

Status Report

MICROBIAL-ENHANCED WATERFLOOD FIELD EXPERIMENT
Field Baseline Data and Monitoring Procedures

Project OE10, Milestone 4

By Dr. Rebecca S. Bryant, Dr. Thomas E. Burchfield,
Mike Dennis, and Dr. Donald O. Hitzman

James Chism, Project Manager
Bartlesville Project Office
U. S. Department of Energy

Work Performed for the
U. S. Department of Energy
Under Cooperative Agreement
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MICROBIAL-ENHANCED WATERFLOOD FIELD EXPERIMENT

Field Baseline Data and Monitoring Procedures

By Dr. Rebecca S. Bryant,¹ Dr. Thomas E. Burchfield²,
Mike Dennis³, and Dr. Donald O. Hitzman⁴

SUMMARY

Site selection for a microbial-enhanced waterflood field experiment was completed after surveying approximately 200 different oilfields surrounding the Bartlesville area. After the Mink unit site was agreed upon, a baseline monitoring program was initiated that included weekly sampling for 18 weeks. The baseline period officially ended March 17, 1987. Microbial injection was initiated on March 19 and 23, 1987. Laboratory studies during the monitoring phase indicated a relatively stable trend regarding concentration of total dissolved solids, pH, and oil viscosities from each producing well.

Chemical tracer studies and single well microbial injectivity tests were conducted to obtain further information regarding fluid flow patterns in the field and survivability and injectivity of the microbial formulation. The results from these experiments indicated that there was communication between the injectors and all producing wells. A few high permeability streaks were evident. The microbial formulation could survive and metabolize in the field, and no changes in injection pressures or rates were observed after microbial injection. The field testing and laboratory monitoring phases are now in progress.

INTRODUCTION

This status report contains information pertaining to the baseline period prior to injection of microorganisms for the field experiment. Baseline monitoring and microbial injection optimization tasks were completed, and results are reported here. The end of the baseline monitoring period and beginning of microbial injection occurred the third week of March, 1987.

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Laboratory studies were conducted on the samples obtained weekly from the Mink unit during Oct. 28 through March 17. Overall, the parameters measured, total dissolved solids (TDS), pH, oil viscosity, and trace mineral analyses, have been fairly stable. The total dissolved solids of produced water from each production well and the injection plant water have remained constant to within $\pm 0.01\%$. The pH of the produced water from each producing well has remained between 6.4 and 7.0. Oil viscosity values from oil obtained from each producing well have not varied more than 2 centipoises. Trace mineral and ion analyses (Table 1) have indicated no abnormal concentrations of the following: sodium, calcium, magnesium, strontium, barium, potassium, iron, copper, zinc, nickel, chloride, sulfate, bicarbonate, carbonate, hydroxide, and phosphate.

A comprehensive field sampling program was initiated in November 1986, and has been continued to March 17. All data are tabulated and graphed, including: (a) total oil production (Mink lease); (b) total water production (Mink lease); (c) injection well pressures and fluid rates from each well; and (d) production well fluid rates and water-oil ratio from each well. Field samples were collected each week although sampling was increased to twice per week during the tracer injection.

Two separate chemical tracer injections were done in the injection wells in the pilot area, and fluorescein concentrations in the produced water from the 10 producing wells and 5 monitoring wells were determined twice a week. The fluorescein has appeared in all producing wells.

In January 1987, injection of the microbial system was started to substantiate survivability in the reservoir. Two Mink injection wells which were outside the pilot area were chosen for this project, injected with the system, and shut in for a "soak" period to allow establishment of the microorganisms. Subsequent backflush samples indicated a high degree of microbial survivability and activity. Normal water injection was then resumed and injection rates and pressures were monitored to serve as an indicator of possible injection profile modification. No changes in injection rates or pressures have been observed to date.

The injection protocol has been based upon the field conditions of the Mink site and the behavior of the microbial system in the laboratory. The survivability test injection provided an excellent opportunity to evaluate the

microbial system in the reservoir and to test and refine the injection equipment and protocol.

FIELD DATA

Injection Pressures and Oil Production

The daily injection pressure at the B & N injection plant was graphed from Dec. 16, 1986, through Mar. 17, 1987, to establish an injection pressure baseline before injection of the microbial formulation. The injection pressures at the plant ranged from 525 to 555 psi.

The Mink Unit (Fig. 1) was selected as the site for the MEOR waterflood experiment because oil production data from the Mink Unit was relatively constant during 1985-1986 (Figs. 2 and 3). The cumulative annual oil production from the Mink Unit in 1985 was 2,330 bbl; whereas in 1986, the production was 2,366 bbl, a difference of 36 bbl for the entire year. When the average production for 8 weeks in 1986 (363 bbl) is compared to that for 1987 (345 bbl), the difference is only 18 bbls of crude oil. This gives a stable baseline to measure any effects from microbial injection in this unit.

Monitoring of Field Data

Since Nov. 11, 1986, weekly oil production data have been obtained from each of the 10 producing wells in the Mink Unit. A representative sample sheet is shown in figure 4. This sampling procedure has provided 19 weeks of baseline monitoring information before the microbial injection. Water-oil ratios for each producing well have been determined for the baseline monitoring period. These numbers vary much more on a well-to-well basis than for the total Mink unit; however, we have enough baseline data to make a statistically justifiable extrapolation of the curves to determine if there are any significant changes after microbial injection.

Microbial Survivability Tests

Single-well injection tests were performed in February to establish certain parameters before injection of the microbial system was initiated in the Mink Unit site. Two off-pattern injection wells were inoculated with 100 liters of NIPER's microbial formulation (NIPER BAC 1) (DW1 well) and INJECTECH's microbial formulation (CW2 well; see figure 5). All wells are

designated by a preceding C or S: meaning Candy or Sally Mink Lease. Well DW3 was used as a control well (no injected microorganisms). The microorganisms were grown as a mixture in 4 percent molasses. The microbial formulations were designed to give optimal growth and compatibility with the Mink Unit formation water and oil, as well as the molasses. The cultures were transported to the field from the laboratories. Injection was accomplished on Feb. 4, 1987. The wells were shut in for 12 days and then backflushed. During backflushing, samples were collected every 10 to 15 minutes until microorganisms and molasses were detected. Several interesting observations were noted during this test.

1. The first sample had a slight odor of molasses.
2. Samples from injection wells, showed a dramatic change in color and turbidity after about 1 1/2 hr of backflush (Fig. 6). The first sample bottle was relatively clear, and the second sample was yellow, turbid, and smelled like molasses. The samples contained some gas.
3. The injection rates and pressures after the microbial incubation and activity were normal, indicating no plugging in either well.
4. The control well (DW3) was monitored to determine whether backwash pressures were normal, and the pressures were equivalent to those of the two test wells (CW2 and DW1); again further evidence that no loss in injectivity occurred.
5. All microorganisms injected into both wells were detected in the backflush samples. The microbial counts were high, indicating the microorganisms were still growing and metabolizing after 12 days of incubation in the wells under reservoir conditions.
6. The pH of the backflush samples decreased from about 8.0 to 5.0 when microorganisms were observed in the sample.
7. No sulfate-reducing bacteria were found in the backflush samples.

Fluorescein Injection - Tracer Studies

Chemical tracer studies were initiated in December to determine the flow patterns of the injected fluids in the Mink Unit (figure 7). Fluorescein was found to be compatible with the formation fluids as well as the microbial cultures, and it was chosen as the tracer for the test. On Jan. 13, 1987, 27 bbl of fluorescein solution at a concentration of 53 ppm and 8.3 bbl of a fluorescein solution at a concentration of 174 ppm was injected into wells BW-2 and BW3, respectively. Sampling of each producing well was initiated on a bi-weekly basis; samples were protected from light and transported to NIPER and the fluorescein concentration was determined using a spectrophotometric method. On March 5, 1987, wells DW2 and AW3 were injected with 5.2 bbl of 302 ppm fluorescein and 210 ppm fluorescein solution. The sampling protocol continued except that samples were taken daily for the first 5 days after this tracer injection. The fluorescein concentration curve for each producing well showed that every producer received some fluorescein. This was an encouraging finding. The cumulative fluorescein detection graph is presented in figure 8. As expected, the highest amount of fluorescein was detected in wells P47R and AP2, since these wells are nearest the injectors and would be most affected by the injection. The final analysis of the tracer study is still in progress, and will be reported at a later date.

LABORATORY DATA

Weekly samples from each producing well have been analyzed to determine crude oil viscosity, total dissolved solids, trace mineral analyses, and in pH. Based upon samples from Oct. 28, 1986, through Mar. 3, 1987, the following observations were recorded:

1. The concentration of total dissolved solids (percent) in produced water from each well and the injection plant water have remained stable (within ± 0.01 percent).
2. The pH of the produced water from each producer has remained between 6.4 and 7.0.

3. Oil viscosities from each producing well have not varied more than 2 centipoises.
4. Trace mineral and ion analyses did not indicate any abnormal concentrations of: sodium, calcium, magnesium, strontium, barium, potassium, iron, copper, zinc, nickel, chloride, sulfate, bicarbonate, carbonate, hydroxide, or phosphate (table 1).

POROUS MEDIA STUDIES

Several different microbial formulations from INJECTECH and NIPER were tested in Berea sandstone cores to determine oil recovery efficiency. A field core from the Delaware-Childers field (Costen lease) was obtained and tested with the microbial formulation selected for the field. Table 1 and figures 9 and 10 summarize the results from this microbial coreflood. Based upon these data, it was found that the microbial system recovered 28.3 percent of the residual Mink crude oil remaining in the core after waterflooding. The pH of the core effluent fractions was lower during the oil recovery period, and higher at the beginning and end of the waterflood, which indicates that the microbes are producing acids that may improve the oil recovery. Gas chromatographic analyses of the metabolites produced by the microbial consortia are in progress.

Micromodel studies were carried out simultaneously with this coreflood to determine if the microbial formulation could mobilize oil in the simulated porous media. A glass micromodel was saturated with brine from the Mink tank battery and flooded with crude oil from the Mink lease. The micromodel was then flooded with Mink plant injection water until no more oil movement was obtained (residual oil saturation). The microbial formulation was injected and the micromodel shut in at room temperature for 3 days. The micromodel was then waterflooded and video-taped using a video-enhanced microscopy apparatus. It was observed that there were some gas bubbles produced during incubation of the micromodel, and when the micromodel was waterflooded, there was a large amount of oil mobilization.

