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ENHANCED OIL RECOVERY BY IMPROVED WATERFLOODING

Fourth Annual Report, October 1980—September 1981

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DR. 544

MASTER

May 1982
Date Published

Work Performed Under Contract No. AC19-77ET12065

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Houston, Texas

and

Bartlesville Energy Technology Center
Bartlesville, Oklahoma

U. S. DEPARTMENT OF ENERGY

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Fourth Annual Report
October 1980–September 1981

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Work Performed for the Department of Energy
Under Contract No DE-AC19-78ET12065

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SECTION ONE

INTRODUCTION AND SUMMARY

Energy Resources Co. Inc. and its subcontractor Elf Aquitaine Oil and Gas Company are conducting a 100-acre pilot polymer flood in the Storms Pool Field near Carmi, in White County, Illinois (see Figure 1). The project is a cost-sharing venture in which the United States Department of Energy (DOE) bears \$1,579,189 of the \$3,750,144 project costs. Preparation for the polymer flood began in September 1977, under DOE Contract Number DE-AC19-78ET12065, and the project is scheduled for completion in December 1983. This report reviews progress during the fourth year of performance (October 1980 through September 1981). Progress during the first year is reported in DOE document BETC/2541-12, "Enhanced Oil Recovery by Improved Waterflooding: First Annual Report," while progress during the second and third years is reported in DOE documents DOE/ET/12065-26, "Enhanced Oil Recovery by Improved Waterflooding: Second Annual Report" and DOE/ET/12065-38, "Enhanced Oil Recovery by Improved Waterflooding: Third Annual Report," respectively.

The Storms Pool is typical of many old fields in the Illinois Basin which are candidates for enhanced oil recovery. Once highly productive, the field has yielded over 12 million barrels of oil from the Waltersburg formation since its discovery in 1939. The field has been waterflooded for over 20 years and is now largely in stripper production with high watercuts at most producing wells. Material balance and recent electric logs indicate, however, that there is a substantial volume of movable oil still in place, presumably bypassed by the inefficient waterflood. The polymer flood is intended to improve the sweep efficiency, showing that the engineering, management, and financial resources required for such tertiary techniques can be applied to similar fields that might otherwise be abandoned for lack of investment by parties knowledgeable in enhanced oil technology.

The first annual report reviewed the groundwork upon which much of the second year's work was based. That report included a geologic analysis of the Storms Pool and its production potential, the rationale for the selection of a pilot site (shown in Figure 2 and detailed in Figure 3), some preparation of wells and facilities, an extensive plan for testing candidate polymers in the laboratory, and a proposed approach to the computerized simulation of the pilot polymer flood. The second annual report reviewed a

Figure 1. Location of the Storms Pool Pilot Polymer Flood.

Figure 2. The Storms Pool and Location of the Pilot Area.

Figure 3. Layout of Storms Pool Pilot Facilities.

year of intensive laboratory design and field work, including a reservoir and well test program, the results of the polymer selection and additional laboratory testing, workovers and construction of facilities, preliminary reservoir simulation, and program support activities. The third annual report discussed the final polymer selection, design of the graded polymer banks, results of reservoir pressure tests and plans for continued testing, and completion of basic plant construction. Because the second annual report actually covered a 15-month period, the third annual report overlapped somewhat with information contained in the second annual report.

This fourth annual report discusses progress between October, 1980 and September, 1981. Preflush injection and polymer injection were both initiated during this period with total polymer injection now standing at 179,453 barrels (or about 6 percent pore volume).

Laboratory testing has continued throughout the year with the emphasis being on field support (troubleshooting field problems and monitoring the field injection and production systems). No evidence of polymer break-through has been detected at the production wells.

Details of the interference testing program and the radiotracer study executed during this period are also presented in this report along with a diagram of the injection and production facilities as they stand after design refinements.

SECTION TWO

INJECTION AND PRODUCTION

Preflush and polymer injection have continued throughout most of the year. Preflush water injection was begun on October 21, 1980, but was limited to eight to ten hours per day. Once confidence in the system was attained, continuous unsupervised injection was begun on November 29, 1980. Polymer injection was commenced on March 7, 1981, and continued, with some interruptions, through the remainder of the year.

2.1 Produced Water Disposal

During September, 1980, it was discovered that Jim Haley, operator of the Storms Pool Unit, would not be able to handle the produced water from the improved waterflood area. Because our laboratory studies rejected the use of the produced water for polymer dilution at an early stage, the laboratory data base had been built up using the fresh river water. Using produced water for polymer dilution would result in a renewed laboratory effort and its associated time delay. The decision was made to convert four wells to salt water injection in order to expand the disposal system. These wells, numbers 3-1A, 3-1B, 6-7, and 11-11, are located as shown in Figure 4.

The workover of wells 11-11 and 6-7 were completed in October, but continued work on wells 3-1A and 3-1B was delayed by inclement weather. Poor performance by the retained contractor led to further delays in the laying of the lead lines required to each disposal well. After hiring a new contractor to lay lines and waiting for the water in the Little Wabash River flood plain to recede enough to allow access by the workover rig and crew, the two remaining disposal wells were activated in March.

It was understood that the activation of these four new produced water disposal wells would alleviate the shortage of disposal capacity. Disposal of produced water became a problem again, however, in September. Rather than commit to the large expense involved with opening new disposal wells, it was decided that polymer dilution using produced water would be the best method of eliminating the occasional shut-down of production wells in order to allow the disposal system to catch up. The use of produced water rather than the fresh river water has necessitated an increase in the

Figure 4. Disposal Well Locations.

polymer concentration in order to obtain the same viscosity, but has created no other problems. With almost 180,000 barrels of polymer (6 percent pore volume) in the formation prior to the change, the reservoir performance should not be affected compared to that predicted using the laboratory data generated with river water.

2.2 Injection

2.2.1 Preflush Injection

Preflush water injection began on October 21 on a discontinuous basis (only when personnel were on location) in order to gain confidence in the automatic control system. Continuous injection began on November 6. During the first two months of continuous injection, the plant suffered approximately 35% downtime as a result of debugging the automatic controls and harsh winter weather (power failures, freezing of inadequately protected lines, etc.). Preflush injection history is shown in Figure 5.

During the preflush operation, the injection fluid quality was very good, ranging from 5 to 10 percent turbid after treatment compared with 40 to 65 percent turbid before treatment. During the preflush stage, the turbidity was determined using a spectrophotometer at 3400 Angstroms calibrated to 0 percent for distilled water. A turbidimeter was received later and has been utilized throughout polymer injection to determine water quality.

Several plant design changes were made during the preflush stage which increased the injection capacity of the plant. The most significant change involved the system from the charge pump to the sand filters. Due to system vibrations, severe leaks had developed in the plastic manifold. A new manifold system was installed which includes expansion loops and a buffer tank. Besides dampening flow variations in the chemical feed pumps, this tank increases the fluid residence time to a sufficient level to insure that all ancillary chemicals have time to fully react.

During the final month of the preflush injection, the injection plant was prepared for polymer injection. These preparations included final installation of the viscometer system, minor plumbing connections to the broth storage tanks, and purging of the plant system using a 25 ppm acrolein solution. This purging step was designed to completely sterilize the injection facility using this potent biocide. Modification work to make the filters more

[illegible]

- 9 -

efficient was designed. Polymer injection began in early March at a reduced rate, which enabled the filters to perform more adequately while parts required for the planned modification were being delivered.

