Implementation of Gelled Polymer Technology - An Example of a Joint Industry-University Project

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ABSTRACT

The Tertiary Oil Recovery Project (TORP) at the University of Kansas has been in existence since 1974. The Project is state supported and was established to conduct research on enhanced recovery processes which are applicable in Kansas and the Mid-Continent area.

TORP has been investigating gelled polymer technology which was developed to improve sweep efficiency in waterflooding and other displacement processes. The technology has been tested in several field pilot projects in the State. A number of these have been conducted as cooperative ventures between independent operators and the University. In this paper, the technology and its application in several fields are described. The manner in which the cooperative efforts have been undertaken are discussed.

INTRODUCTION

Waterflooding, or secondary recovery, has been used to increase oil production in Kansas and the Mid-Continent Region for many years. Many of the waterfloods are approaching or are presently at their economic limit due to high producing water/oil ratios, and many have low volumetric sweep efficiency. Poor performance in many cases is due to water channeling through reservoir layers of relatively large permeability or through fractures. Fractures, when they exist, are often the result of over-pressuring a formation at some point in the life of a project. A schematic of a typical fracture problem is presented in Figure 1.

The Tertiary Oil Recovery Project (TORP) at the University of Kansas has been working on such production problems for a number of years. TORP was established in 1974 by the Kansas Legislature to conduct research on improved oil recovery processes which are applicable in the State. TORP also has as objectives the field testing and implementation of new and improved processes and transfer of information about new technology to oil operators in the State. The Project is funded primarily by the State, but also has support from the DOE and industry.

* Originally presented at the Interstate Oil Compact Commission Annual Meeting, December 4 - 7, 1988.

One solution to the water channeling problem described in the first paragraph involves the use of polymer gel technology. In practice, polymer gels are injected and formed in situ to seal off and effectively reduce the permeability of a channel or high permeability zone. Water subsequently injected is diverted to previously unswept portions of the formation, thereby increasing the sweep and oil recovery. TORP has extensively investigated this technology with the specific objective of improving sweep efficiency in waterflooding.[1] One particular gel system which involves a time-delayed gel has been developed to the point of field testing in the State.

This paper presents a brief description of gel polymer technology and its application in the State of Kansas. Joint projects, involving TORP and independent operators, to field test the technology in fractured systems in the eastern part of the State are described. The manner in which TORP works with independents is discussed. Additionally, other applications of the technology by the industry in central Kansas are described.

TORP INTERACTION WITH INDUSTRY

Our experience indicates that research liaison programs can be beneficial by employing technology transfer to assist independent oil operators. TORP's technology transfer program involves 1) joint industry - university demonstration projects, 2) educational seminars and conferences, 3) newsletters, 4) publications, and 5) one-on-one discussions with the operators. Joint demonstration projects develop a working relationship between the parties involved. The interaction is two-fold: 1) liaison personnel become acquainted with field problems from the viewpoint of the independent operator, and 2) independent operators experience first hand that new processes can be implemented successfully in their oil fields. When properly done this increases the overall confidence of both parties.

Seminars are important in liaison programs. Many independent operators want to become knowledgeable about new technology and will participate in short courses and seminars. They want to understand how to assess reservoir potential and increase production on marginal or uneconomical leases. Seminar activities are beneficial in two ways: 1) independent operators get a chance to meet liaison personnel and become acquainted with some of the EOR processes and applications, and 2) the liaison personnel have an opportunity to assess the needs of operators. TORP has held seven biennial oil recovery conferences directed toward the independent operator to introduce new and current technologies. Also, TORP has conducted several short courses and seminars at county community colleges in the oil producing areas of the State.

Newsletters are an effective means of increasing an operator's understanding of EOR applications. Through the newsletter operators are made aware of new processes that have been implemented in reservoirs similar to their own. TORP's newsletter has been well received with approximately 1,300 individuals on the mailing list. Newsletters are also helpful in advertising EOR conferences, workshops, and seminars.

Additionally, a great deal of information is provided through publications and through one-on-one discussions between operators and liaison personnel. This latter approach is widely used by TORP.

