MASTER

COO-4207-16
Dist. Category MTP

PILOT DEMONSTRATION - ENHANCED OIL RECOVERY

BY MICELLAR-POLYMER WATERFLOODING

BELL CREEK FIELD

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

**MONTHLY TECHNICAL PROGRESS REPORT
FOR OCTOBER 1977**

950 4383

**GARY OPERATING COMPANY
ENGLEWOOD, COLORADO 80110**

NOVEMBER 10, 1977

**PREPARED FOR THE UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION**

**UNDER CONTRACT NO. EF-77-C-02-4207
ORIGINALLY CONTRACT NO. E(49-18)-2237**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

EBB

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

BELL CREEK FIELD
MONTHLY TECHNICAL PROGRESS REPORT - 16
OCTOBER 1977

ABSTRACT

This is the sixteenth Monthly Technical Progress Report submitted under ERDA Contract No. EY-77-C-02-4207, formerly Contract No. E(49-18)-2237. As such, it continues the coverage of the activities undertaken by Gary Operating Company, as well as by the major subcontractors, Union Oil and Intercomp. The work described herein covers the tasks for: Micellar-Polymer Systems Selection and Evaluation, Site Development, Pilot Performance Predictions and Fluid Distribution Facilities.

This monthly report (COO-4207-16) continues the reporting serial sequence. The Annual Report (COO-4207-15) under this contract covered the work in the fifteen month period July 1976 - September 1977. Thus, the Annual Report, COO-4207-15, dated October 1977, also stands for the first quarter report of the second contract year and for the monthly report of the fifteenth month.

PHASE II - PRELIMINARY TEST PROGRAM

Task 1: Micellar-Polymer Systems Selection and Evaluation

Work Accomplished:

The results of the work in Phase II, Task 1, was that the Union Process was selected for final pilot design and additional work was specified as follows:

1) A long-core flood using a 16-foot Berea sandstone and the preliminary optimal design for the Uniflood Process to demonstrate that the overall process efficiency remains high at the longer flood path.

2) Comparative one-foot core floods using pilot test area reservoir fluids and the previously delivered preliminary optimal design for the Uniflood Process to determine the reason for the degradation in process performance between Berea and Bell Creek cores.

Laboratory tests on Item 1 are under way. Laboratory tests on Item 2 are also under way and some preliminary results are available. It appears that at least 35% of the decrease in process performance between 4' long Berea core tests and 1' long core tests with sequenced Bell Creek plug segments can be attributed to overall length effects and effects of segmentations. A statistical analysis is being conducted to determine the effects of vertical heterogeneity introduced by the sequencing of the Bell Creek plug segments into the 1' core. Also being investigated is the effect of moving fines which may be important in laboratory tests, but not in field scale process operation.

Work Forecast:

The additional work described in Items 1 and 2 above will be continued. GOC will have a minimum of 10 Bell Creek pilot plug relative permeability curves determined from which a maximum effective viscosity will be determined for the mobilized oil/water bank. The Union Process will be designed for this maximum effective viscosity.

PHASE II - PRELIMINARY TEST PROGRAM

Task 2: Site Development

Work Accomplished:

Log-Inject-Log tests were run on the two pilot injectors, MPP-1 and MPP-3, during July and August. The primary objective of these tests was to obtain an estimation of the in-situ ultimate residual oil saturation (S_{or}) to waterflood in the pilot area. In addition, the technique and logging tools used on MPP-1 had the possibility of yielding a departure curve that could subsequently be used to correct Schlumberger's TDT-K log for neutron diffusion effects in our wells.

The log-inject-log test on MPP-1 was performed without any major difficulties. Two types of pulsed neutron devices, Schlumberger's TDT-K and TDT-L, were used during the test. Comparison of the data from the TDT-K and TDT-L indicated that the neutron diffusion correction for the TDT-K was essentially a constant for our conditions. Examination of the results following the injection of the first brine slug indicated that either incomplete displacement of the fresh water had

occurred or that there had been a redistribution of fluids within the wellbore and adjacent formation following shut-in of injection. Therefore, a third step was performed in which additional brine was injected. In this step, the logging was performed during the last portion of the injection.