2.2.2 Polymer Injection

Polymer injection was begun on March 7 at a rate of about 700 barrels per day. This low rate was a result of poor performance from the water clarification system. In order to achieve a water turbidity of less than 5 ppm silicate, it was necessary to reduce the filter flow rate from the designed 100 gallons per minute to 30 gallons per minute and to reduce the length and frequency of the backwash cycle. Calibration and correction of the in-line viscometer were finally achieved on March 20, resulting in a more uniform polymer concentration.

Polymer injection was shut down from mid-May through late June due to the extremely low quality of the injection water. The heavy rainfall experienced during the late spring resulted in a high particulate loading of the Little Wabash River water which is used as a fresh water supply source. After several futile efforts by local vendor personnel to correct the poor filtration performance of their rapid sand filter system, representatives of Production Profits of Dallas were called in to examine the clarification system and to recommend modifications to improve its performance.

The major observations and recommendations made in Production Profits, Inc. report of June 18, 1981, are quoted below:

Samples were collected from the following locations: (1) river water, (2) after 1000 barrel water collection tank, (3) after cyclone filter, (4) after Culligan sand filter and (5) after Filtrite filter.

RIVER WATER

Samples collected from the river on two occasions show a total dissolved solids average to be 208 mg/l with a total iron content of 5 mg/l. A membrane filter test taken on June 2, 1981, showed a total in-line solids content of 57.5 mg/l and compares very well with the suspended solids test from a water sample taken on June 3, 1981, which shows 63.8 mg/l. Both tests show the solids

to consist of about 75% acid insoluble material. A particle size distribution analysis shows 89% of the solids to be 5 micron or less and 99% to be of 10 micron or less in size. The type of solids will probably vary with rainfall, temperature and depth of river. The turbidity reading on June 2, 1981, was 68 JTU at the time of sampling.

INJECTION PLANT

Tests taken at various points in the system confirmed that over 90% of the solids found were of 10 micron or less in size. The cyclone filters are removing a small amount of solids and probably act as good insurance against a surge of large solids coming from the river. The Culligan filters are not the proper filters for this type of water. This filter media is designed for solids larger than 10 micron in size. The Culligan filter is probably not 100% effective except with particles that are 20-25 micron or greater in size. Therefore, a large amount of the solids are not being trapped even though a chemical flooding [coagulating] agent is being added to the water. Most of the solids are being trapped by the Filtrite filter containing filter cartridge elements. However, the type cartridges being used at the time of testing are not the proper ones for small micron size material. These elements do not have a good, even distribution of pore size and will allow a large amount of the solids to pass through the filter. Since the field testing, a new type of cartridge element has been installed and is performing better in removing the solids. It must be pointed out that this type of filtering is not designed for heavy solids loading and could be very expensive as the injection volumes and solids increase.

CHEMICAL TREATMENT

The Culligan F-86 cationic polyelectrolyte treatment level at the time of testing was too high. Chemicals of this type are usually effective in a range of 1 to 10 ppm. The chemical treatment has been reduced since the time of testing to 3 to 5 ppm and seems to be doing better. There is a need for testing of other polyelectrolytes to see if one could be found that would be more effective in this water. [See

Section 3.4 for a discussion of further flocculent testing.]

Bactericide is being injected at a point near the river and at the plant. The amount of chemical being used is excessive and should be reduced. A total of 10-20 ppm concentration should be able to control the bacteria in this system. [Note that Production Profits is not familiar with polymer flooding nor were they privy to the microbiological laboratory data for the polymer system.] A batch treatment of different chemicals every three to four weeks at about 50-100 ppm for several hours in order to go through the system would be an excellent assist to the normal treating program. The amount of bacteria chemical treatment needed will vary with the seasons and will probably be at the highest during the hot summer months or when the river is at a low level.

RECOMMENDATIONS

(1) Run experimental test using Micro-clean filter cartridges of 5, 10 and 25 micron size. From these tests determine the most effective size cartridge to use in order to achieve best water quality.

(2) Install a second filter housing downstream of each of the Filtrite filters. This will allow the use of a ten micron cartridge element before a 5 micron cartridge element. This type of hookup will usually extend the life of the smaller element by a factor of the square of its useful life. For example, if you get 3 days run with a 5 micron element alone, you should expect to get close to a 9 days run when hooked in series with a 10 micron element.

(3) Chemical treatment levels used for flocculating solids should be tested. Also, other chemicals should be considered and tested.

(4) Long range planning should include the possible use of some other types of filtration. One filter which has been used very successfully in this type of situation is the upflow filter.

All of these recommendations were pursued. The optimum solution appeared to be the use of consecutive cartridge filters downstream of the sand filter. Utilizing a 10 micron upstream and a 5 micron downstream yielded very acceptable filter life and fluid quality.

During the shut-down due to water filtration problems, the auxiliary injection pump and the new high pressure manifold were installed. These changes allowed the injection pressure to be increased to 700 psi, which is approximately 50 psi less than the parting pressure of the reservoir.

Modifications were made in August which allowed the sand filter backflush operation to utilize filtered, rather than unfiltered, Little Wabash River water. This change, recommended in June but delayed while awaiting delivery of the required equipment, resulted in longer filter life and less plant downtime. This change was the primary reason for the significant increase in polymer injection which occurred beginning in August. Polymer injection history is presented in Figure 6.

2.3 Production

Design errors in the oil collecting station resulted in the possibility for operator error which could be disastrous. An operator error in November led to a burst production pipe and a salt water and oil spill. The 3-way valving system was replaced with a less complicated 2-way valving system, easing operation and minimizing the possibilities for future operator error.

Timers were placed on wells 9-4, 10-2, and 10-5 on July 24 in order to more evenly balance the injection-production ratio. The use of these timers (set at 12 hours per day) eliminated the tendency for fluids to be drawn into the pilot area from the surrounding reservoir due to unbalanced fluid movements. The time-clocks were removed on September 9 after injection had been increased to yield an injection-production ratio of 1.09.

Oil production has been spotty as a result of the production downtime experienced due to time-clock operation, injection water clarity, and produced water disposal limitations. Since late summer, very little production downtime has been experienced and the production data becomes more meaningful. Production history, shown in Figure 7, is now showing the effects of polymer injection, rather than extraneous factors, suggesting a daily oil production of 11.6 barrels per day compared to the secondary decline production of 7.8 barrels per day.

FIGURE 6
POLYMER INJECTION HISTORY
STORMS POOL POLYMER PROJECT, WHITE COUNTY, ILLINOIS

[illegible]

SECTION THREE

LABORATORY TESTING AND EVALUATION

Laboratory work during the period of this annual report was focused primarily on the sampling of the field system in an effort to closely monitor the effectiveness of the ancillary chemical program. Special attention has been paid to the biocide treatment program to prevent bacteriological contamination. Troubleshooting efforts were necessary for the coagulant selection program.

3.1 Site Visits

Periodic site visits have been made by laboratory personnel to collect samples and monitor operations. Each of these site visits will be discussed separately.