TABLE 1. - Mineral and ion analysis of water samples from Mink lease

| Cation | Plant Injection | Tank Battery mg/l | Well SAP2 |
|-----------|-----------------|----------------------|-----------|
| Sodium | 12 | 1,183 | 3,176 |
| Calcium | 34 | 156 | 330 |
| Magnesium | 53 | 289 | 217 |
| Strontium | 0.4 | 30 | 20 |
| Barium | 0.2 | 134 | 144 |
| Potassium | 4.5 | 8.7 | 14 |
| Iron | 0.7 | 5 | 2 |
| Copper | < 0.1 | < 0.5 | < 0.5 |
| Zinc | < 0.1 | < 0.5 | < 0.5 |
| Nickel | < 0.1 | < 0.1 | < 0.5 |

| Anion | Plant Injection | Tank Battery mg/l | Well SAP2 |
|---------------------------|-----------------|----------------------|-----------|
| Chloride | 17 | 2,037 | 5,294 |
| Sulfate | 15 | 12 | 12 |
| Bicarbonate | 135 | 1,450 | 1,800 |
| Carbonate | 0 | 0 | 0 |
| Hydroxide | 0 | 0 | 0 |
| Phosphate | < 0.5 | < 2 | < 2 |
| Total Dissolved Solids | 0.027% | 0.5% | 1.1% |

TABLE 2. - Microbial field core data and preparation protocol
- Core No. MSC23

| | | | | | |
|-------------------------------|------------|------------------|------------|--------------------------|-------|
| Rock composition: | field core | Porosity, %: | 19.35 | Viscosity, cp: | 7 |
| Dry weight, g: | 2461.5 | Encapsulation: | epoxy | Water vol., ml: | 32.7 |
| Wet weight, g: | 2509.8 | Brine conc., %: | 0.55 | Oil vol., ml: | 17.5 |
| X-sec area, cm ² : | 11.045 | Flow rate, ml/s: | 0.058 | Residual oil, ml: | 15.2 |
| Length, cm: | 22.6 | Pressure, psi: | 33.5 | S _{Oi} , % PV: | 67.70 |
| Core vol., ml: | 249.6 | Permeability, D: | 0.052 | S _{Owf} , % PV: | 31.47 |
| Pore vol., ml: | 48.3 | Oil type used: | Mink lease | | |

| Tube Vol, ml | | Oil/ Water | S _{Ocf} , % PV | Recovery, % | Brine, PV | pH |
|--------------|------|---------------|----------------------------|----------------|--------------|------|
| Water | Oil | | | | | |
| 8.50 | | 0.000 | 31.47 | | 0.17 | 7.70 |
| 8.90 | | 0.000 | 31.47 | | 0.36 | 7.75 |
| 9.20 | | 0.000 | 31.47 | | 0.55 | 7.00 |
| 9.40 | | 0.000 | 31.47 | | 0.74 | 6.35 |
| 9.20 | 0.50 | 0.054 | 30.44 | 3.28 | 0.94 | 6.20 |
| 9.20 | 0.20 | 0.022 | 30.02 | 4.60 | 1.14 | 6.25 |
| 9.30 | | 0.000 | 30.02 | 4.60 | 1.33 | 6.15 |
| 9.35 | 0.05 | 0.005 | 29.92 | 4.93 | 1.53 | 6.55 |
| 9.40 | | 0.000 | 29.92 | 4.93 | 1.72 | 6.65 |
| 9.40 | | 0.000 | 29.92 | 4.93 | 1.92 | 6.70 |
| 9.30 | | 0.000 | 29.09 | 4.93 | 2.11 | 6.85 |
| 9.30 | 0.40 | 0.043 | 29.09 | 7.56 | 2.31 | 6.50 |
| 9.30 | | 0.000 | 29.09 | 7.56 | 2.50 | 6.60 |
| 9.60 | | 0.000 | 29.09 | 7.56 | 2.70 | 6.85 |

TABLE 2. - Microbial field core data and preparation protocol
 - Core No. MSC23 (continued)

| Tube Vol, ml | | Oil/ Water | S _{ocf} , % PV | Recovery, % | Brine, PV | pH |
|--------------|------|---------------|----------------------------|----------------|--------------|------|
| Water | Oil | | | | | |
| 9.50 | | 0.000 | 28.26 | 7.56 | 2.90 | 6.75 |
| 9.35 | 0.40 | 0.043 | 27.64 | 10.19 | 3.10 | 6.50 |
| 9.50 | 0.30 | 0.032 | 27.64 | 12.17 | 3.30 | 6.55 |
| 9.50 | | 0.000 | 27.64 | 12.17 | 3.50 | 6.55 |
| 9.40 | | 0.000 | 26.81 | 12.17 | 3.70 | 6.65 |
| 9.30 | 0.40 | 0.043 | 26.81 | 14.80 | 3.90 | 6.65 |
| 9.40 | | 0.000 | 26.81 | 14.80 | 4.09 | 6.70 |
| 9.30 | | 0.000 | 25.77 | 14.80 | 4.28 | 6.80 |
| 9.20 | 0.50 | 0.054 | 25.16 | 18.09 | 4.48 | 6.55 |
| 9.50 | 0.30 | 0.032 | 24.43 | 20.06 | 4.69 | 6.55 |
| 9.50 | 0.35 | 0.037 | 24.22 | 22.36 | 4.89 | 6.45 |
| 9.85 | 0.10 | 0.010 | 23.60 | 23.02 | 5.10 | 6.50 |
| 9.90 | 0.30 | 0.030 | 23.60 | 25.00 | 5.31 | 6.85 |
| 10.00 | 0.10 | 0.010 | 23.40 | 25.65 | 5.52 | 6.55 |
| 9.50 | 0.40 | 0.042 | 22.57 | 28.28 | 5.72 | 6.55 |
| 7.90 | | 0.000 | 22.57 | 28.28 | 5.89 | 6.55 |
| 7.90 | | 0.000 | 22.57 | 28.28 | 6.05 | 7.10 |
| 8.00 | | 0.000 | 22.57 | 28.28 | 6.21 | 7.10 |
| 14.00 | | 0.000 | 22.57 | 28.28 | 6.50 | 7.35 |
| 11.50 | | 0.000 | 22.57 | 28.28 | 6.74 | 7.80 |
| 11.50 | | 0.000 | 22.57 | 28.28 | 6.98 | 7.80 |
| 13.00 | | 0.000 | 22.57 | 28.28 | 7.25 | 7.75 |
| 13.00 | | 0.000 | 22.57 | 28.28 | 7.52 | 7.75 |
| 10.10 | | 0.000 | 22.57 | 28.28 | 7.73 | 7.60 |

BASELINE MICROBIAL DATA

Table 3 and figures 11 through 21 illustrate the baseline microbial populations for the Mink Unit site. The following microbial counts were established prior to microbial injection over a 20-week period covering 10 producing wells and the injection water. Samples were analyzed weekly and in some instances, bi-weekly.

The baseline microbial counts appeared to be very low and were consistent throughout the monitoring period. These data should enable us to see a change in microbial populations after microbial treatment. We would expect the microbial population to increase by 3 or 4 in order of magnitude if they reach the producing wells.

Sulfate-reducing bacteria are consistently present in the tank battery water and intermittently present in plant injection water. There are sporadic occurrences of sulfate-reducing bacteria in the produced waters.

TABLE 3. - Baseline microbial counts

| | cfu/ml ¹ |
|-------------------------------|---------------------|
| <u>Aerobic plate counts</u> | |
| Injection water average | 3,000-5,000 |
| Produced water average | 0-100 |
| Tank battery water average | 300-500 |
| <u>Anaerobic plate counts</u> | |
| Injection water average | 100-300 |
| Produced water average | 0-10 |
| Tank battery water average | 5-50 |

¹cfu/ml = colony-forming units per milliliter of water.

CONCLUSIONS

All baseline data to date have been very stable. It should be relatively simple to determine any deviations in the parameters that are being monitored from their baseline values caused by injection of the microbial system. It is noteworthy that all injection pressures are stable, indicating that no plugging of any well has occurred. The laboratory porous media studies show that the microbial system does significantly increase oil production over that of a waterflood. The microbial counts and tracer studies will be examined very closely to determine if a correlation between transit time of microbes and transit time of fluorescein can be made. In summary, all systems appear to be very positive, and we are continuing to receive information weekly.

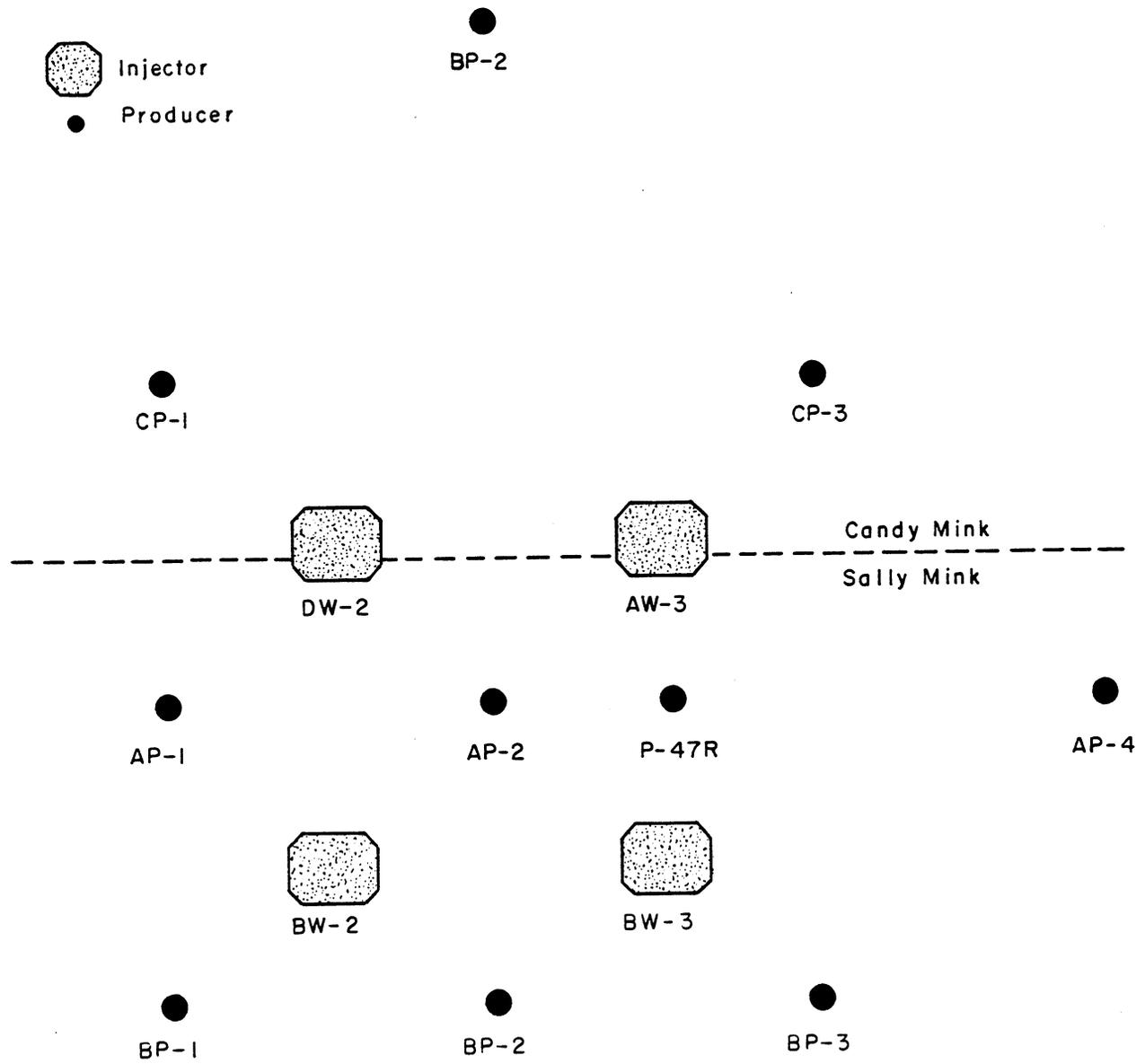


FIGURE 1. - Map of Mink Unit.