TORP DEMONSTRATION PROJECTS

TORP has investigated a gel system for which the gelation time can be made to be relatively long, on the order of days or even months. With such a system, it is possible to mix polymer solutions at the surface and inject them as slugs which will gel in situ at a predetermined time. For systems with relatively long gelation times, in-depth treatment around injection or production wells can be done and presumably permeability modification would be more effective.

This time-delayed gelation method involves formation of chromium(III)-polyacrylamide gels.[2,3,4,5,6] The time-controlling mechanism is an oxidation-reduction reaction which generates Cr(III) by reducing Cr(VI), using thiourea as a reducing agent. The Cr(III) crosslinks with the polymer to form a gel structure. The polymer solution injected consists of polyacrylamide, sodium dichromate, thiourea and brine.

This system was utilized in the two demonstration projects which are to be described. Interaction with independent operators in cooperative field projects to test the gel system has been in progress for about five years. TORP has established a screening committee to assist in the selection of demonstration projects. The screening committee is made up of oil operators and oil service company managers. The objective is to select the demonstration projects that are most applicable to the overall needs of the industry. An organization chart showing the screening procedure is given in Figure 2.

The majority of the demonstration projects to date have involved application of the gel polymer technology to improve waterflood sweep efficiency in fractured systems. Through the experience gained in the demonstration projects a procedure has been worked out as to how specific channeling problems might be solved. Steps followed have been: 1) definition of problem location and it's severity, 2) definition of equipment needs and resources, and 3) design and implementation of the gel treatment.

In the specific liaison activities described here, TORP's responsibilities were to take the lead in the design of the field test procedures, design the gel system and provide laboratory support. The operator was responsible for chemical-equipment expenditures and data collection in the field. Both parties assisted in the implementation of field tests and the gel polymer treatments. This close interaction was beneficial for both parties. The next sections will describe 1) the method of approach used in defining the problem, 2) equipment requirements for implementation of the treatments, and 3) results from five demonstration projects.

Defining the Problem in the Field

The first step in field implementation of the process was to define the problem as clearly as possible. If high permeability zones or channels existed they had to be identified and this was done using inter-well tracer tests or material balances between injection and production wells on injected and produced fluids. Therefore, data collection was very important throughout the cooperative projects. In some cases, channels could be identified by observing the production response of surrounding wells immediately after an injection well was shut in. Also water/oil ratio versus cumulative oil production curves were used.

Injection well data were used to estimate resistance to flow around the injection well. Knowing the flow rate and well pressure, the injectivity index was calculated, which is an indication of flow capacity. Typically, an anomalously high injectivity index indicates the likelihood that a channel exists. This index should be compared with similar data from surrounding injection wells.

Once it was established that a problem existed in a flood, inter-well tracer tests were conducted between wells where channeling was suspected. Tracer tests give an indication of the severity and magnitude of the problem. For instance, tracer test information can indicate 1) the time period required for injected water to reach a production well, and 2) the fraction of injected fluid being produced by specific production wells. This information provides an estimate for design of the gelation treatment. Typical tracers used were fluorescein dyes, and salts of nitrates and thiocyanates. A tracer manual has been written on tracer test implementation.[7]

Equipment

Equipment for implementation of the type of polymer gel treatments described in this paper can vary from expensive, automated equipment used for large volume, long-term injection treatments to less expensive (batch-type) equipment used for small-volume treatments. Certain basic equipment is required for both types of treatment:

1. Wetting device (dry polymer only)
2. Tanks
3. Tank mixer
4. In-line mixer
5. Chemical pumps
6. Variable injection positive displacement pump
7. Pressure bomb (sampling device)

Figure 3 presents a schematic diagram of a typical equipment arrangement.

Results from Demonstration Projects

TORP has participated with independent operators in approximately 21 field treatments involving the gel polymer technology. The success ratio has been good with approximately three barrels of incremental oil produced for every pound of polymer injected. This average includes both successes and failures. Two successful field demonstration projects with independent operators using time-delayed gel polymer technology will be described. One field-wide project is located in Allen County, Kansas in the Savonburg Field. The second project is located in Elk County, Kansas in the New Albany Field.

Nelson Lease Project

This cooperative project consisted of eleven polymer treatments with additional treatments planned for the future. With TORP's assistance, a polymer treatment unit was fabricated and mounted on a trailer for the purpose of mobility.

