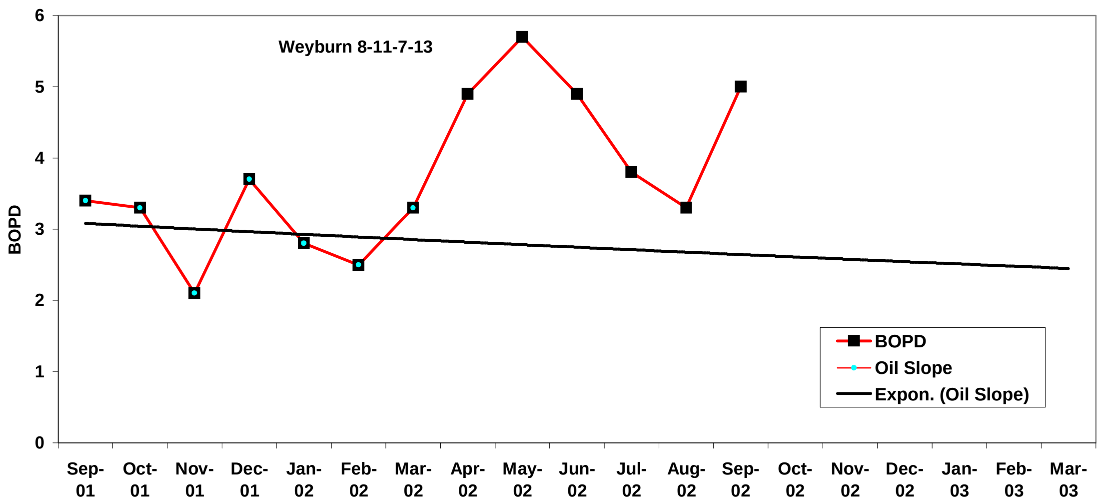

Figure 20. Weyburn 8-11-7-13.

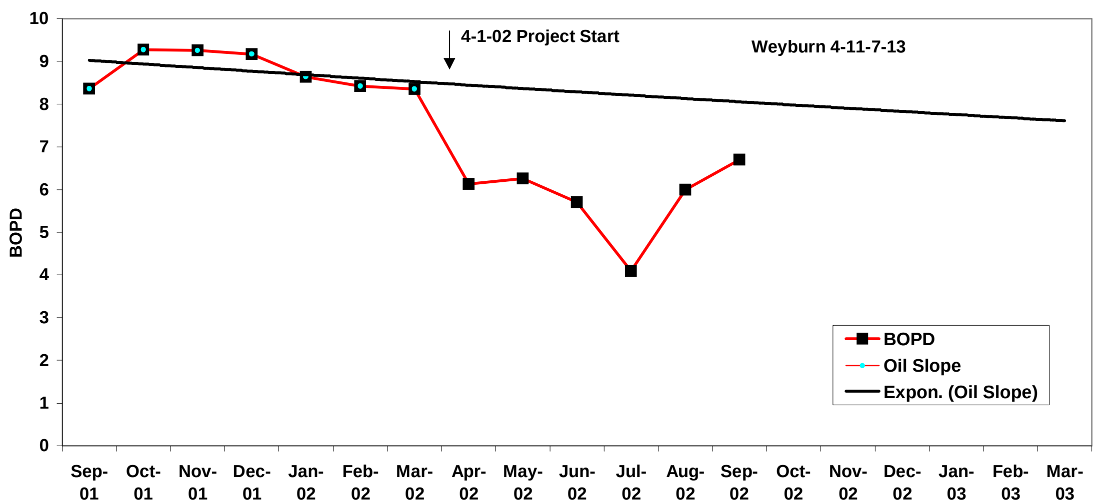

Figure 21. Weyburn 4-11-7-13.

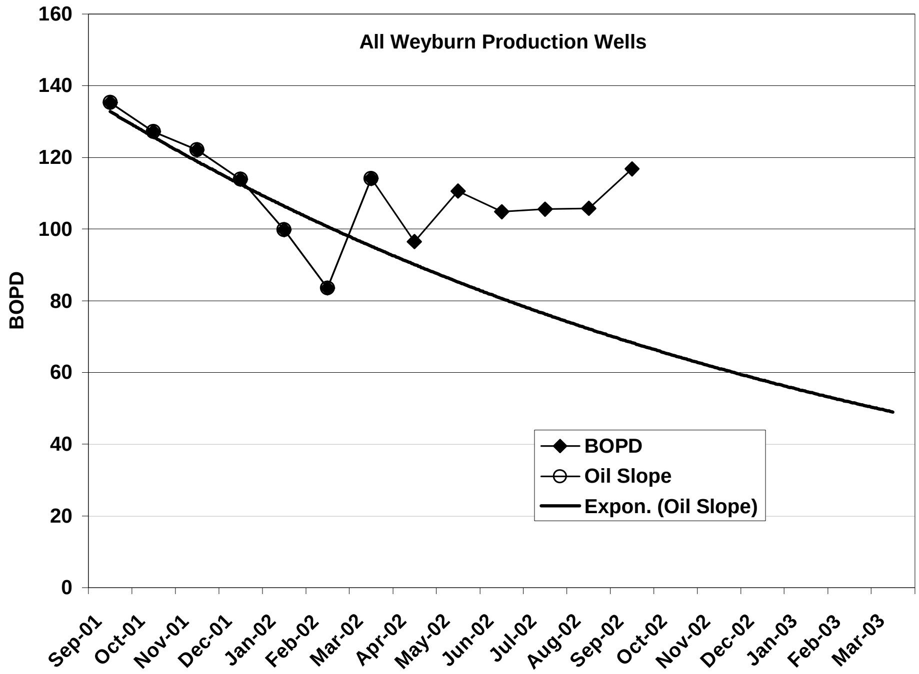

Figure 22. All Weyburn Production Wells.

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 fifth 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. 2001. Innovative MIOR Process Utilizing Indigenous Reservoir Constituents. DOE Semi-Annual Report, April 2002.

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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