Analysis of results indicated an apparent average S_{or} of 30.5%.

The test on MPP-3 encountered a number of operational problems which may have influenced the resulting apparent S_{or} . Fortunately, none of the difficulties was due to the logging tool, a Dresser-Atlas Dual Neutron Lifetime Log. It performed quite well throughout the test. The difficulties included: cleaning out the well following the injection of fresh water (the logging tool would not go below the top of the slotted casing); a total loss of injectivity during the brine injection step and the subsequent swabbing down of the well in an attempt to recover it; and injection of the brine with a hot-oil truck at rates and pressures which were considerably higher than appropriate, according to test design. Analysis of results provides an apparent average S_{or} of 38%. This value is somewhat higher than would be expected by comparison with analogous numbers from core tests and open hole logs within the pilot area. It is possible that this result is due to incomplete displacement of fresh water by brine during the second injection step.

A detailed discussion of these tests is given in a memorandum attached here as Appendix I. This work was presented at the Technical Committee Meeting of October 13, 1977 with the S_{or} results from open hole logs, Table 1, $S_{or} = 26.3\%$, and from core tests, Table 2, $S_{or} = 30.2\%$.

Essentially this work indicates three values for S_{or} : $S_{or}^{core} \approx 25\%$; $S_{or}^{log} \approx 30\%$; and $S_{or}^{material\ balance} \approx 35\%$. The Technical Committee members recommended to the Operator that the Operator approach DOE for additional funds in order to drill an additional observation well(s) and take S_{or} data via the more advanced techniques of pressure core barrels and/or Exxon Single Well Tracer Test.

Injection of produced water into the pilot area has begun to complete floodout of the area and allow tracer surveys to be run. Injection is being handled through produced water injection facilities. The produced water injection facilities will be incorporated into the fluid injection system and plant facilities for the complete micellar process. This incorporation will allow the use of the produced water facilities throughout the process and into the drive water phase without further modification.

Work Forecast:

The tracer test will be initiated as indicated in Table 3. The letter proposal to DOE on S_{or} testing will be prepared and submitted.

PHASE III - ENGINEERING AND ANALYSIS

Task 1: Performance Prediction

Work Accomplished:

Intercomp completed a detailed geologic and fluid dynamic pattern containment study for the pilot area, Appendix II. From this analysis, a repeated 5-spot streamline pattern should be obtained in the pilot area from approximately equal injection rates into the MPP injection wells, and tracer breakthrough should occur within three to five months from time of injection.

Work Forecast:

The 8/24/77 Resolution of the Technical Committee called for additional work between Intercomp and Union in order to assure a physically reasonable and self-consistent description of the physico-chemical mechanics of the Union Process. This work is proceeding.

PHASE IV - DEMONSTRATION PROGRAM

Task 1: Fluid Distribution System Facilities

Work Accomplished and Forecast:

With the selection of the Uniflood process, final design work was begun on the fluid injection facilities. The preliminary design of fluid injection facilities submitted in Gary Operating Company's proposal was based in general on the Uniflood process, but minor design changes were necessary because of the final fluid characteristics.

The final injection plant design will be based on "batch mixing" of process fluids. One day volume of each fluid will be mixed prior to injection. This method of mixing and injection will allow more certain quality control of injected fluids and more certain control of injected volumes.

The final size and configuration of the building to house the fluid handling facilities has been made and the building specifications have been given to building suppliers for construction bids. Bids were received on October 28, 1977, and construction should begin the week of November 7, 1977. Building construction should be completed in six to eight weeks. Construction of piping and pump facilities inside the building will begin following completion of the building foundation.