The lease is located in Allen County, Kansas in the Savonburg Field. The producing sandstone is in the Bartlesville formation in the Cherokee group. It varies in thickness between 20 ft and 40 ft and is at a depth of approximately 600 ft. Average permeability of the rock is about 18 md and effective permeability to water at residual oil saturation is approximately 0.1 of this value. The wells in the field were fractured early in their life because of the relatively low permeability. Prior to the treatments, the producing water/oil ratio was climbing dramatically. Lifting costs were increasing and the economic limit of the flood was approaching. It was important that the producing water/oil ratio be reduced.

Tracer tests and production well response tests were conducted throughout the field to define the channeling problems. Eleven polymer gel treatments were implemented with polymer solution injected in 11 separate water injection wells. The chemical system contained sodium thiosulfate as a reducing agent rather than thiourea, based on an initial assumption that the thiosulfate system was not as sensitive to pH as the thiourea system. However, pH control was found to be a critical parameter in field application and pH adjustment became a standard part of the field procedure.

Six treatments were implemented in April 1986 and five additional treatments in the fall of 1987. Results for the treated patterns are presented in Figure 4. About 8,837 barrels of incremental oil have been produced. It is clear that the treatments shifted the decline curve upward and increased the economic life of the waterflood. The volume of incremental oil is based on an assumed waterflood decline rate which is typical for the area (Figure 4).

Total weight of the polymer used in the 11 treatments was 2,384 pounds and thus approximately 3.7 barrels of incremental oil were produced per pound of polymer.

<u>Cook Lease Project</u>

The second project described is the Cook Lease project located in the New Albany Field in Elk County, Kansas. It is another typical, shallow Southeastern Kansas reservoir, producing from the Wayside sandstone. The project pattern is an inverted five-spot. The producing sandstone is 20 ft thick located at a depth of 600 ft. The operator started a waterflood on the lease in 1983. Despite high injection rates, the reservoir could not be pressured up, indicating a possible channeling problem. A tracer test indicated that there was a severe channeling problem between the injection well and one of the producing wells. The producing water/oil ratio was approximately 30 and climbing, causing high lifting costs and poor economics.

A 50 bbl gel treatment was designed with the objective of sealing the fracture system. The gel solution was the Cr(III)-polyacrylamide system using sodium dichromate and thiourea as previously described. The injection well responded immediately with a 300 percent decrease in injectivity index. Oil production on the lease increased from about 6 bbl/day to 10 bbl/day as shown in Figure 5.

The producing water/oil ratio also responded favorably, as shown in Figure 6. However, it is noted that the producing water/oil ratio on the lease could only be estimated from metered injection water. The produced water was recycled into the metered injection well at steady-state conditions with no makeup water.

The oil production declined to a value near the pretreatment value over a period of about one year, as seen in Figure 5. The assumption was that the original gel treatment had either broken down or had been slowly displaced. A second gel treatment of the same composition, but with twice the volume, was implemented with excellent results. Production again nearly doubled. Approximately 8 to 12 months after the treatment the production declined as noted in Figure 5. However, this production drop was caused by operation problems and wellbore plugging. Water injection rate was down for approximately 8-9 months, causing the premature drop in oil production. After the wellbore cleanup, oil production returned to the previous post-treatment rate.

As of August, 1988, approximately 5,000 barrels of incremental oil were recovered as a result of two polymer gel treatments. The incremental oil is based on a waterflood exponential decline rate of 25% (shown in Figure 5) which is the average rate for similar waterfloods in the area. In the treatments, 225 pounds of polyacrylamide were used. Recovery efficiency is approximately 23 incremental barrels of oil per pound of polymer -- and climbing.

ADDITIONAL INDUSTRY APPLICATIONS OF POLYMER GELS IN KANSAS

Industry has done applications of polymer gels in the State other than through TORP. Two applications which have been quite successful will be described. The first involved the formation of a gel in the vicinity of a water injection well to reduce channeling through a high permeability zone. The gel in this case was formed through in situ polymerization of a monomer. The second application was for treatment of production wells which had high water/oil ratios.