During a December visit, laboratory personnel set up the field laboratory equipment, demonstrated test procedures to field personnel, collected water samples from the various sample points in the system, and analyzed the water samples to determine injection water quality. Samples of recently delivered polymer broth were also collected for detailed analysis in the Houston laboratory. Water samples collected showed continued microbiological activity after biocide addition, but at a significantly reduced level. This was apparently a result of using 18 ppm Magnacide 480 rather than the recommended 50 ppm concentration, suggesting that 18 ppm is sufficient to physiologically insult the bacteria, but not sufficient to destroy them. The biocide dosage rate was increased to the recommended level of 50 ppm.

A site visit in January was made to obtain a second set of data recording the preflood conditions in the surface system and to confirm that the biocide treatment program was effectively controlling bacterial growth in the surface system after the changes made in December. Sample stations are located as shown in Table 1 and Figure 8. Samples collected from each of these sample points were analyzed for the parameters shown in Table 2.

Two series of flocculent tests were performed to determine the optimum flocculent concentrations needed for water clarification. These tests indicated that no significant changes in the turbidity were observed by varying the Culligan F-86 flocculent concentration. Samples of alternative flocculents were ordered so that additional

TABLE 1

LOCATIONS OF SAMPLING STATIONS AT STORMS POOL UNIT

<u>STATION NUMBER</u>	<u>LOCATION DESCRIPTION</u> ¹
1	Little Wabash River
2	River Pumping Station
3	1000 Barrel Storage Tank
4	Biocide Injection
5	Flocculent Injection; Mixing
6	Polymer Injection; Sand Filters
7	Chelator Injection
8	Polymer Injection ²
9	Injection Well (Well 10-1)
10	Production Well (Well 9-1)

Notes: 1. All stations except the injection well are located downstream of the description item.

2. These stations were not sampled on January 26-30, 1981.

Figure 8. Locations of Sampling Stations at Storms Pool Unit.

TABLE 2

PARAMETERS TESTED AT STORMS POOL UNIT
JANUARY 26-30, 1981

BIOLOGICAL:

Acridine Orange Direct Count (AODC)
Mineralization Potential
 Glutamate
 Xanthan
Sulfate Reducing Bacteria (SRB)
Total Heterotrophic Bacteria

CHEMICAL:

Acidity
Alkalinity
Chloride
Iron
Oxygen
Sulfate
Sulfide

PHYSICAL:

Conductivity
Eh
Hardness
pH
Total Suspended Solids (TSS)
Turbidity

testing during a February site visit could be performed. The existing flocculent and filtration system produced a 98.5 percent reduction in the turbidity (from 74.0 ppm silicate at Station 3 to 1.10 ppm silicate at Station 7). The 1.2 micron millepore test, however, was 8.1 on the injection water collected at Station 7, suggesting that the turbidity reduction seen was insufficient to prevent possible wellbore plugging. Alternative flocculent testing (to be discussed later) resolved this filterability problem.

Xanthan broth samples were collected from each of the broth storage tanks. The dry weight data were satisfactory for all tank surface samples. The low values obtained from the drain posts highlighted the need for sampling only from the delivery truck or tank top ports for examining concentrate quality. Diluted polymer is sampled at Station 8.

The physical-chemical data were unremarkable, in general. The sulfate concentration seemed sufficiently low as to not provide a significant energy source for sulfate reducing bacteria. The oxygen concentration in the river water was super-saturated. At all the other pre-formation stations the water was oxygen saturated. This was reflected in the Eh data as well. The oxygen and Eh data from Station 10 clearly show that the formation water is anoxic and strongly reducing. Conductivity at this station was also high. This was reflected in the turbidimetric and total suspended solids data.

Conductivities observed in January were similar to those reported in December, although pH values were two units higher (the range in December was 6.25-6.99).

The total viable counts continued to be unacceptably high. As of January 29, the biocide concentration was boosted to 100 ppm, providing 1.5 ppm active ingredient (isothiazolin) to the system.

Energy Resources laboratory personnel were on-site for the entire week of February 16. The purpose of this trip was to test additional flocculents for the water clarification system and to assist in the planned start-up of polymer injection.

The flocculent testing program was conducted under the most stringent conditions seen to date due to the heavy rainfall in the previous few weeks. This rainfall caused water runoff which produced an especially muddy river. Flocculent tests performed using this river water showed that Calgon's Catfloc T at 8 ppm will generate large flocs

of river water particulates which could be more readily filtered. This flocculent is far superior to the Culligan F-86 previously used. The Catfloc T has been used since these tests to help clarify the river water prior to injection.

Even with the improved flocculent, river water quality was so poor that water injection had to be halted temporarily. This also delayed the initiation of polymer injection.

Laboratory personnel next visited the project site during the week of May 4. In the interval between the visit in February and the visit in May, continued monitoring of the injection fluids was achieved by the analysis of samples collected regularly by field personnel and transmitted to the Houston laboratory. The purpose of the May visit to the project was to (1) monitor the conditions in the surface system after 60 days of polymer injection, (2) begin monitoring the produced water for polymer breakthrough, and (3) check the quality of the polymer broth in storage.

Viable bacteria counts in the samples collected were generally of the same order of magnitude as those reported six months earlier. The inoculum population from the Little Wabash River was, however, four orders of magnitude greater than it had been six months earlier.

As with viable counts, direct counts at most surface stations were similar in December and May. However, bacteria associated with the xanthan were detected in the latter series. Downstream of xanthan addition, direct counts increased by two orders of magnitude. That the biocide was working effectively was demonstrated by the fact that viable counts did not show a comparable increase after polymer addition. This phenomenon reflected the function of formaldehyde as a preservative. Although formaldehyde, at the concentrations used, inhibited bacterial growth, it preserved the population against autolysis.

Metabolic activity was lower in the May samples than it had been earlier. This further demonstrated the effectiveness of the biocide treatment program. Glutamate mineralization at a rate of 22,500 picograms glutamate mineralized per hour was completely inhibited by Kathon injection (45 ppm as supplied) at the river pumping station. Mineralization remained low throughout the surface system. Xanthan mineralization was minimal at all stations. Again mineralization was lower in May than it had been in December.

Specific mineralization activities (SMA) reflected the lower mineralization activities. Uniformly SMA was significantly lower in the spring than it had been during the winter before the present biocide supplementation program was instituted.

The water clarification system was operating satisfactorily, reducing turbidity from approximately 170 ppm silicate to 7.0 ppm silicate. It is noteworthy that the turbidity at Stations 3 and 4 was more than double the turbidity of the river water. The water hardness was in the same range observed in January. Sulfate concentrations were higher during the May sampling. Oxygen concentrations reflected the warmer water temperatures by decreasing from an average 12 ppm (January) to an average of 6.1 ppm (May). Although the water pH was lower in May than in January, the alkalinity was almost two orders of magnitude greater, suggesting much greater buffering. This may have been reflecting the effect of the higher total suspended solids (TSS) loading in the water during the spring.

As expected, there was no evidence of polymer breakthrough at any of the production wells. Quality assurance testing of the mixing tank, storage tank, and truck tank demonstrated that carbohydrate (xanthan) concentrations were within specifications in all samples except the sample from broth storage tank E-33. This latter sample contained a substantial quantity of water at the polymer surface. This water had apparently accumulated as a result of condensation on the tank wall above the broth. Samples collected from the bottom and from approximately three feet off bottom had carbohydrate concentrations of 2.4 percent and 2.1 percent, respectively, indicating good quality xanthan broth.