Concurrent with the construction of plant facilities, tank and storage facilities for fluid handling will be installed. Storage will consist of six (6) 1000 barrel tanks and two (2) 300 or 400 barrel tanks. These tanks will be used for all fluid storage and mixing.

All producing wells in the pilot area have been placed on a production status and are being produced to complete floodout of the pilot area. Well testing and tank battery facilities are in operation.

APPENDIX I

M E M O R A N D U M

GARY OPERATING COMPANY

FOUR INVERNESS COURT EAST • ENGLEWOOD, COLORADO 80110 • 303/770-4710

TO: Fred
Arnold
FILE

DATE: October 18, 1977

FROM: Jay

RE: Log-Inject-Log Tests on
Micellar-Polymer Pilot
Injection on Wells
MPP-1 and MPP-3

INTRODUCTION

Log-Inject-Log tests were run on the two pilot injectors, MPP-1 and MPP-3, during July and August. The primary objective of these tests was to obtain an estimation of the in-situ ultimate residual oil saturation (S_{or}) to waterflood in the pilot area. In addition, the technique and logging tools used on MPP-1 had the possibility of yielding a departure curve that could subsequently be used to correct Schlumberger's TDT-K log for neutron diffusion effects in our wells. The test consisted of four basic steps: (1) inject produced water (fresh) into the well; (2) log the interval of interest with a pulsed-neutron tool; (3) inject a sodium chloride brine; and (4) run a second pulsed neutron log. Knowing the salinities of the two injected waters, the formation porosity and the logging tool response from the two runs the apparent residual oil saturation could be calculated from a simple equation relating these variables.

SUMMARY AND CONCLUSIONS

The log-inject-log test on MPP-1 was performed without any major difficulties. Two types of pulsed neutron devices, Schlumberger's TDT-K and TDT-L, were used during the test. Two days were lost due to a malfunction of the TDT-L equipment. However, no additional tool problems were encountered subsequent to its repair. Comparison of the data from the TDT-K and TDT-L indicated that the neutron diffusion correction for the TDT-K was essentially a constant for our conditions. Examination of the results following the injection of the first brine slug indicated that either incomplete displacement of the fresh water had occurred or that there had been a redistribution of fluids within the wellbore and adjacent formation following shut-in of injection. Therefore, a third step was performed in which additional brine was injected. In this step, the logging was performed during the last portion of the injection.

Analysis of results indicated an apparent average S_{or} of 30.5%.

The test on MPP-3 encountered a number of operational problems which may have influenced the resulting apparent S_{or} . Fortunately, none of the difficulties were due to the logging tool, a Dresser-Atlas Dual Neutron Lifetime Log. It performed quite well throughout the test. The difficulties included: cleaning out the well following the injection of fresh water (the logging tool would not go below the top of the slotted casing); a total loss of injectivity during the brine injection step and the subsequent swabbing down of the well in an attempt to recover it; and injection of the brine with a hot-oil truck at rates and pressures which were considerably higher than appropriate, according to test design. Analysis of results provides an apparent average S_{or} of 38%. This value is somewhat higher than would be expected by comparison with analogous numbers from core tests and open hole logs within the pilot area. It is possible that this result is due to incomplete displacement of fresh water by brine during the second injection step.

RECOMMENDATIONS

1. The logging during a log-inject-log type of test should be performed while injecting in order to assure that fluid drift or fluid redistribution within the wellbore does not effect the recorded values.
2. Log-inject-log tests should be complemented by an injection profile survey to assure that the injected fluid is indeed entering the formation as expected.

DISCUSSION

MPP-1

During the months of July and August, a log-inject-log test was performed on the pilot injector, MPP-1. The primary purpose of this test was to obtain an in-situ estimate of the ultimate residual oil saturation to waterflood in the pilot area. In addition, it was hoped that the procedure would permit the determination of a departure curve correction for our specific type of injection-well completion. Our first goal appears to have been achieved, since the measured saturations were within the expected range. However, the

data was such that no departure curves could be obtained.