Results Using an In situ Polymerization Process to Reduce Channelling

In this process, a low viscosity (~1-2 cp) monomer solution of acrylamide and activators is prepared at the wellsite and pumped down the wellbore into the formation to be treated. Polymerization of the monomer occurs in situ, forming a gel.[8]

This process has the advantage that the injected solution is of very low viscosity and injectivity is high. Since monomers are injected, shear degradation is not a problem. Also, the resultant gel is of very high strength. A disadvantage is the necessity of having a controlled environment since oxygen will inhibit the polymerization by reacting faster with the growing polymer chain than the monomer can. Also, crude oil can be a factor in limiting polymerization if there are unsaturates and organic sulfides present. However, the latter concern has not been a significant problem from experience.[8]

A field application utilizing this process was done in the Gillespie SE Field of Decatur County, Kansas. The producing formation is the "C" zone in the Lansing-Kansas City formation. The reservoir was being waterflooded utilizing one injection well and three production wells. Because of the poor waterflood response and an unusually high producing water/oil ratio early in the life of the flood, operating engineers felt that the water was channeling through a high permeability zone. A tracer dye test was implemented with no dye show at the production wells. It is suggested that the dye might have adsorbed on the rock, thus being removed from the brine prior to production. The pretreatment producing water/oil ratio was over five and climbing.

A 285 bbl gel treatment was implemented in February of 1985. Oil production on the lease is presented in Figure 7. As shown on the plot, incremental oil did not respond for several months. However, after 13 months the oil production had more than doubled and the water/oil ratio was reduced to less than two. Incremental oil on the project is estimated at 24,000 barrels of oil. Approximately 5,000 pounds of monomer was used in the gel treatment and recovery efficiency was approximately five incremental barrels of oil per pound of monomer.

Results From Treatment Of Production Wells To Reduce The Water/Oil Ratio

Another problem in the Mid-Continent region is high producing water/oil ratios as a result of water coning in production wells with active water drives. Water coning into producing oil wells is often a problem in oil reservoirs underlain by bottom water and occurs because of gradients in flow potential established around the wellbore by oil production. If vertical permeability exists, the flow potential causes mobile water to flow into the wellbore, i.e., to "cone" from below.

The gel system in this case was a two-component system containing an anionic polyacrylamide and an organic crosslinker specifically designed to suppress water production in producing wells. The polymer is hydrophilic in nature and tends to be highly adsorbing, a characteristic of many polymers. The gel time is a function of temperature, salinity and hardness of the water used for mixing. The gel time can be controlled from several hours to several days.

The producing well polymer treatments were implemented in the Riffe Field located in Rooks County, Kansas. The producing formation is the Arbuckle which is characterized as having a water drive from a large bottom aquifer. This aquifer is the primary energy source for oil production. After a period of time, water coning occurs causing high producing water/oil ratios and high lifting costs.

A total of 23 gel polymer treatments were implemented in the field in the time period from April 1987 to September, 1988.[10] Prior to the gel treatments, the average daily oil and water production rates were 201 bbl/day and 8461 bbl/day, respectively. Post treatment totals were improved considerably with 710 bbl/day oil production and 1667 bbl/day water production. Production on the total field in September of 1988 was 517 bbl/day oil and 1899 bbl/day water, indicating that the treatments are holding at a reasonable level.

Detailed oil production and water/oil ratios on two treatments are presented in Figures 8 through 11. Pretreatment oil production on the Walker Miller #10 was 10 bbl/day. As shown in Figure 8, oil production increased to over 70 bbl/day. Producing water/oil ratio decreased from 10 to less than 1, as illustrated in Figure 9. Pretreatment oil production on the Walker A#1 was 12 bbl/day. As shown in Figure 10, oil production increased to nearly 70 bbl/day. Producing water/oil ratio decreased from 52 to approximately 2, as illustrated in Figure 11.

CONCLUSIONS

Independent oil operators can successfully implement EOR projects in their reservoirs if care is taken to use processes which are applicable and economically feasible. It is vital to our nation and the domestic oil economy that independents understand these EOR methods and the potential for application to their reservoirs.

One type of EOR method that has been demonstrated to be successful is gel polymer technology for in situ permeability modification. Projects have been successful in injection wells in eastern Kansas shallow sandstone reservoirs, and in central Kansas Lansing-Kansas City limestone reservoirs. Also, the technology has been demonstrated to be successful in reducing water/oil ratios and improving oil recovery in wells producing from the Arbuckle formation in central Kansas.