Representatives of Pfizer were at the project on June 23 in order to gather samples and inspect the facility to insure that all the necessary precautions were being taken to prevent biopolymer contamination prior to injection. The results of their study confirm the data gathered by ERCO laboratory personnel during their visit of early May.

ERCO laboratory personnel again visited the project site in mid-September. The objectives of this visit were to obtain data for monitoring conditions in the surface system after six months of polymer injection and to perform quality assurance tests on stored xanthan broth.

As before, total direct counts remain uniform throughout the system. The Kathon WT injection downstream of the sand filters appears to be inhibiting metabolic

activity more aggressively than it is reducing viable counts. However, between the biocide injection point and the polymer addition point there is a four orders of magnitude decrease in viable counts. This probably reflects speed of kill. Xanthan mineralization activity in the surface system downstream of xanthan addition is two orders of magnitude greater than at upstream stations. The low specific mineralization rates suggest that a large population of not particularly active bacteria is being introduced with the polymer.

3.2 Houston Laboratory Testing

Laboratory work in Houston primarily involved the support of field injection and production activities. Between site visits by laboratory personnel, field personnel routinely collected injection and production samples. These samples are transmitted to Houston and monitored to insure no bacterial activity is present in the surface injection system and to obtain produced concentration data for both xanthan and radiotracer. Special troubleshooting work on field problems is also performed in the Houston laboratory.

One such problem was the discovery of significant volumes of solids in the xanthan broth delivered to the project. During the polymer unloading process, broth is pumped from the dedicated tank truck through an 8-mesh strainer to the storage tanks. The broth is then passed through a 140 micron cartridge filter before dilution to injection concentration (500 ppm). During March, both the strainer and the filter collected significant quantities of solids. Analysis of these solids by both Pfizer and ERCO laboratories indicated that about 15 percent of the solids were inorganics. Some of the inorganic content was most likely iron and iron oxide, while the organic content was xanthan (about 75 percent of which is insoluble).

Apparently at least some of these solids were caused by our attempts to clean the tank trailer between loads. The use of steam did sterilize the trailer and prevent bacterial growth, but it also caused a drying and charring of residual polymer in the trailer. Because the tank was not thoroughly rinsed out, the dried xanthan then sloughed off the tank walls and contaminated the newly introduced broth. This dried material was seen as an insoluble xanthan solid. The exact source of the iron oxide has not been pinpointed but may have been due to previous contamination of the stainless steel trailer. This small presence of iron oxide (less than 15 percent of the solids in a very small solids loading) has had no detectable deleterious effect on the polymer. The

tank truck cleaning procedure was modified to eliminate this solids problem. The new procedure involves periodic treatment of the tank trailer with formaldehyde to prevent bacterial growth. Steam cleaning had not been utilized except after a thorough rinsing to remove residual polymer from the tank walls. Filter life has been extended considerably by this new procedure, indicating that solids loading has been decreased significantly.

Early in May, a fungal growth was noted on the surface of the polymer broth held in the tank trailer. This shipment had remained in the tank truck for about three weeks after delivery while tankage space was cleared for it. The lower, uncontaminated layers were off-loaded and the surface layer returned to Pfizer for disposal. The tank trailer was then thoroughly rinsed and steam-cleaned prior to loading the next shipment. Laboratory tests have shown that this fungal contamination did not result in the deterioration of the polymer broth. It has, however, resulted in a modification of the shipment procedures utilized.

It was felt that this contamination was a direct result of the long holding time in the large surface area of the tank trailer. The truck driver was furloughed to allow plant operation to consume some of the polymer in storage. The driver could then be utilized for one week per month to haul polymer, immediately off-loading it into the storage tanks. Before each cycle of shipments, the trailer was thoroughly cleaned and steamed to eliminate any residual bacterial contamination. In this way, the driver was utilized in a more optimum manner and holding time in the trailer was reduced.

Produced fluid samples have been collected and analyzed routinely. All samples had reducing sugar concentrations below the detection limits (0.1 milligrams per liter). Only the sample from Well 9-4 showed carbohydrate (xanthan) concentrations above the minimum detection limit (0.0002 percent). The observed value of 0.0006 percent carbohydrate for the sample collected on July 29 from Well 9-4 may have been due to contamination during sampling. Later samples have shown no detectable carbohydrate in Well 9-4.

3.3 Continued Biocide Testing

Biocide testing continued throughout the year. Much of this testing was to confirm that the proper biocide and concentration had been chosen. Dr. Fred Passman of ERCO's

microbiology laboratory developed the approach and performed the studies discussed below.

3.3.1 Confirmation of Biocide Application Program

ERCO's approach entailed supplementing natural water samples with Carbon-14 radiolabeled substrate and treating the samples with biocide. As reported earlier, Kathon WT and Magnacide 480 were selected as the biocides of choice as a result of the screening data. However, the application concentrations recommended, based on ERCO's data, were significantly higher than those suggested by the suppliers.

Concentration recommendations from the suppliers were based on results of standard bacteriostatic tests (API RP38, 1975) which used cultivated strains of the bacteria Pseudomonas fluorescens, Bacillus cereus, and Desulfovibrio desulfuricans. It is well documented in the microbiological literature that bacteria maintained in the laboratory often lose the characteristics of wild type strains. This is particularly true regarding response to antagonistic treatments. In order to verify ERCO's observations on the effect of biocides on natural populations, ERCO conducted an experiment in which the radioisotope method was compared directly with the API viable count method.

Lyophilized preparations of P. fluorescens (NRRL B-4290) and B. cereus (NRRL B-4278) were obtained from the American Type Culture Collection, revitalized and maintained in accordance with procedures delineated in "API Recommended Practice for Biological Analysis of Surface Injection Waters" (API RP38, 3rd. edition, 1975). Kathon WT (1.5%) and Magnacide 480, provided courtesy of Rohm and Haas Company and Magna Corporation respectively, were tested for bacteriostatic activity. The API procedure was modified in that all tests were run in triplicate rather than duplicate and the following biocide concentrations were tested.

Kathon WT (1.5%) - 0, 1.0, 2.5, 5.0, 10, 20, 25, 50, 75, and 100 ppm

Magnacide 480 - 0, 10, 20, 25, 30, 40, 50, 75, 100 ppm

Concentrations were of biocide as supplied. The Kathon WT contained 1.5% active ingredients and the Magnacide contained 20% active ingredients.

The ERCO bacteriostatic test method used was analogous to the API method, except that the test medium was

supplemented with 0.01 μ Ci/ml Carbon-14 glucose (0.0005 g glucose/ml). At the appropriate time interval, samples were acidified with 0.1 ml of trichloroacetic acid then sparged with nitrogen for 30 minutes. The sparged gas was dispersed through a pair of carbon dioxide traps (25 ml B-phenethylamine and 2.5 methanol in each trap). After sparging, 15 ml Aquasol (New England Nuclear) scintillation cocktail was added to each trap (scintillation vial) and radioactivity was determined by liquid scintillation spectrometry. The carbon dioxide traps were more than 99.9% efficient in recovering carbon(14) dioxide.