Logging Equipment - MPP-1

Two Schlumberger pulsed neutron tools were used in the test on MPP-1. One, referred to as the TDT-K, is a continuous logging device common to the oil patch. The other is the seldom-seen stationary logging tool called the TDT-L. The 'K' tool is subject to inaccuracies due to both the statistical variation in readings common to all radioactive devices and also the phenomenon referred to as neutron diffusion. The effects of statistical variation may be minimized by making several logging passes during a run and subsequently averaging the data. Corrections for diffusion require departure curves for the particular type of well completion encountered by the tool. Since these curves were not available for our configuration, it was hoped we might be able to develop them as a by-product of this test. The TDT-L tool is not considered to be affected by either statistical variation or diffusion when properly used. However, it is considerably more difficult to run in that it must be supplied with a "first guess" at the decay time (τ), and must remain at the desired location for possibly as long as 30 minutes accumulating data. The tool is then moved to the next station (1-2 ft. up) and the process repeated. The data from each station is subjected to a curve-fitting type of analysis in order to determine the decay time. The capture cross section (Σ) used in the oil saturation calculation is directly proportional to τ . The "first guess" for the "L" tool at any depth is supplied by the reading from the previously-run TDT-K log.

Operations - MPP-1

Attachment 1 summarizes the operations during the test on MPP-1. A third inject-log sequence was added to the test when the analysis of data from the first two indicated that the fresh water had not been completely displaced by the brine during the second step. It is also conceivable that redistribution of the brine within the wellbore and adjacent formation could have occurred with the same result. Therefore, injection was continued at ~6 BPH during the last logging run in order to assure that this would not happen.

The initial failure of Schlumberger's TDT-L equipment required that they return to Casper to facilitate repairs. No additional equipment problems were encountered during the remainder of the test. A second run of the TDT-K (Run 2) following the injection of fresh water was deemed prudent since there had been a two day delay following shut-in. Runs 1 and 2 of the TDT-K were almost identical; therefore, it appeared no error would be introduced by the delay. At the time of the last logging run (Run 4), the TDT-L equipment was not available for our use. There is only one set of this equipment in existence. Therefore, it must be scheduled far in advance of the date when it is required. In addition, it is quite expensive and, therefore, it is inadvisable to keep it on standby. In our case, it was judged from the results of Runs 2 and 3 that the TDT-K would give satisfactory results.

Analysis of Data - MPP-1

Data from Runs 2 and 4 of the TDT-K were used in the calculation of apparent S_{or} for MPP-1. This data, which is the average of five logging passes for each of the runs is shown in Table 1. Also included are the data from the TDT-L runs. The difference in the readings from the 'K' and 'L' tools which would be the "corrections" necessary for the 'K' log readings, are shown in Table 2. An attempt was made to determine a departure curve for the TDT-K by plotting this difference vs. the 'K' readings. However, it was not successful. The scatter in the data made any best-fit approach seem of little value. Therefore, an average value for the "correction" in the net pay interval was determined. These averages for Runs 2 and 3, which are shown in Table 2 were almost identical. The implication is that the "correction" for our type of completion is essentially a constant and not a function of brine concentration. If this value is a constant, it drops out of the equation from which oil saturation is calculated. Therefore, TDT-K readings may be used without correction for diffusion effects. The apparent residual oil saturations which result from this data are included in Table 3. The two lowest S_{or} values were averaged to obtain a representative number for this test. Figure 1 shows the gamma ray curve, the averaged Σ curves for Runs 2 and 4, and the configuration of the well completion.

MPP-3

A log-inject-log test was performed on the southeast pilot injector MPP-3 during August. Dresser-Atlas Dual Neutron Lifetime Log, a pulsed neutron device, was used in this attempt to provide a second and confirming value for S_{or} in the pilot area. Unfortunately, operational problems encountered during the second injection step may have resulted in the incomplete displacement of the fresh water by the brine. If this did indeed occur, the resulting data would indicate a higher S_{or} than actually present in the formation. As will be discussed, the apparent S_{or} values from this test are somewhat greater than expected.