Research liaison programs can assist independent operators in assessing their EOR needs through field demonstration projects. Other methods of developing interest among independent operators are: 1) individual meetings, 2) educational seminars and conferences, and 3) newsletters. Additional liaison programs are needed to assist independent oil operators to implement new technology applicable to their reservoirs and to provide technical assistance in improving day-to-day operations.

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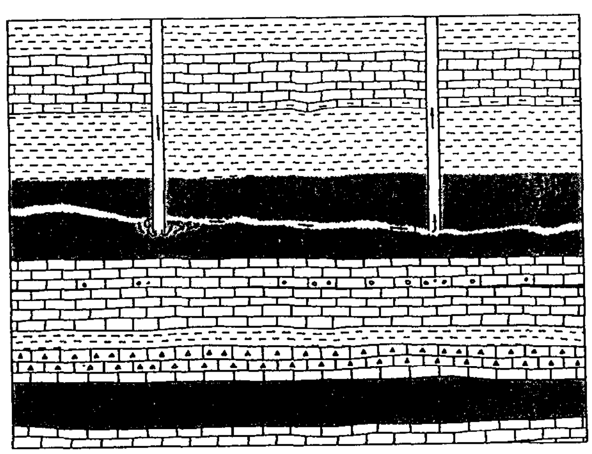

Figure 1 — Fractures: natural or induced

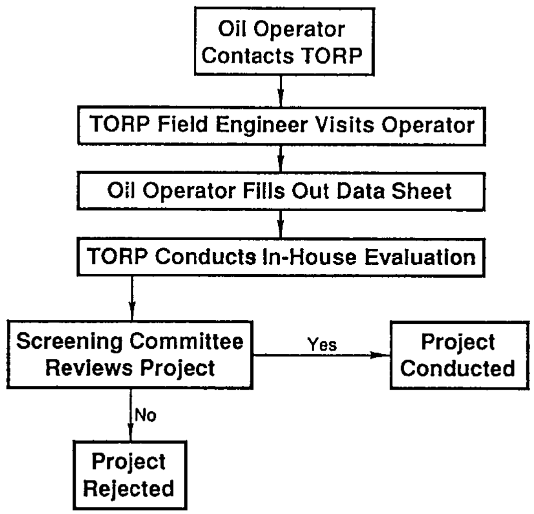

Figure 2 — Demonstration project screening procedure

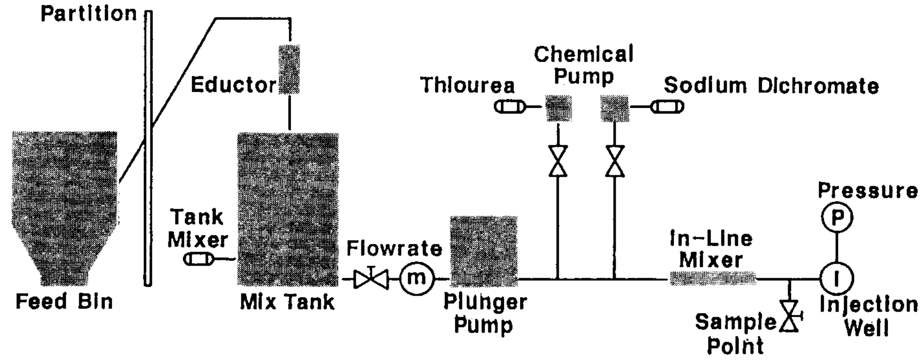

Figure 3 — Schematic diagram of field equipment — Cr^{+3} — polyacrylamide systems