The results of the API and ERCO tests are presented in Tables 3 through 6. P. fluorescens and B. cereus represent the predominant gram negative and gram positive bacterial genera recovered from flooding waters. (This was determined during the preliminary microbiological investigation performed on the Storms Pool system in 1978.) They also represent the two principal groups of Eubacteriales - the gram negative bacteria and the gram positive bacteria. Broad spectrum antibiotics and biocides should be effective against both types of bacteria. However, as a reflection of the significantly different cell membrane structures of these two groups, antimicrobial agents are often not as effective against one group as they are against the other. This phenomenon can be seen clearly by comparing Tables 3 and 4 and Tables 5 and 6. B. cereus is more sensitive than P. fluorescens to Magnacide 480 and, to a lesser degree the reverse phenomenon is observed for Kathon WT.

The API method and ERCO method gave analogous results. The minimum lethal doses (MLDs) of biocides as reflected by both parameters is summarized in Table 7. MLDs were defined as doses necessary to reduce the viable counts by more than two logs or reduce the mineralization coefficient by a factor of two. As can be seen in Table 7, in three of the four cases, MLD viable count occurred one dose lower than MLD mineralization coefficient. This indicated that the bacteria were injured sufficiently to be unable to produce colonies on solid growth media, but remained metabolically active. This is an essential point. The biocide application program at Storms Pool is targeted primarily towards preserving biopolymer and secondarily towards preventing downhole plugging. The ERCO test provides a more direct indication of the efficiency of biocide treatment against substrate degradation. Moreover, since the MLDs obtained by the ERCO method are more conservative than those obtained by the API method, recommendations derived from the former are more likely to result in a biocide application program which fulfills both objectives.

TABLE 3
 BIOCIDES PERFORMANCE TEST
 MAGNACIDE 480 vs. PSEUDOMONAS FLUORESCENS (NRRL B-4290)

<u>Biocide Concentration (PPM as Supplied)</u>	RESPONSE			
	24h		96h	
	<u>Mineralization Coefficient</u>	<u>Log CFU/ml</u>	<u>Mineralization Coefficient</u>	<u>Log CFU/ml</u>
0	290	7.95	64	7.67
10	260	7.91	46	7.46
20	190	7.66	36	7.74
25	100	(6.04)	0.88	7.68
30	2.4	7.72	14	7.57
40	<0	<0	14	<0
50	22	<0	1.4	<0
75	<0	<0	0.50	<0
100	<0	<0	0.80	<0

TABLE 4
 BIOCIDE PERFORMANCE TEST
 MAGNACIDE 480 vs. BACILLUS CEREUS (NRRL B-4278)

Biocide Concentration (PPM as Supplied)	RESPONSE			
	24h		96h	
	<u>Mineralization Coefficient</u>	<u>Log CFU/ml</u>	<u>Mineralization Coefficient</u>	<u>Log CFU/ml</u>
0	500	6.19	12	6.41
10	<0	<0	<0	<0
20	11	<0	<0	<0
25	1.6	<0	<0	<0
30	<0	<0	<0	<0
40	0.7	<0	<0	<0
50	<0	<0	12	<0
75	<0	<0	<0	<0
100	<0	<0	1.7	<0

TABLE 5
 BIOCIDES PERFORMANCE TEST
 KATHON WT (1.5%) vs. PSEUDOMONAS FLUORESCENS (NRRL B-4290)

Biocide Concentration (PPM as Supplied)	RESPONSE			
	24h		96h	
	<u>Mineralization Coefficient</u>	<u>Log CFU/ml</u>	<u>Mineralization Coefficient</u>	<u>Log CFU/ml</u>
0	67	8.00	46	7.63
1.0	28	7.94	<0	7.74
2.5	60	7.80	<0	7.76
5.0	24	7.49	<0	7.86
10	2.1	4.23	<0	7.81
20	1.9	<0	<0	<0
25	0.19	<0	0.9	<0
50	<0	0.95	1.2	<0
75	<0	1.20	<0	<0
100	<0	<0	<0	<0

TABLE 6
 BIOCIDES PERFORMANCE TEST
 KATHON WT (1.5%) vs. BACILLUS CEREUS (NRRL B-4278)

Biocide Concentration (PPM as Supplied)	RESPONSE			
	24h		96h	
	<u>Mineralization Coefficient</u>	<u>Log CFU/ml</u>	<u>Mineralization Coefficient</u>	<u>Log CFU/ml</u>
0	370	7.80	160	5.11
1.0	330	7.71	<0	6.28
2.5	1.4	3.63	<0	<0
5.0	1.0	<0	0.70	<0
10	0.24	<0	0.23	<0
20	0.28	<0	<0	<0
25	1.6	N.D.	<0	<0
50	10	1.83	<0	<0
75	1.7	<0	<0	<0
100	<0	<0	<0	<0

TABLE 7

DETERMINATION OF MINIMUM LETHAL DOSES (MLD) OF MAGNACIDE 480 AND KATHON WT
AGAINST P. FLUORESCENS (NRRL B-4290) AND B. CEREUS (NRRL B-4278)

<u>BIOCIDE</u>	<u>ORGANISM</u>	<u>MINIMUM LETHAL DOSE</u>	
		<u>VIABLE COUNT</u>	<u>MINERALIZATION COEFFICIENT</u>
Magnacide 480	<u>P. fluorescens</u>	30 ppm	40 ppm
	<u>B. cereus</u>	10 ppm	10 ppm
Kathon WT	<u>P. fluorescens</u>	10 ppm	20 ppm
	<u>B. cereus</u>	2.5 ppm	5.0 ppm

When preliminary biocide evaluations were performed using the ERCO procedure and Storms Pool Unit river and formation water samples, effective biocide concentrations were considerably higher than those reported by the manufacturers. This discrepancy could have been due to two factors. Different methods had been used to evaluate biocide effectiveness (ERCO method versus API method). ERCO tests were performed on natural microbial communities rather than laboratory cultures. The experiments reported above were performed to ascertain which factor(s) affected the results in order to substantiate the Microbiology Laboratory's recommendations for biocide application.

The results from the pure culture studies were more similar to the manufacturer's data than were the preliminary screening tests. As reported above, the ERCO method provided a more sensitive indicator of microbial activity and was therefore considered a more appropriate test apropos of biopolymer flooding. The data also demonstrated that the pure culture tests provide less conservative estimates of effective biocide concentrations than the tests performed using natural samples. Environmental factors including water chemistry, mixed microbial population dynamics, and physical handling (temperature; mixing or aeration) could affect the outcome of any biocide test. Accordingly, the effectiveness of any biocide application program should be determined by evaluating the effect of the complete injection mixture on microbial activity. Moreover, the microbial activity monitored should be the one of most concern. For example, degradation of xanthan is the critical parameter in the biopolymer flood. Preliminary tests have been run investigating the metabolism of Carbon-14 xanthan.

3.3.2 Microbial Inhibition Using Secondary Alcohols

Based on the observations made at the El Dorado field, and reported in other sources, a series of test cultures was set up on April 24, 1980, using water samples collected at the Carmi site. Testing was completed on July 17, 2.5 months after initiation, but was not reported prior to drafting of the third annual report.

The following cultures were set up:

1. Three samples of Wabash River water containing 1000 ppm xanthan (in the form of Pfizer broth), and: (a) 2% iso-butanol, (b) 2% sec-butanol, or (c) no alcohol.

2. Three 2.5 liter samples of Storms Pool formation water containing the same additions.

Cultures were incubated at room temperature without light.