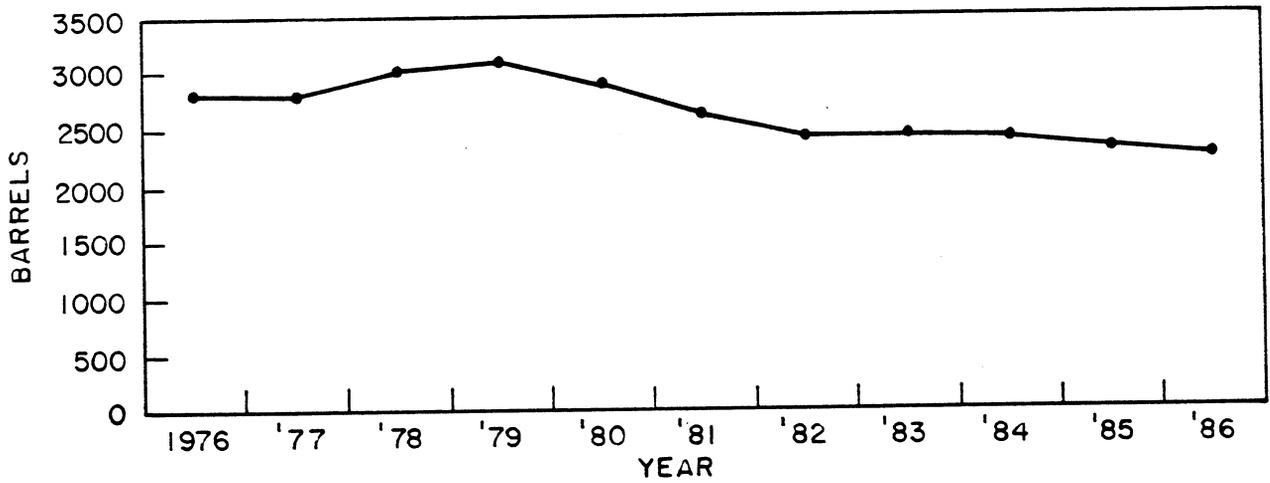


FIGURE 2. - Total production from Mink Unit, 1976 to present.

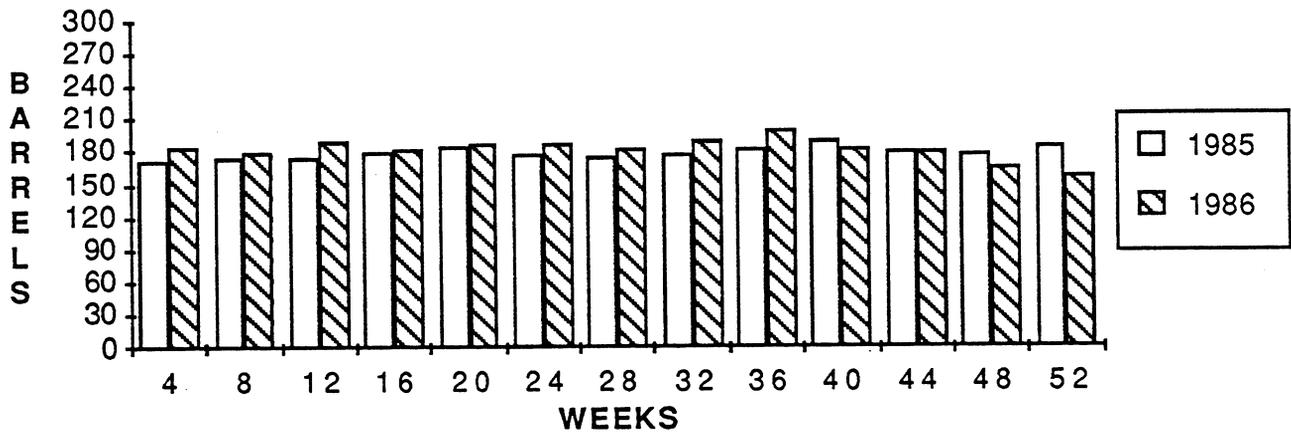


FIGURE 3. - Production from Mink Unit in 1985 and 1986.

DOE PROJECT - FIELD SAMPLES

| | | | | | |
|-----------------------|-------------|-----------------|------------------|------------------|----------------------|
| | | | | DATE: | |
| | | | | TIME: | |
| WELL | BWPD | BOPD | TOTAL BPD | % OIL CUT | H2O/OIL RATIO |
| S-BP-1 | | | | | |
| S-BP-2 | | | | | |
| S-BP-3 | | | | | |
| | | | | | |
| S-AP-1 | | | | | |
| S-AP-2 | | | | | |
| S-P-47R | | | | | |
| S-AP-4 | | | | | |
| | | | | | |
| C-CP-1 | | | | | |
| C-CP-3 | | | | | |
| C-BP-2 | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| T.B. | | | | | |
| | | | | | |
| | | | | PRESSURE | TEMPERATURE |
| | | | | | |
| PLANT | | | | | |
| | | | | | |
| | BWPD | PRESSURE | | | |
| | | | | | |
| S-BW-2 | | | | | |
| S-BW-3 | | | | | |
| C-DW-2 | | | | | |
| S-AW-3 | | | | | |
| | | | | | |
| | | | | | |
| PRODUCED H2O | | | | | |
| | | | | | |
| | | | | | |
| WEEKLY OIL PRODUCTION | | | | | |
| | | | | | |
| AIR TEMP | | | | | |
| | | | | | |
| COMMENTS | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

FIGURE 4. - Field sample data sheet.

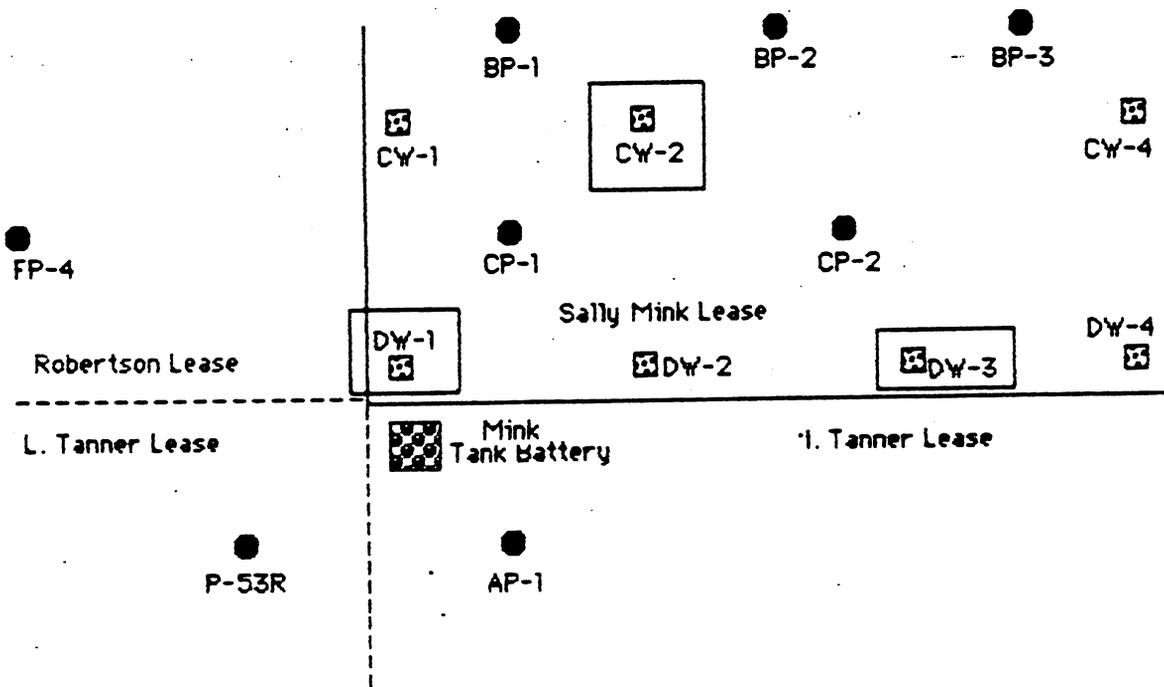


FIGURE 5. - MEOR survivability field test map.



FIGURE 6. - Survivability test backflush samples.