Logging Equipment - MPP-3

The Dual Neutron Lifetime Log (NLL) is a continuous logging device similar to Schlumberger's TDT-K. However, according to Dresser-Atlas, it does not require any correction for neutron diffusion effects. Like the TDT-K readings, its readings are subject to statistical error and an averaging technique employing data from several passes across the interval of interest should be used to improve their accuracy. Comparison of the log curves obtained before and after injection of brine would appear to indicate that no diffusion correction is necessary. However, as previously discussed, the S_{or} calculation involving the subtraction of the capture cross sections before and after brine injection tends to minimize the effects of any correction which might be required.

Operations - MPP-3

Attachment 2 summarizes the operations during the test on MPP-3. Since this well had been cleaned out only six weeks earlier and had been inactive during the interim, the difficulty caused by fill-up was indeed a surprise. The real problem arose with the loss of injectivity experienced during the brine injection step. It was hoped that swabbing the well down to the top of the slotted casing would allow it to back flow and clean up the damage apparently caused by the drilling mud which had previously been cleaned out with the sand pump. This did not occur. In addition, any attempts to recover the well's former injectivity through the use of chemical washes would have undoubtedly destroyed the validity of the log-inject-log test. Since the major part of the test's cost had already been incurred, it was decided to try to salvage the test by simply injecting the brine at a higher pressure, mechanically breaking

down the flow barrier. The injection went as expected with the wellhead pressure reaching 1500 psig before the well began taking any significant amount of water. Since the formation parting pressure is approximately 2300 psig (surface pressure) in Unit 'A', it is not likely that any fracturing occurred during the brine injection process. In addition, an injection profile run subsequent to the second NLL indicated that the brine was not moving into the formation either above or below the slotted portion of the casing. As shown in Figure 2, the slotted casing is positioned across the net pay interval of the well.

Analysis of Data - MPP-3

The analysis of the log data from Runs 1 and 2 of Dresser's NLL was quite straightforward. Unfortunately, unlike Schlumberger, Dresser-Atlas did not have a computer program available to average the readings from a number of logging passes during a run. Therefore, a hand calculation of the average capture cross section across an interval of interest was required. These data are shown in Table 4. The results of the averaging process are included in Table 5 along with effective porosities from the sonic log. Table 5 lists the apparent residual oil saturations from the test. The most appropriate average S_{or} for the test was considered to be that which would result from values bracketing the best part of the pay. This average of 38% is higher than would be expected in light of all the additional Unit 'A' S_{or} data available from other sources. One explanation for this value would be the incomplete displacement of the fresh water by brine during the second injection step. It is easy to conceive of a number of ways in which this result might have occurred during this trouble-plagued test. Perhaps the most likely is that only a small portion of the slotted casing was open during the injection, resulting in incomplete displacement of fresh water near the wellbore. Since pulsed neutron logging tools measure only about one foot radially from the wellbore, this would have a significant effect on the values for capture cross section.

Figure 2 is a graphic presentation of the averaged data for Runs 1 and 2. The gamma ray curve and well completion are also shown. Perhaps the most interesting feature of the Σ curves is their separation in the uncemented section above

Memorandum to Fred, Arnold, FILE
October 18, 1977
Page 7

what is considered to be the gross sand interval in this well. Reference to Figure 1 shows that this did not occur in the test on MPP-1. Only 47% of the cored interval was recovered in MPP-1. This recovery did not include any portion of the suspected non-pay interval. However, by analogy with MPP-5, in which a substantial portion was recovered, this zone appears to be a non-porous siltstone or shale. This is supported by the gamma ray response opposite this interval. It is possible that considerable caving or movement of the shale has occurred in this section, resulting in the formation of some secondary porosity adjacent to the wellbore. The separation of the Σ curves could therefore reflect the displacement of the fresh water by brine within this interval.