Samples were taken from each culture on a semi-monthly basis. These were used to monitor changes in viscosity in centipoises (cps) and in the concentrations of viable bacteria (cells/ml). The data are plotted as functions of time in Figures 9 through 12.

The presence of 2% alcohol appeared to have a significant inhibiting effect in each of the two water samples. In Wabash River water, the absence of alcohol led to an enormous drop in the viscosity, from 28.6 cps to 4.5 cps during the second week of testing (Figure 9). The corresponding test cultures containing 2% alcohol did not show any significant viscosity changes, remaining at about 30 cps throughout the duration of the test. However, the presence of alcohol did not seem to have any significant inhibitory effects on bacterial viable cell counts in these same cultures (Figure 10). It is possible that the alcohol was providing an alternative more easily metabolized substrate for the populations in these cultures. If this were the case, then a longer incubation period might have resulted in depletion of the alcohol supply. Xanthan might then have become the available substrate.

Another, not necessarily exclusive, possibility is that the alcohol was exerting a selective pressure on the bacterial populations, either by selectively killing off xanthan-degraders, or more likely by enriching for alcohol metabolizing bacteria.

In Storms Pool formation water, the absence of 2% alcohol did not lead to significant changes in viscosity over the 2.5 month incubation (Figure 11). This is not surprising, since in radio tracer tests performed earlier the xanthan degrading activity of formation water was very low relative to activity in river water. However, the presence of alcohol appears to have had a much more toxic effect on the bacterial population of the formation water than on that of the river water (Figure 12). In both of the formation water cultures containing alcohol, the viable cell counts were reduced to less than 10 colony-forming units per milliliter (CFU/ml) from about 1,000,000 CFU/ml in the non-alcohol control.

Figure 9. Viscosity Data; Wabash River Water.

Figure 10. Viable Cell Count Data; Wabash River Water.

Figure 11. Viscosity Data; Storms Pool Formation Water.

Figure 12. Viable Cell Count Data; Storms Pool Formation Water.

3.3.3 Biocide Comparison Retest

During the original biocide screening tests, shelf biocide samples from the laboratory were used. This apparently resulted in the comparison of an old sample of Visco 3991 (2,2-dibromo-3-nitrilo-propionamide, also called DBNPA) and a fresh sample of Magnacide 480 (with the identical active ingredient). A series of re-tests have been performed utilizing fresh samples of both Visco 3991 and Magnacide 480. The tests are detailed as follows:

Biocides compared were:

Magnacide 480	(DBNPA, 20%)
Visco 3991	(DBNPA, 20%)
Kathon 886	(Isothiazolin, 1.5%)

Biocidal activity was determined as inhibitors of Carbon-14 glutamate mineralization by natural populations of Little Wabash River water and Storms Pool Unit produced water. Samples (100 ml) were treated with 100 ppm biocide (as supplied) then supplemented with 0.3 μ Ci Carbon-14 glutamate (0.025 mg/l). All samples were incubated at room temperature (20° C) under oxic conditions or anoxic conditions. Aerobic growth proceeded for 5 hours and anaerobic growth proceeded for 24 hours before samples were poisoned with mercuric chloride and trichloro-acetic acid and sparged.

Precision:

Visco 3991 was tested in quadruplicate under aerobic conditions in river water. K is a constant and is defined as the ratio of the radioactive degenerations per minute recovered to the radioactive degenerations per minute of the injected material. The value of K for four replicates is:

3.2 E-3
2.6 E-3
3.4 E-3
3.2 E-3

$k^{avg} = 3.1 \text{ E-3}$

S.D = 3.4 E-4

Coefficient of Variation = 11%

Inhibition Efficiency:

Inhibition efficiency data as percent inhibition to untreated controls are presented in Table 8. DBNPA appeared to be equally inhibitory under both aerobic and anaerobic conditions. The isothiazolin formulation performed as well as the DBNPA preparations in river water, but not in produced water. Apparently some constituent (divalent cations, hydrogen sulfide, etc.) in the produced water interferes with the inhibitory activity of isothiazolin. Data from other sources suggest that the hydrogen sulfide is the interfering constituent.

When these tests were performed a year ago, there had been a significant difference in inhibitory activity demonstrated by the two DBNPA preparations sampled. As the only known difference between the two preparations was the supplier, the possibility of different behavior due to different shelf storage times was considered. Since custody control had not been exercised during the period preceding the preliminary screen tests, this time the two preparations were retested using products known to be fresh (less than two months on the shelf). As demonstrated in Figure 13, there were no significant differences between the DBPNA supplied by Nalco (Visco 3991) and that supplied by Magna (Magnacide 480).

As reported during the first series of tests, the screening procedure does not account for speed of inhibitory action. Isothiazolin acts more slowly than DBPNA. Consequently, metabolic activity that occurs early during the incubation period is reflected as apparently lower inhibition efficiency.

TABLE 8
INHIBITION EFFICIENCY OF THREE BIOCIDES

Biocide	Aerobic		Anaerobic	
	River Water	Produced Water	River Water	Produced Water
A	99.2	99.5	98.9	99.1
B	99.5	99.5	98.6	99.0
C	89.0	70.0	98.9	46.0

Note: A = Magnacide 480 20% 2,2 -dibromo-3-nitrilopropionamide
 B = Visco 3991 20% 2,2 -dibromo-3-nitrilopropionamide
 C = Kathon 886 1.15% 5-chloro-2-methyl-4-isothiazolin-3-one
 0.35% 2-methyl-4-isothiazolin-3-one

Figure 13 Inhibition Due to Biocide Application

SECTION FOUR

FIELD TESTING

Field testing continued during the fourth year of this project. Interference tests were performed in order to obtain more detailed information about the reservoir and radiotracers were injected to monitor the fluid performance in the reservoir.

4.1 Interference Tests

The interference testing program was begun on January 26 using Well 10-1 as the injector (see Figure 14) and monitoring the pressure response of the other ten wells. This test was commenced somewhat later than originally scheduled due to the poor reliability of the injection plant. Consistent operation is critical to the success of any interference testing program. The first phase of the program was completed on February 2. After one week of no injection to allow the reservoir pressure to re-stabilize, the second phase of the program was begun on February 9. This phase, scheduled to be completed on February 16, was terminated on February 13 due to a break in the river water line near the river station, which eliminated the water supply for injection. Fortunately, sufficient pressure had been observed at all the monitoring wells to validate this phase of the test.

Evaluation of the test data indicates that the pilot area is fairly uniform with no free gas present; the average reservoir pressure has increased by 45 psi since the October, 1979, static pressure tests due to pilot fluid injection; the drift across the pilot is 40 psi from southwest to northeast and will be minimized by the four new disposal wells to the north; and reservoir permeabilities range from 100 to 400 millidarcies while the porosities range from 15 to 22 percent.

4.2 Radiotracer Test

A tracer study was planned to begin after polymer injection to provide data on polymer sweep efficiency and possibly on polymer-inaccessible pore volume. Chemical tracer costs for the designed study were very high compared to costs for radioactive tracers. Radiotracers have the additional advantage that their small volume can be injected as a spike, resulting in a more easily evaluated test.

LEGEND

- Polymer Injection Well
- Project Producing Well
- New Oil Well
- Plant Site
- TR 9 Tract Number

- Test No. 1
- Test No. 2
- Test Injection Well

Figure 14. Interference Testing Plan.