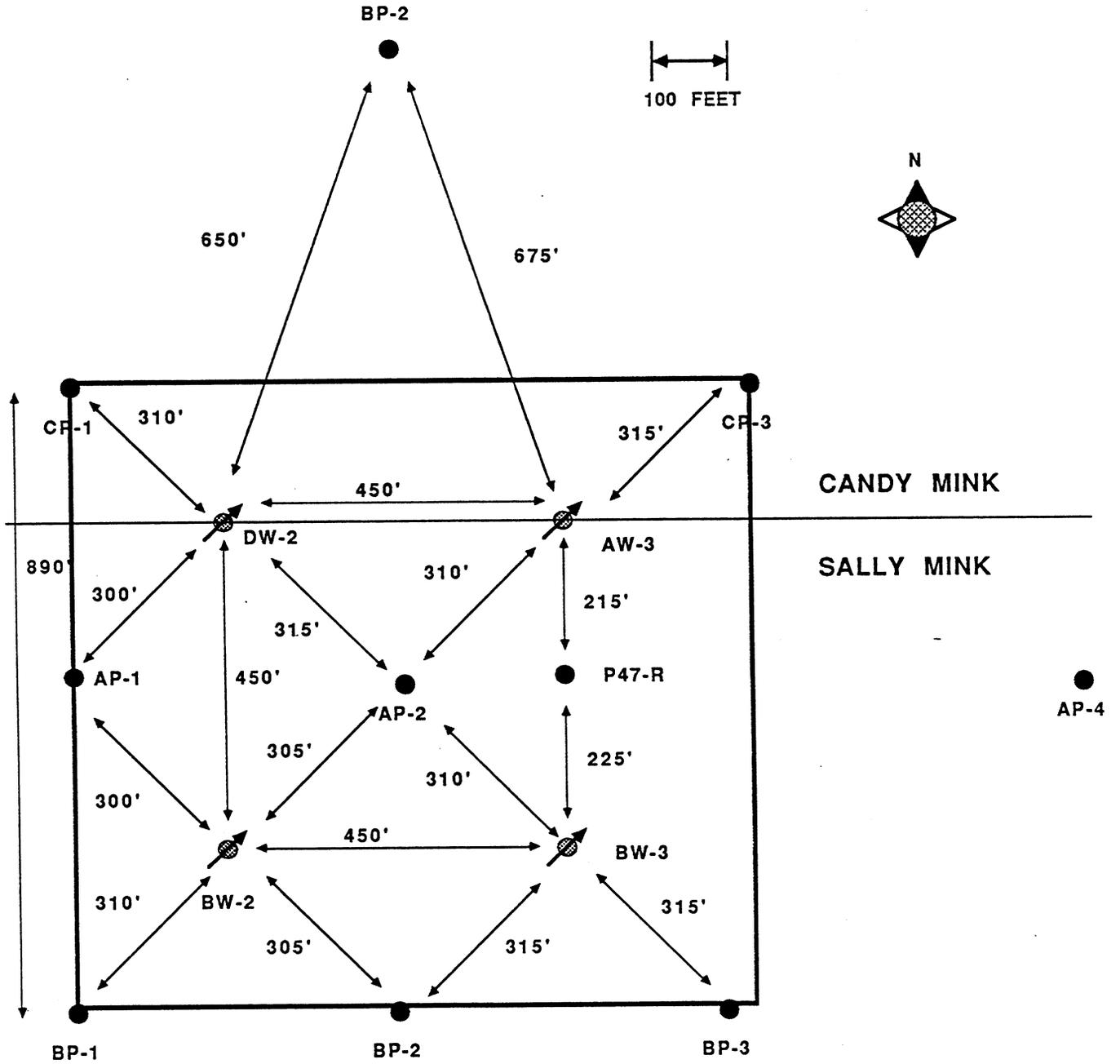


FIGURE 7. - MEOR field project

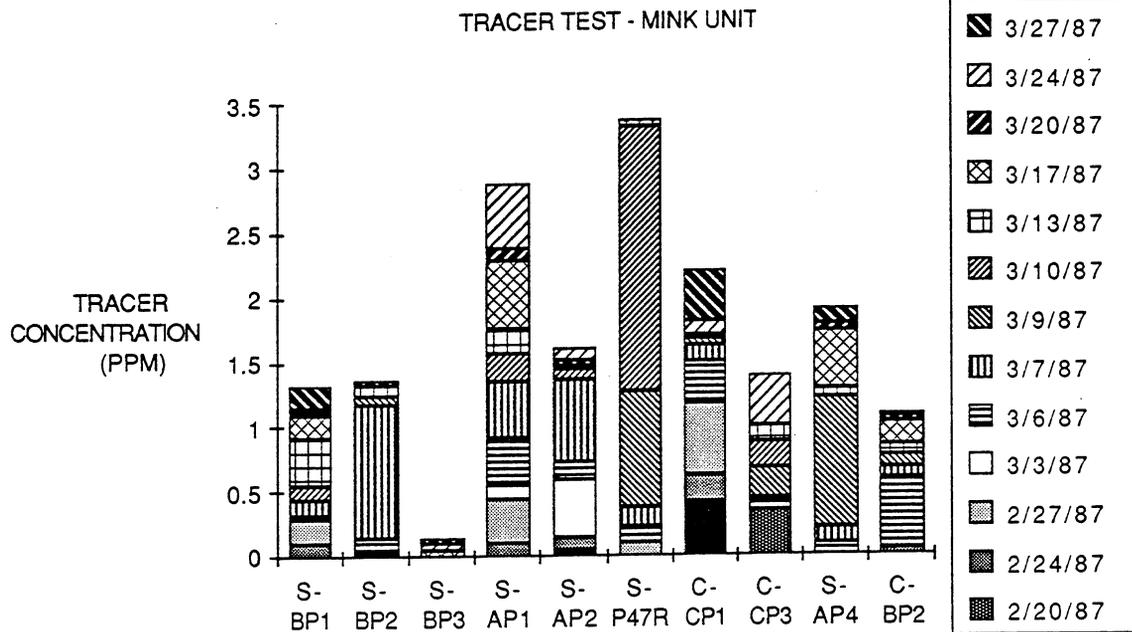
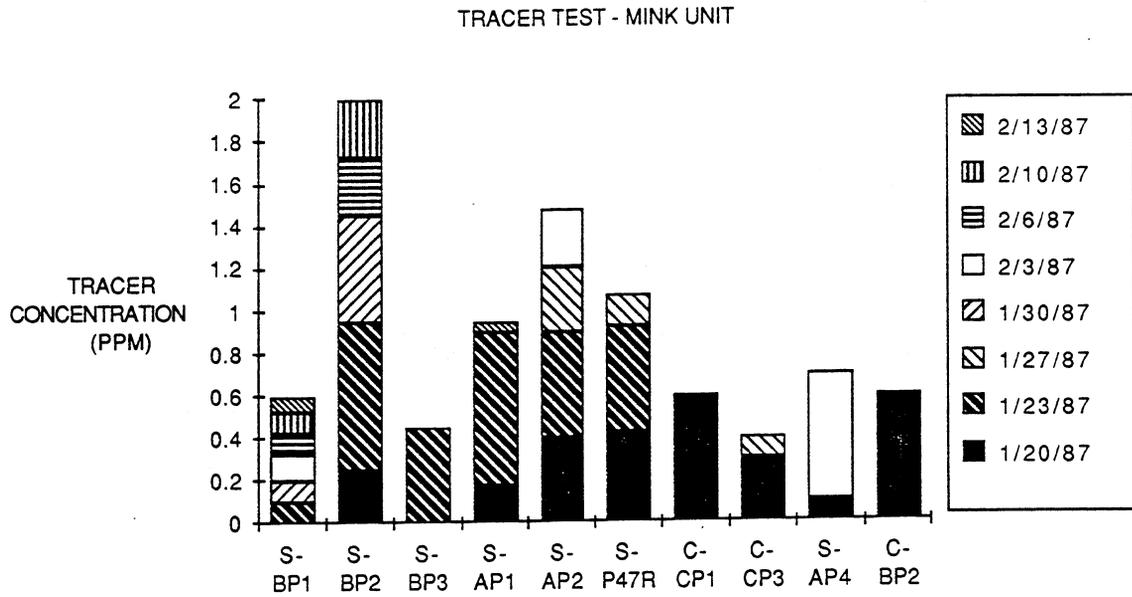


FIGURE 8. - Cumulative fluorescein in monitored producing wells.

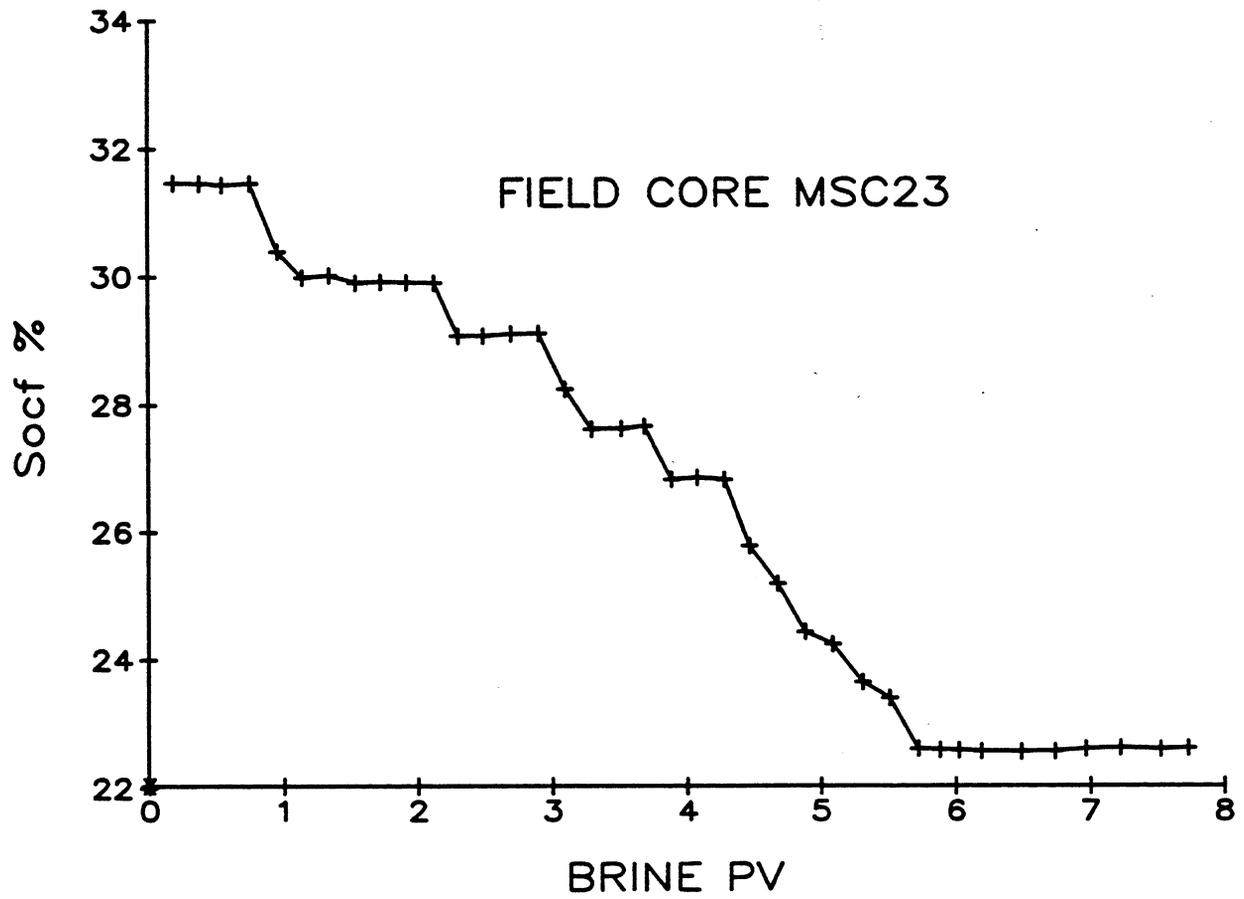


FIGURE 9. - Residual oil saturation versus brine injected.