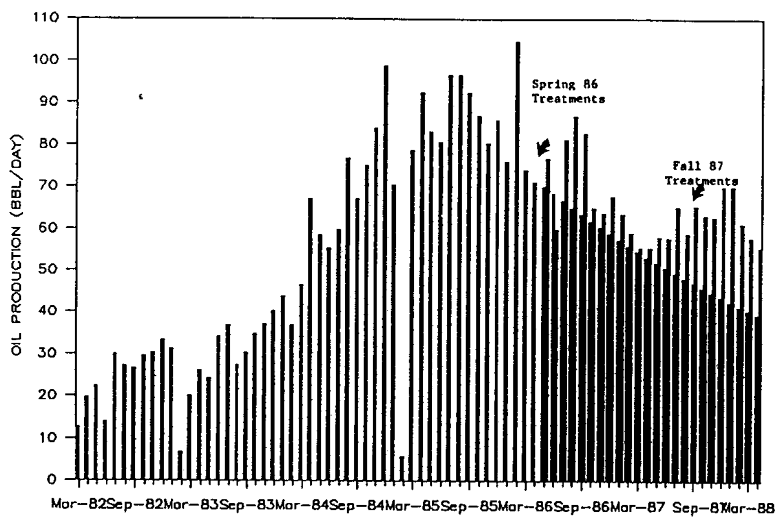

Figure 4 — Nelson Lease oil production (all treated patterns)

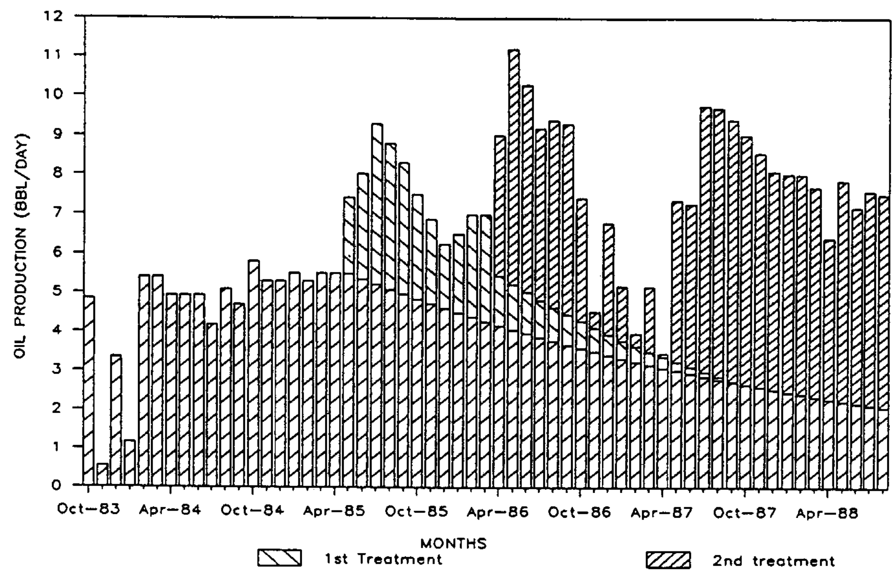

Figure 5 — Oil production — Cook II Lease New Albany Field

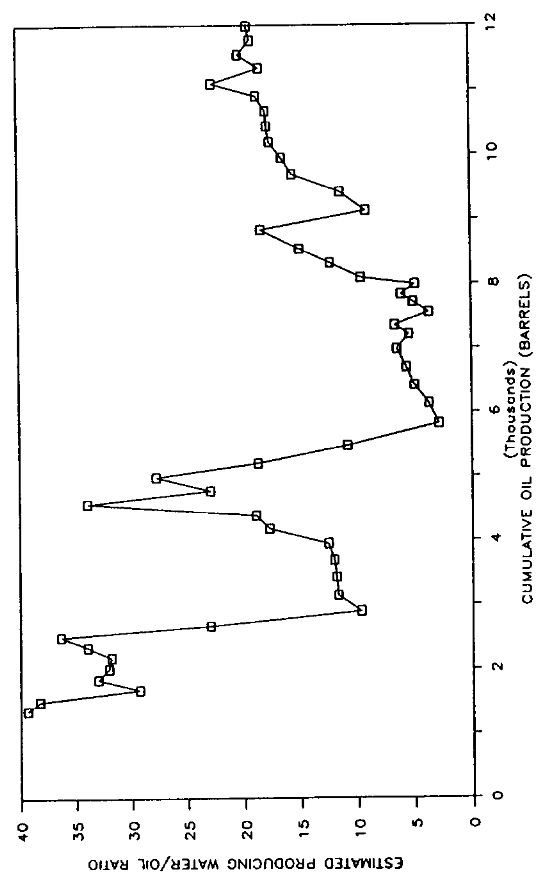

Figure 6 — Water-oil ratio vs. cumulative oil production — Cook II Lease New Albany Field