Petroleum Tracers, Inc. of Dallas quoted a price of \$21,943 to inject radioactive tracers into the six injection wells of this project. The radioactive elements and their concentrations were determined by Petroleum Tracers and Teledyne Isotopes, after consultation with ERCO personnel.

On May 4, Jake Netherland of Petroleum Tracers and John Pasinosky of Teledyne Isotopes arrived at the project to inject the radiotracers into the injection wells. The plan they intended to utilize was as follows:

<u>Injection Well</u>	<u>Isotope</u>	<u>Quantity</u>
6-4	CO-60	20 μ Ci
10-3	HTO	5 Ci
10-1	I-125	30 μ Ci
9-3	CO-58	100 μ Ci
9-2	HTO	5 Ci
12-4	CO-60	20 μ Ci

After injecting Cobalt-60 into Well 12-4, Mr. Pasinosky proceeded to inject Cobalt-60 into Well 9-3, rather than utilizing Cobalt-58. This error was apparently due to failure to check the vial labels carefully and grabbing the wrong Cobalt vial. Radiotracer injection was immediately halted while the injection plan was modified. On May 7, Jake Netherland returned with Andy Carmichael of Teledyne Isotopes to administer the newly designed radiotracer injection. The program was modified by substituting Cobalt-57 for Cobalt-60 in the original plan. This resulted in the following injection scheme:

<u>Injection Well</u>	<u>Isotope</u>	<u>Quantity</u>
6-4	CO-57	20 μ Ci
10-3	HTO	5 Ci
10-1	I-125	30 μ Ci
9-3	CO-58	100 μ Ci
9-2	HTO	5 Ci
12-4	CO-57	20 μ Ci

This injection scheme was accomplished without incident. No additional charge over that originally quoted was made because the error was clearly the fault of Teledyne Isotopes.

Monitoring of production samples for the presence of radiotracer has been performed by ERCO's Houston laboratory. No radioactivity has been detected in any of the production samples collected to date, indicating that the radiotracer (and thus the polymer it was injected behind) are still in the reservoir and have not communicated to the production wells through a permeable streak.

SECTION FIVE

CONSTRUCTION OF FACILITIES

Construction of the pilot injection facility was completed early in the year covered by this report. Pre-flush water injection was begun on October 21, 1980, and no major construction has occurred since. Modifications and improvements have been made as time permitted and the need required.

5.1 Modifications to Injection Plant

Throughout the year, Michel Gellato, the field supervisor, has designed and made modifications to the injection facility to refine its operation. Figure 15 shows the flow diagram of the facility as it now exists, with safety and ease of operation being of primary concern when formulating modifications. Areas of interest on the flow diagram (shown in the figure as numbers inside hexagons) are discussed below.

RIVER STATION

- (1) Syphon - for water supply to underground pump (2).
- (2) Pump - in underground casing.
- (3) Safety tank - The purpose of this tank is to avoid water from the priming line entering the vacuum pump (4); this happens often in the spring when the river level is high due to rains. This tank has a floating level switch which turns off the vacuum pump. The pump (2) will then be turned on automatically.
- (4) Vacuum pump - Before the water supply pump (2) turns on, the vacuum pump works for 10-20 minutes (timer) in order to assure a good priming of the pump.
- (5) Biocide tank with metering pump - 20 to 60 ppm of Magnacide 480 are added at this point.

NOTE: A pressure gauge and safety switch is installed at the outlet of pump (2). This safety switch has a two minute delay. If after two minutes the pump has started and the pressure is too low (leak or syphon unprimed) or too high (pipe plugged), the pump shuts off and has to be manually reset.

The flow rate of pump (2) is 14 bbl/minute.
The pressure at the outlet is about 80 psi.

Figure 15. River Station.

Figure 15. (Continued) Tank E-10.

Figure 15. (Continued) Injection Plant Facility.

Figure 15. (Continued) Oil Production Battery.

TANK E-10 (1000 BBL TANK)

- (6) Strainers - for river water before going into tank E-10 (7).
- (7) 1000 bbl tank E-10 - This tank receives the produced water from the water knock-out (54) and a small amount of fresh water from the river station. This amount is only to balance the water used for backwashing the filters (14), (15), (16). This tank has an overflow pipe to remove the oil layer.
- (8) The produced water receives a measured amount (adjustable from 20 to 60 ppm) of Magnacide 480 in this line, which comes from (10). Biocide and produced water are mixed by a static mixer.
- (9) Level control - activates the vacuum pump (4) and water pump (2) in sequence. Another level control is used as a safety measure; the plant is turned off when the level is too low.
- (10) Tank and metering pump for biocide supply.

CLEAN WATER AND BROTH DILUTION SYSTEM

- (11) Water pump - This pump supplies water to the system.
- (12) 1000 gallon dampener tank - Because the control valve (20) makes the water flow surge, this tank has been installed to smooth the variations of the coagulant concentration injected upstream of (59).
- (13) By-pass valve to release the pressure to the desired setting [70 psi outlet of (11)].
- (14) Sand filter.
- (15) Same as (14).
- (16) Same as (14).
- (17) 5 μ cartridge filter.
- (18) Same as (17).
- (19) Pressure gauge and safety switch - shuts the plant down when the pressure is too low (leak, etc.).
- (20) Control valve - Connected to level control (23). This valve monitors the amount of water needed to maintain the same level in tank (25).
- (21) By-pass valve - Because the control valve (20) was too steeply actuated by level control (23) (from full close to full open), this valve is to insure that no water flows through the system when (20) is closed.
- (22) Number not used in figure.
- (23) Level control - Controls (20) and functions as safety to shut plant down when high or low level.
- (24) Mixing point of the first stage diluted broth.
- (25) 200 bbl tank (tank E-40) for second stage broth dilution to desired viscosity (8.5 cps). This tank is stirred.

- (26) Broth supply pump
- (27) 140 μ stainless steel cartridge filter for broth.
- (28) Same as (27).
- (29) T where broth goes into loop line from injection line and back to dilution tank. Notice that the solution is not made with water itself but with a 500 ppm solution.
- (30) In-line static mixer for homogeneous first polymer solution.
- (31) Same as (30).
- (32) In-line Viscometer.
- (33) Viscosity recorder - This recorder also controls broth pump (26); when the viscosity is too high, (26) is off; when too low, (26) is on.
- (34) Flow meter.
- (35) High pressure regulating valve - It allows a small amount of injection fluid to pass through the viscometer at low pressure. Prior to returning to tank E-40 (25), this liquid is used for first stage polymer dilution.

BROTH SUPPLY AND UNLOADING

- (36) Pump for unloading broth from truck.
- (37) 2 to 3 mm basket strainer.
- (38) 200 Bbl broth storage tank E-33.
- (39) 200 Bbl broth storage tank E-32.
- (40) 300 Bbl broth storage tank E-31.
- (41) 300 Bbl broth storage tank E-30 or settling tank for backwash water [from filters (14), (15), (16)]. Right now the backwash is sent directly to Jim Haley's plant, but by switching valves (43) and (44), the water could be settled first in this tank to remove as much silt and oil as possible, then sent to Jim Haley's plant (or back to tank E-10 (7) if clean enough) through pump (46) (not installed).
- (42) Isolating valve - Notice that the same lines used for carrying the broth from the unloading pump (36) to the storage tanks are also used as suction lines for pump (26). Valve (42) has to be open when unloading the truck, and closed during normal operation.