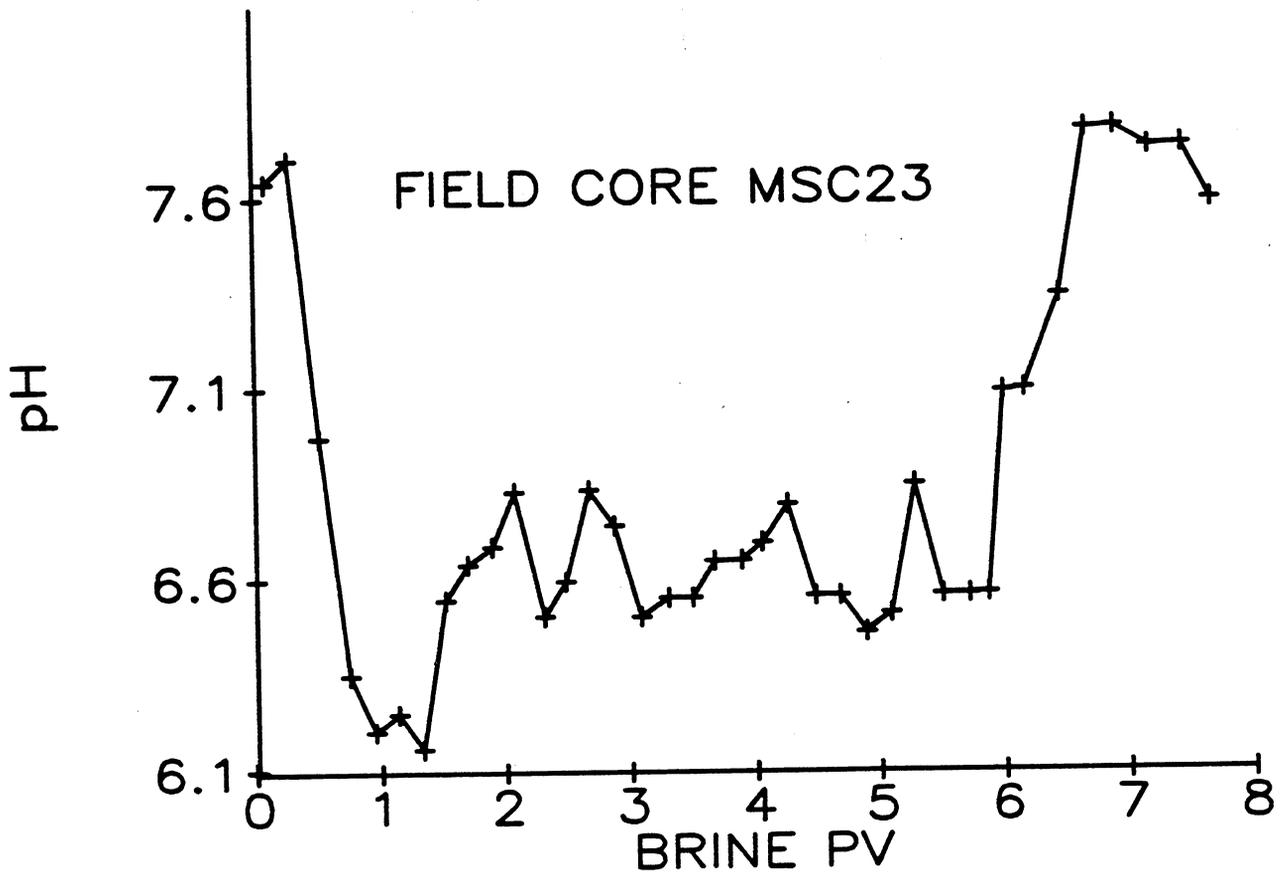


FIGURE 10. - pH of core effluent fractions versus brine injected.

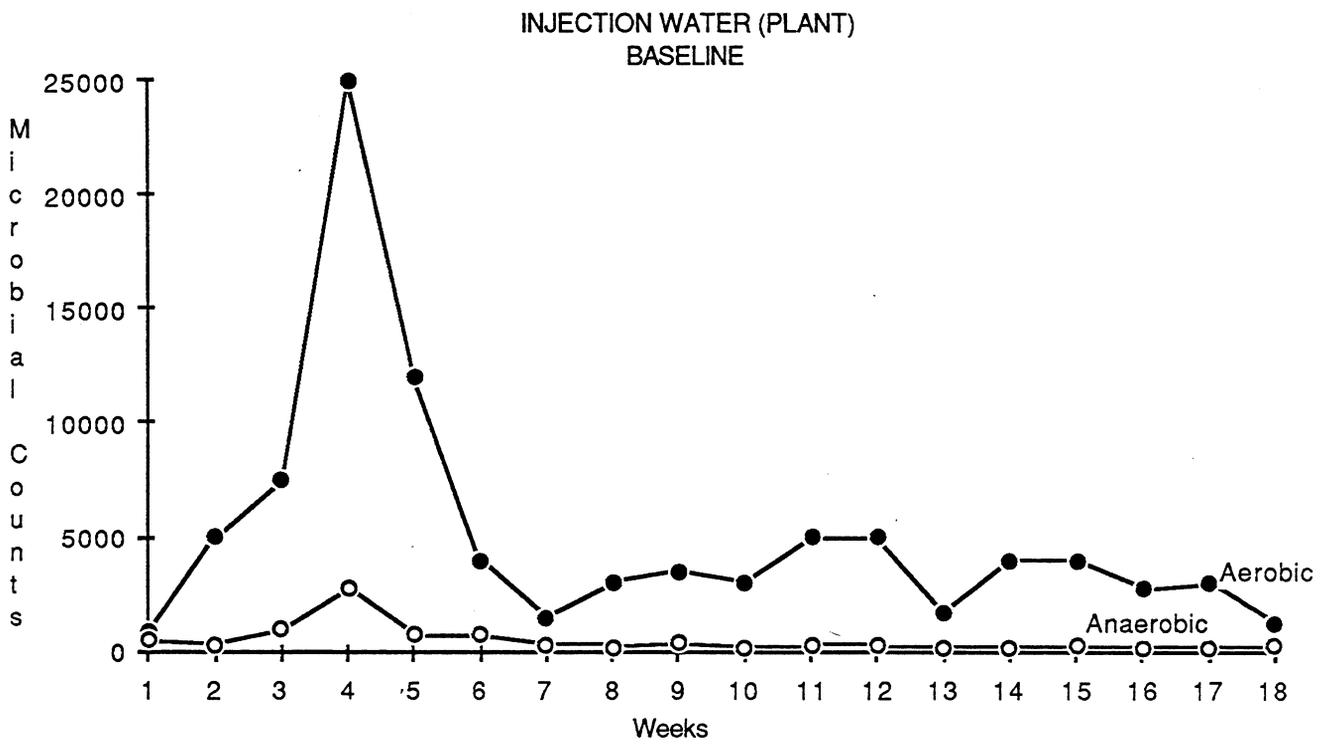


FIGURE 11. - Microbial counts - injection water (plant).

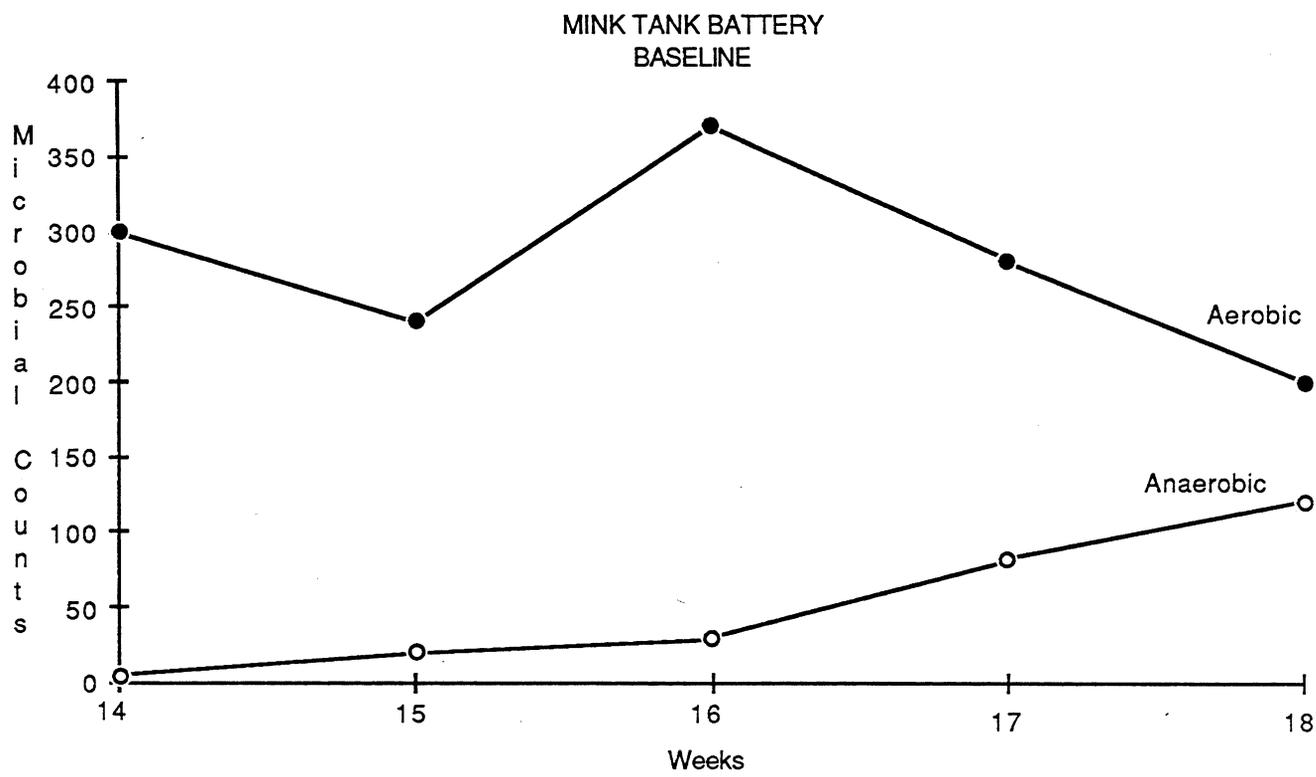


FIGURE 12. - Microbial counts - Mink Tank battery.