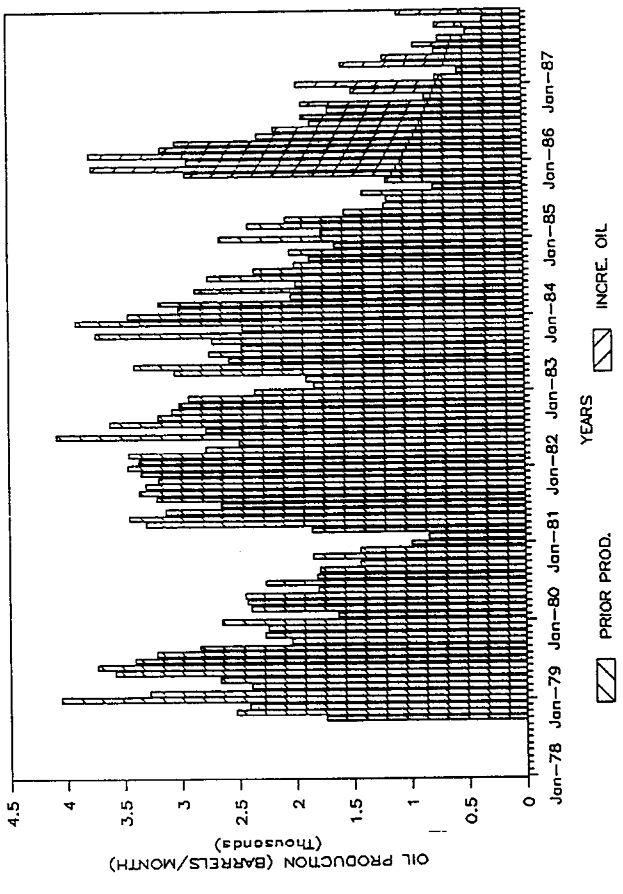

Figure 7 — Oil production — Elvin (Bailey) Lease Gillespie Southeast Field

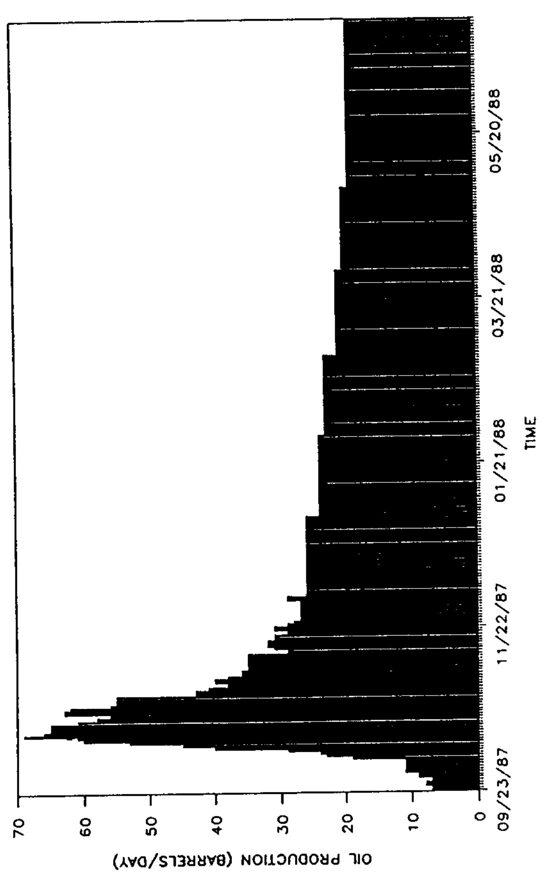

Figure 8 — Oil production Walker Miller #10

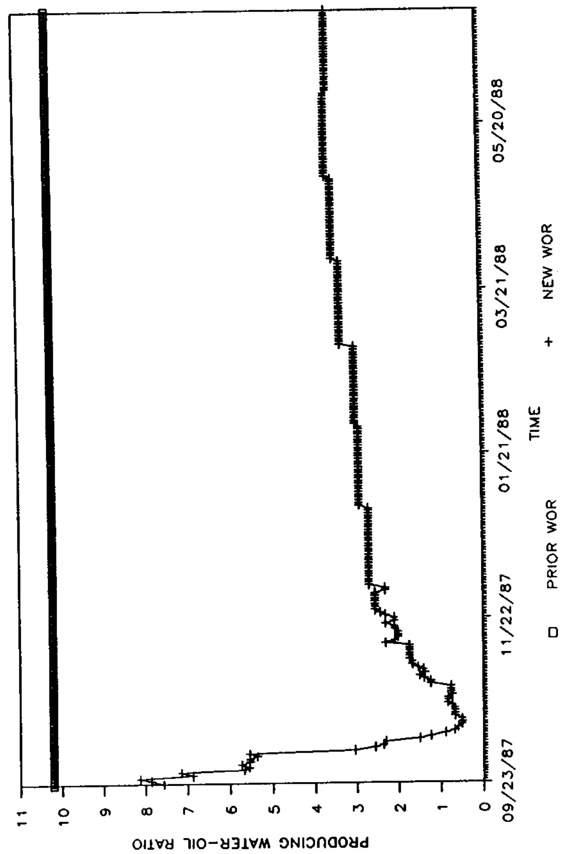