BACKWASH

- (43) Valve for diverting the backwash water from filters (14), (15), (16) to Jim Haley's water plant or to tank (41) for pre-settling.
- (44) Same as (43).

- (45) Inlet of backwash water: 5 ft up from bottom.
- (46) Pump (not installed) for emptying tank (41). See (41).

INJECTION SYSTEM

- (47) Injection pump 1 (Gardner-Denver).
- (48) Injection pump 2 (National) - These two triplex pumps are in parallel and never work together. Manifold pressure: 670 psi.
- (49) Dampener.
- (50) Manual by-pass valve.
- (51) Pressure control valve - monitored through pressure gauge and transducer (53). This valve maintains the same pressure (670 psi) in the manifold, allowing more or less fluid to go back to tank (25).
- (52) Safety pressure release valve - This valve opens when pressure is higher than 700 psi.
- (53) Pressure gauge - transducer for valve (51) and as safety to shut plant down when pressure is too low (leak) or too high (valve malfunction or improper handling).

NOTE: Each injection line is equipped with a manual regulator valve, a pressure gauge and a recording flow device (Halliburton Flow Meter).

OIL PRODUCTION

- (54) Main horizontal free water knock out - The oil is sent to two oil storage tanks (55), (56). Alternately switched over. The water goes through a Halliburton Flow Meter then to tank (7).
- (55) Oil storage tank (200 bbl).
- (56) Oil storage tank (200 bbl).
- (57) Test line - Free water knock out; the oil goes to tank (58) and the water to Haley's water plant. A Halliburton Flow Meter installed between the knock-out (57) and the production manifold computes the total produced fluid of the selected well.
- (58) 100 bbl oil storage tank.

CHEMICALS

- (59) Coagulant storage tank and metering pump - The coagulant used is Cat-Floc T from Calgon. It is injected upstream of tank (12).

- (60) 2nd biocide - This biocide is Kathon. It is injected downstream of sand filters (14), (15), (16) to avoid losses in backwash. Its concentration is 50 - 200 ppm of Tretolite XC-215 (1.5% Kathon).
- (61) Chelating agent - Sodium citrate (20 - 60 ppm), injected downstream of filters (14), (15), (16).

5.2 Completion of Production Battery

The production battery was completed during the year when the new water knock-out was installed and became operational. The previous knock-out had become sufficiently corroded to warrant replacement and is now being utilized for individual well testing. The production battery was also fully insulated to prevent freezing.

SECTION SIX

PROGRAM SUPPORT

Program support for this project has encompassed numerous items in addition to management of the day-to-day operations.

6.1 Polymer Transportation

The use of leased equipment rather than common carriers for polymer transportation had the potential of resulting in lower freight costs and less potential for polymer broth contamination. The use of dedicated drivers has also resulted in simplified operations because field personnel do not need to be present to direct the truck to the injection plant or to unload the polymer.

A used stainless steel tank trailer was purchased from Fruehauf and the tractor unit was leased from Hertz. Rather than hiring drivers, it was found to be less expensive to lease drivers from L.A.D. Corporation of Houston. The first polymer pick-up was made from Pfizer's Groton, Connecticut facility on December 19. During December and January, the 1,000 barrels of polymer storage on-site was filled. Polymer transportation operated smoothly from the Groton facility through late August when the point of shipment was moved to Terre Haute, Indiana. With the new shorter haul, the leased driver will be released and a qualified field man will be utilized as a part-time driver.

Polymer freight costs have been about the same as would be experienced using a common carrier due to the low polymer injection rate experienced until late July. This has lowered the polymer broth needs, resulting in a higher freight cost per pound because of continued fixed lease costs. Greater polymer usage since August has resulted in a more efficient use of the polymer transporting equipment and manpower.

6.2 Technical Decisions

Pfizer has been phasing out their Flocon 1035 biopolymer in preference to their Flocon 4800. These products are nearly identical with the exception that the Flocon 4800 has a higher filtration ratio (specifications are less than 3.0 rather than less than 1.5), the Flocon

4800 is less expensive (\$2.75 per pound rather than \$3.29 per pound), and the Flocon 4800 concentration is higher (3.5 percent versus 2.5 percent). In early September, Flocon 4800 began being delivered to the project. Field experience with this polymer has not contradicted the laboratory data on this material and injection has continued smoothly. The delivery of this higher concentration broth from a facility only 125 miles away will have a major impact on future freight costs.

6.3 Reporting and Meetings

The program support for reporting has included the regular monthly, quarterly, and annual financial and technical reports. In addition to the written reports, personal contacts with representatives of both the government and public sectors have been made throughout the year.

On October 24, Forrest Craig of ERCO and Gerard Stock of Elf Aquitaine met with Fred Burtch, Rex Thomas, and Bob Johansen of the Department of Energy. The purpose of this meeting was to discuss progress made during the previous year and the plans for the coming year. The simulation work performed during the previous year was also a major topic.

Representatives of Mitre Corporation visited the project during the week of March 9. Their visit was part of a Department of Energy sponsored study on the health and safety aspects of enhanced oil recovery. The purpose of their visit was to understand the operation of enhanced recovery projects and to study the chemicals and operations procedures utilized in such a project. This was not a fault-finding visit but rather an effort to develop a set of health and safety guidelines for enhanced recovery projects.

ERCO personnel assisted Jim Haley, owner/operator of the Storms Pool Unit and owner of the Pilot area farm-out, in preparing a presentation about the Storms Pool Polymer Pilot. This slide presentation was made to the Tri-State American Petroleum Institute meeting in Evansville, Indiana on April 30. Haley's presentation was very well received at this meeting, which consisted primarily of independent operators from the Illinois basin.

During the week of August 23, Forrest Craig and Fred Passman of ERCO each made several presentations on different aspects of this project to the Society of Petroleum Engineers symposium on Field Handling of Polymer. This symposium was a valuable opportunity to meet with others who

are involved with polymer projects and exchange the detailed information which is seldom available in publications.

6.4 General Program Management

Throughout the year, ERCO personnel made regular visits to the field in order to stay attuned to progress. Representatives of Elf Aquitaine also visited the project on a routine basis to support the field supervisor and his assistant.

On January 14, Fred Passman and Forrest Craig of ERCO visited Pfizer Chemical's Research Center in Groton, Connecticut. Considerable data was exchanged on polymer properties in the Storms Pool system. It was agreed that the proposed injection fluid (500 ppm Flocon 1035, plus 5 ppm chelating agent, plus a minimum of 50 ppm Tretolite XC-215 or Magnacide 480) should be stable throughout the life of the flood. Other matters, including treatment of the river water, dilution and injection of xanthan, produced water sampling, and tank trailer cleaning, were discussed.

A field hand was hired on March 7 to assist with the start-up of polymer injection and to provide support for the maintenance work required. This field hand was utilized on this project through July when it was decided the field supervisor and his assistant could properly handle the manpower demands of the project without assistance. The hand, now assigned to another project nearby, will be utilized as a driver for polymer transportation.

On April 9, Richard Rosen of ERCO visited the project to observe polymer injection. Dr. Rosen, President of ERCO, expressed to the field personnel his pleasure that polymer injection had begun and was operating smoothly.