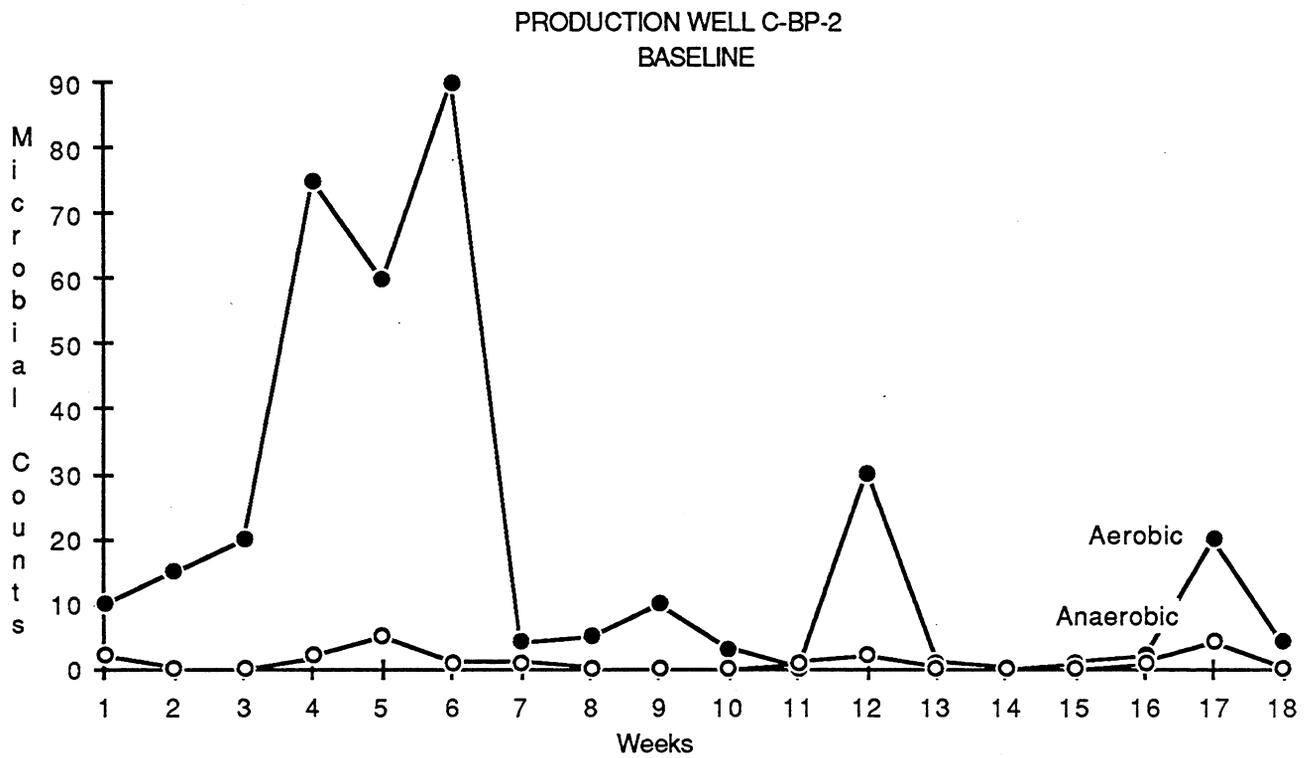


FIGURE 13. - Microbial counts - Production Well C-BP-2.

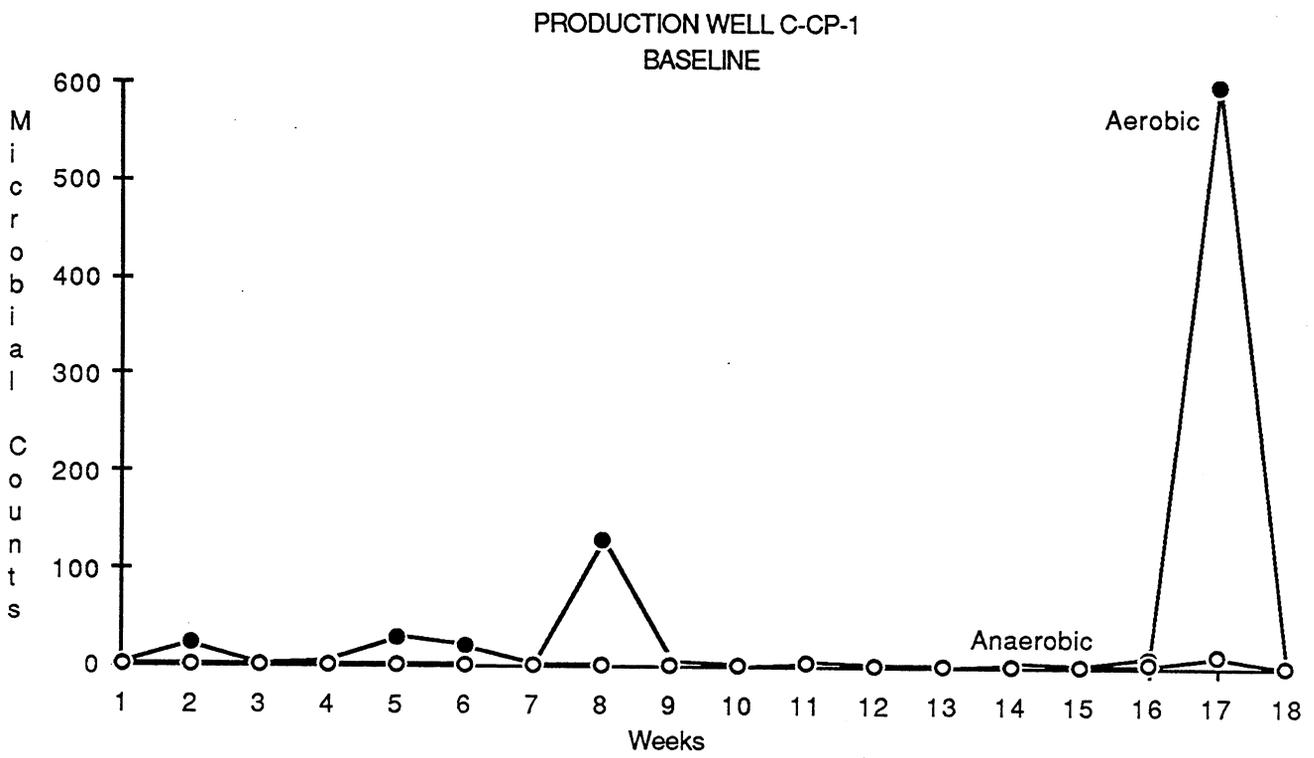


FIGURE 14. - Microbial counts - Production Well C-CP-1.

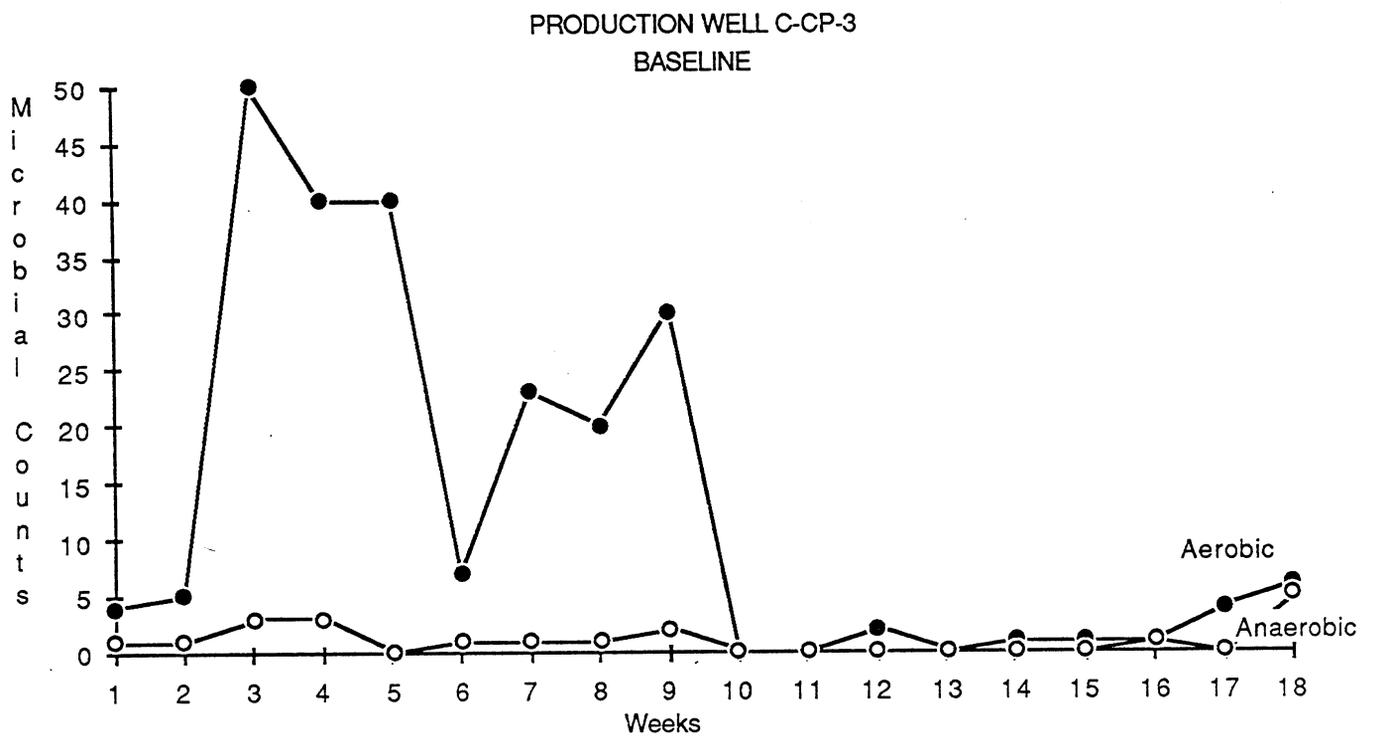


FIGURE 15. - Microbial counts - Production Well C-CP-3.