Figure 9 — Producing water-oil ratio Walker Miller #10

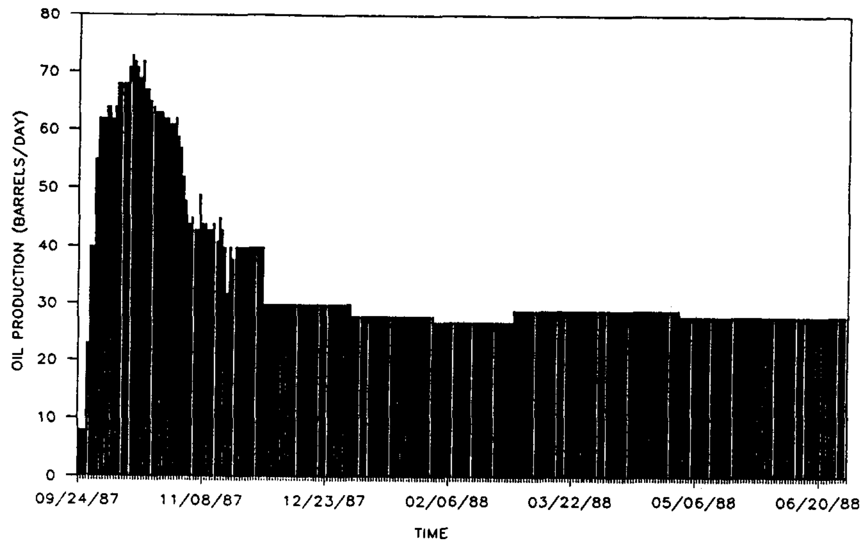

Figure 10 — Oil production
Walker A #1

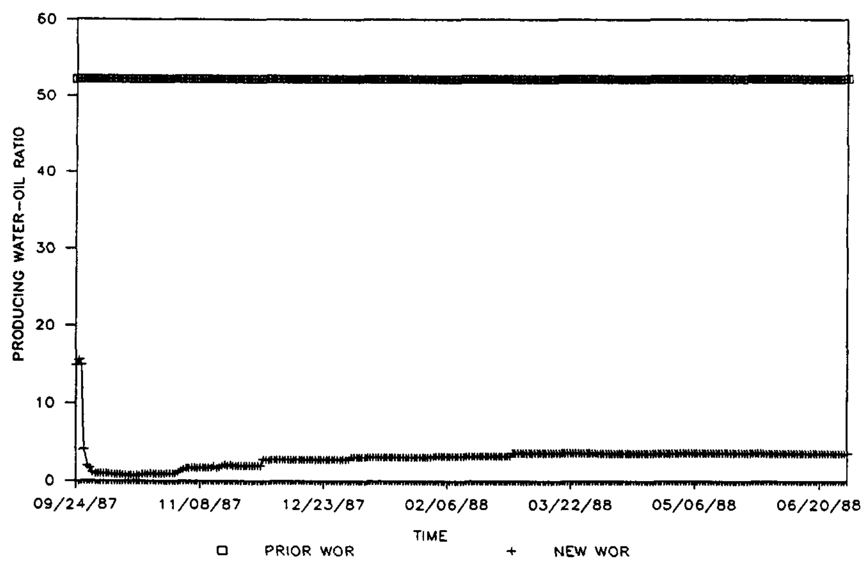

Figure 11 — Producing water-oil ratio
Walker A #1