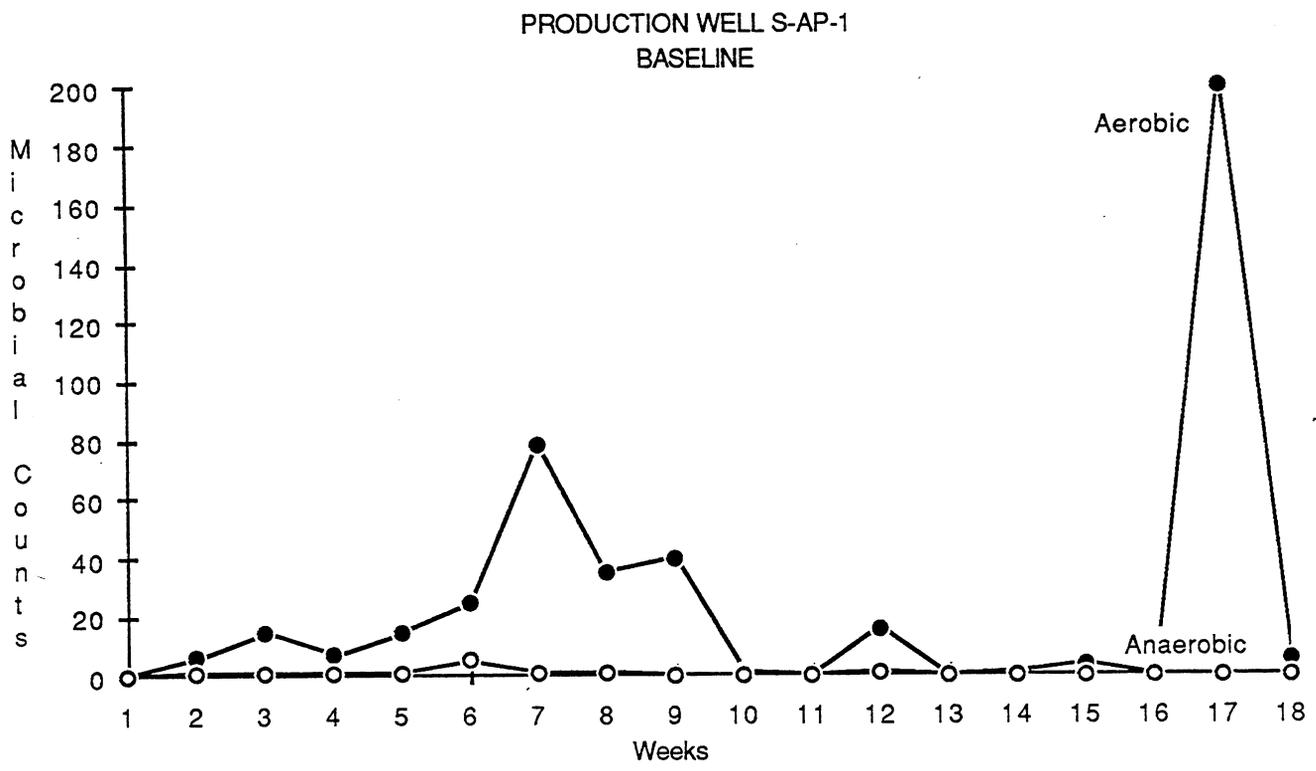


FIGURE 16. - Microbial counts - Production Well S-AP-1.

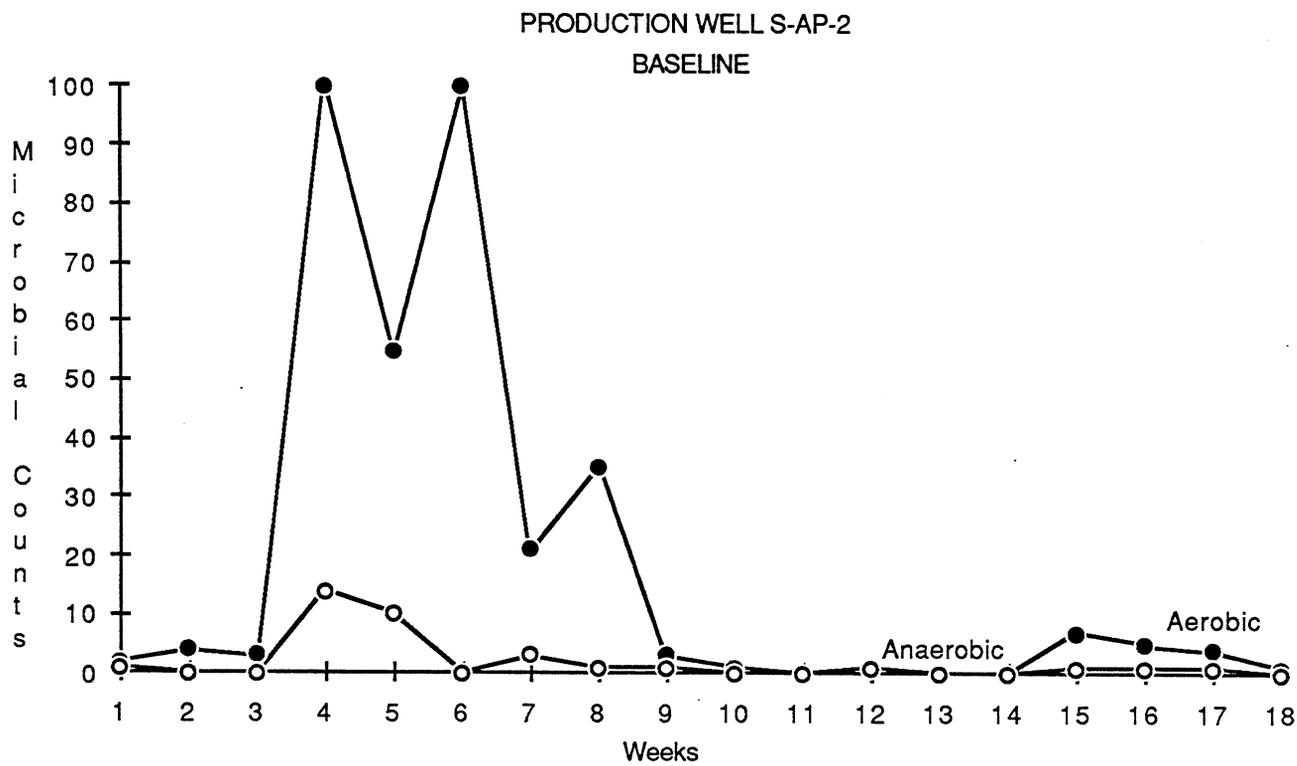


FIGURE 17. - Microbial counts - Production Well S-AP-2.

PRODUCTION WELL S-P47R
BASELINE

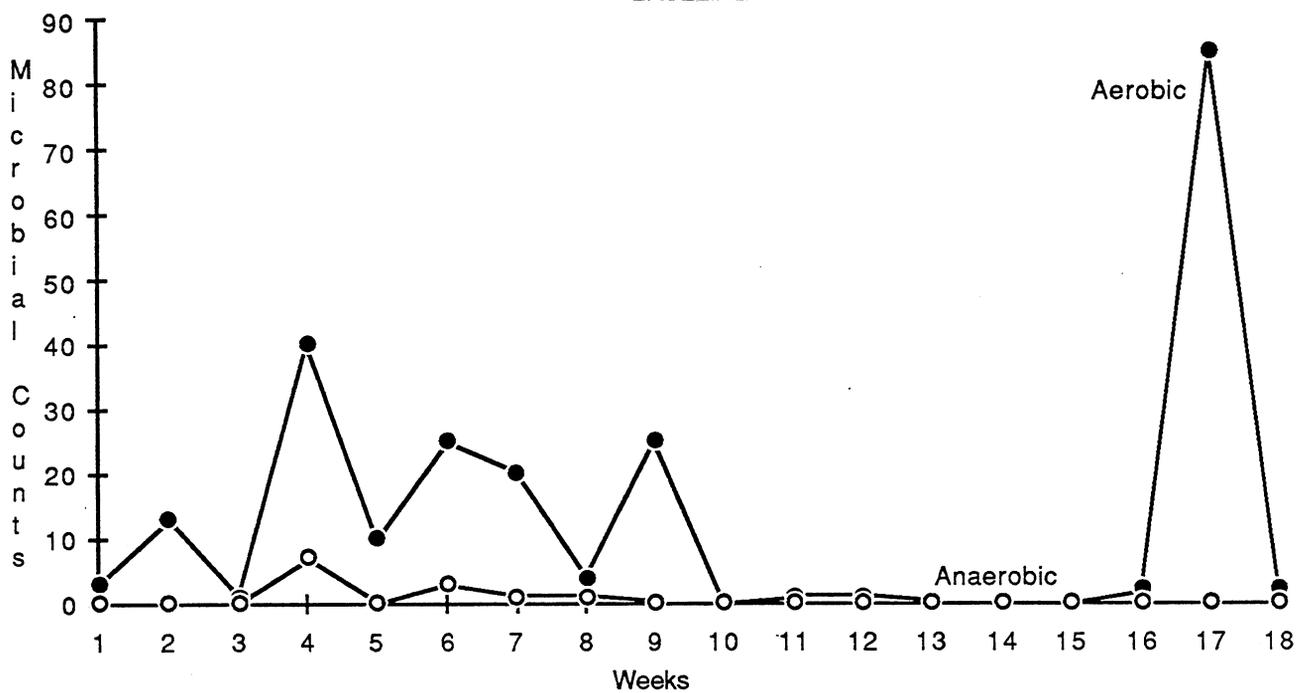


FIGURE 18. - Microbial counts - Production Well S-P47R.

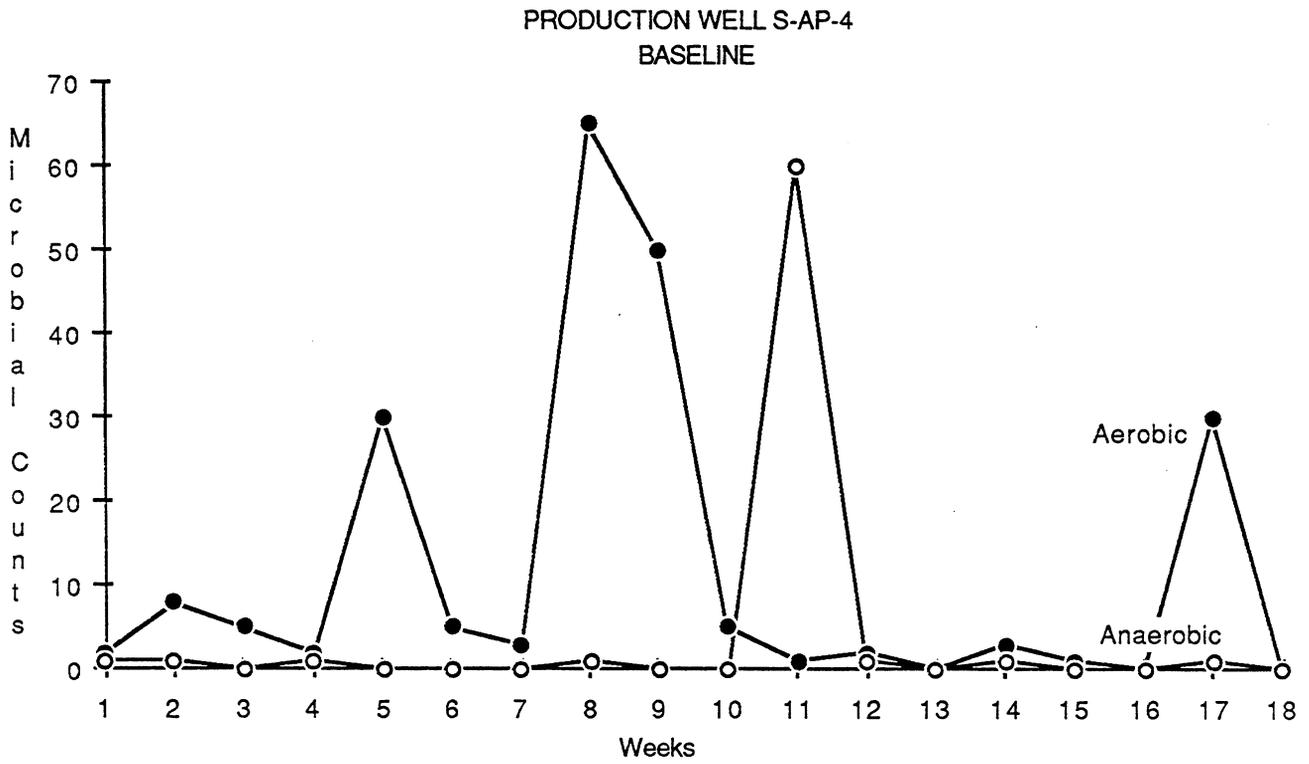


FIGURE 19. - Microbial counts - Production Well S-AP-4.

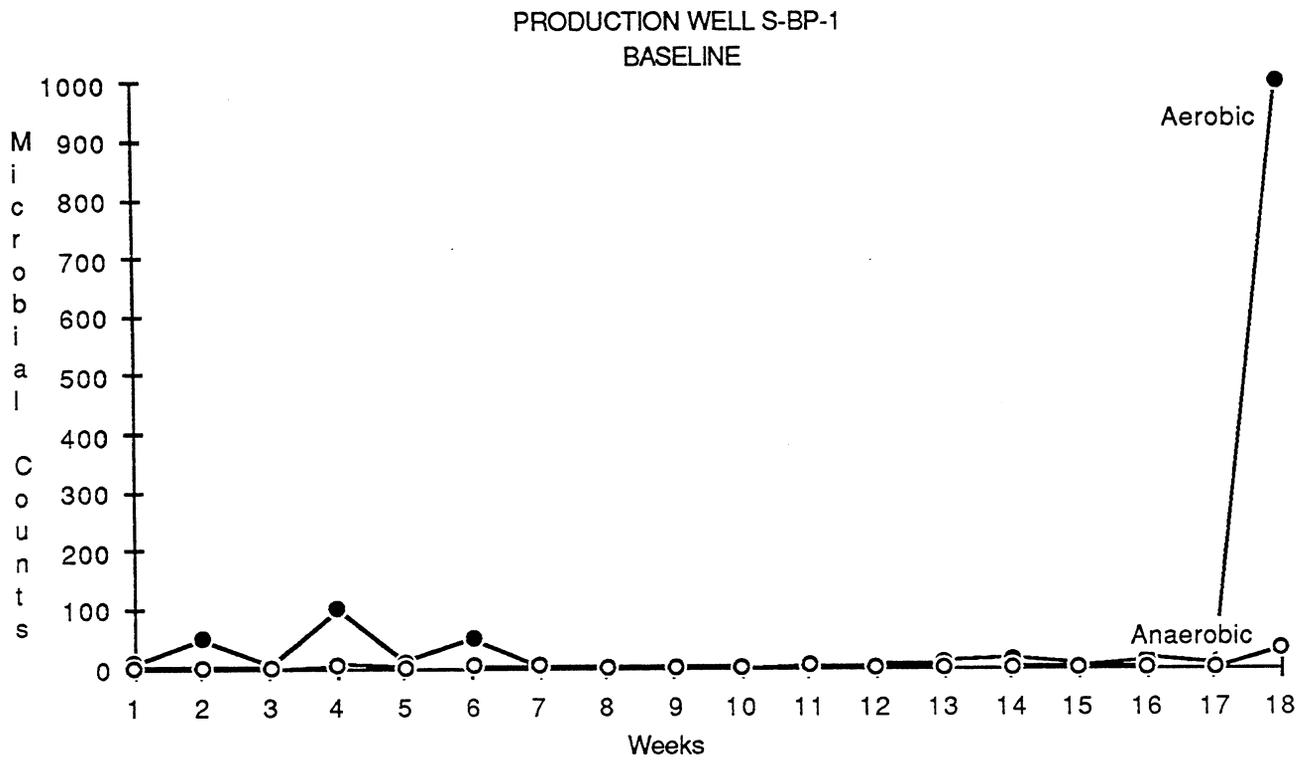


FIGURE 20. - Microbial counts - Production Well S-BP-1.

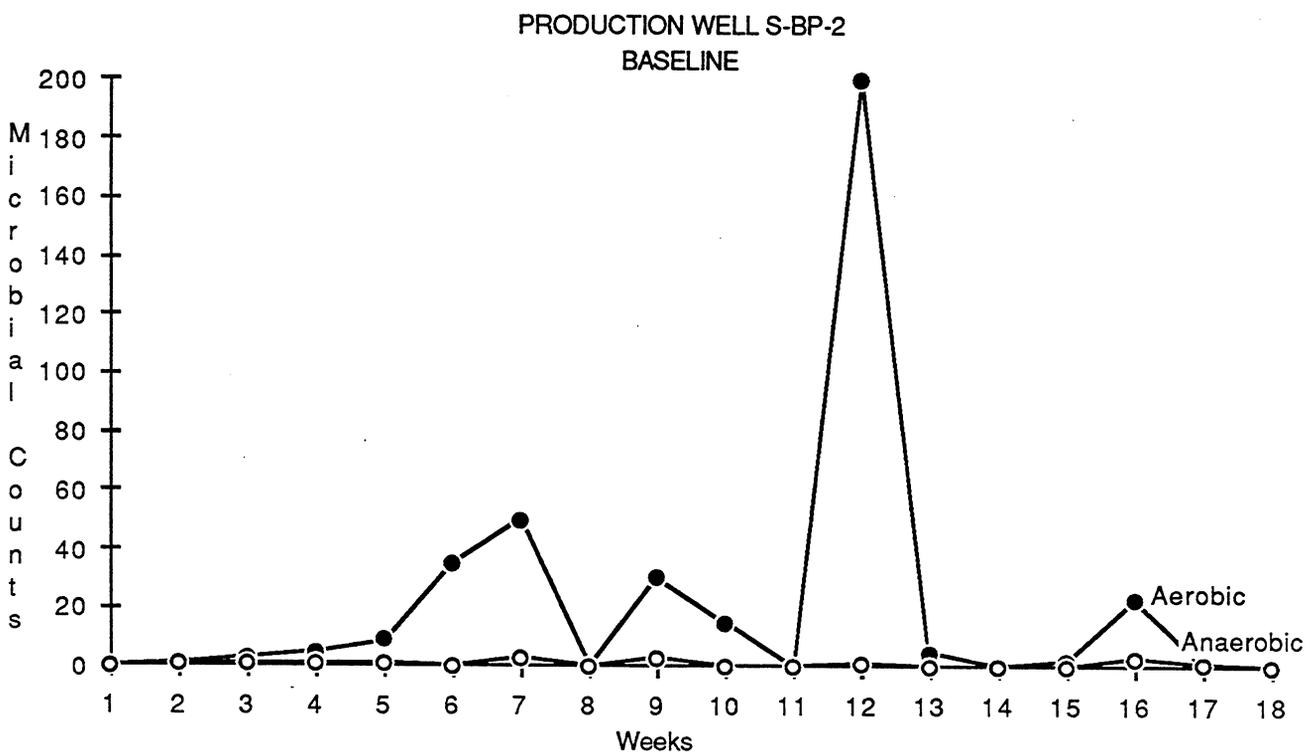


FIGURE 21. - Microbial counts - Production Well S-BP-2.

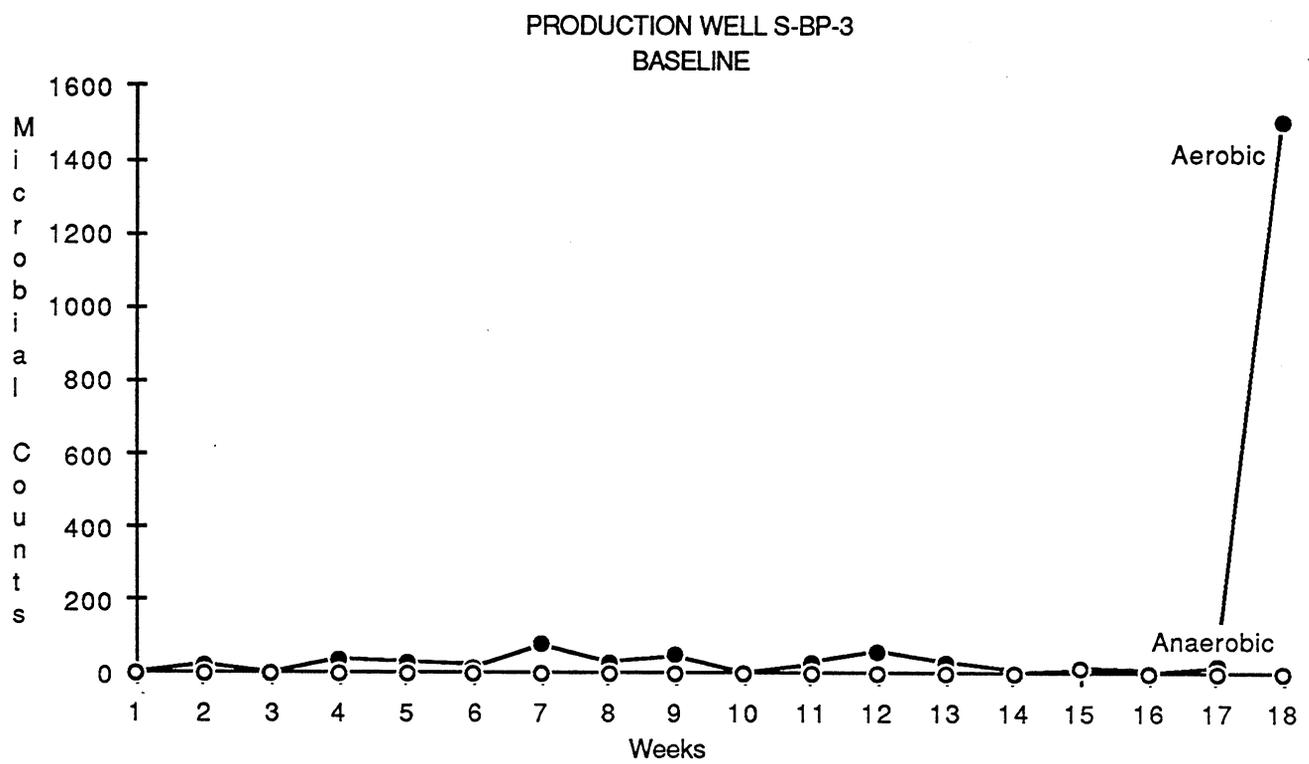


FIGURE 22. - Microbial counts - Production Well S-BP-3.