JV/eg
Attachments

TABLE 1
LOG-INJECT-LOG TEST DATA ON MPP-1

Depth (TDT-K)	TDT-K (Run 2) Σ (c.u.)	TDT-L (Run 2) Σ (c.u.)	TDT-K (Run 3) Σ (c.u.)	TDT-L (Run 3) Σ (c.u.)	TDT-K (Run 4) Σ (c.u.)
4635			26.0	23.8	27.3
4636			24.2	21.0	25.0
4637	24.0	21.0	23.5	21.5	24.3
4638	23.0	18.4	22.5	18.4	23.0
4639	22.5	17.5	22.2	17.7	23.0
4640	23.5	19.3	23.5	19.3	24.5
4641	24.5	20.9	24.5	21.3	26.5
4642	24.0	22.0	24.5	22.5	28.0
4643	21.0	18.9	23.5	19.8	29.8
4644	18.5	15.5	21.2	17.1	30.0
4645	18.0	15.1	20.0	16.9	29.0
4646	18.5	15.5	19.5	16.4	27.3
4647	18.7	15.1	19.2	15.7	24.0
4648	19.7	14.0	19.0	14.3	20.5
4649	22.0	15.1	21.0	15.8	21.3
4650	25.6	18.6	23.5	19.5	23.5
4651	28.0	21.1	26.0	20.7	26.0
4652	31.0	22.3			

$$\Sigma_{wf} = 22.6 \text{ c.u. (Run 1 and 2)}$$

$$\Sigma_{ws} = 72.2 \text{ c.u. (Run 3)}$$

$$\Sigma_{ws} = 73.5 \text{ c.u. (Run 4)}$$

$$\text{c.u.} = \text{capture units } (10^{-3} \text{ cm}^2/\text{cm}^3)$$

TABLE 2
DETERMINATION OF DIFFUSION
CORRECTION FOR TDT-K

Depth	Run 2		Run 3		
	$\Delta\Sigma^{(1)}$ (c.u.)	$\overline{\Delta\Sigma}$ (c.u.)	$\Delta\Sigma^{(1)}$ (c.u.)	$\overline{\Delta\Sigma}$ (c.u.)	
4635			2.2		
4636			3.2		
4637	3.0		2.0		
4638	4.6		4.1		
4639	5.0		4.5		
4640	4.2		4.2		
4641	3.6		3.2		
4642	2.0		3.2		
4643	2.1		3.7		
4644	3.0		4.1		
4645	2.9	3.65	3.1	3.67	NET PAY
4646	3.0		3.1		
4647	3.6		3.5		
4648	5.7		4.7		
4649	6.9		5.2		
4650	7.0		4.0		
4651	6.9		5.3		
4652	8.7				

$$(1) \quad \Delta\Sigma = \Sigma_{\text{TDT-K}} - \Sigma_{\text{TDT-L}}$$

TABLE 3

APPARENT S_{or} FROM LOG-INJECT-LOG TEST ON MPP-1

Depth	$\frac{\Sigma_{fs} - \Sigma_{ff}}{(c.u.)}$	ϕ^* (%)	Apparent S_{or} (%)
4640	1.0	0	
4641	2.0	0	
4642	4.0	23.7	67
4643	8.8	29	40
4644	11.5	32	29
4645	11.0	32	32
4646	8.8	32	46
4647	5.3	31.7	67
4648	0.8	28	94
4649	-0.7	23.3	100
4650	-2.1	0	
4651	-2.0	0	

$$S_{or} = 1 - \frac{\Sigma_{fs} - \Sigma_{ff}}{\phi(\Sigma_{ws} - \Sigma_{wf})} \quad \text{Avg. } S_{or} = \frac{29+32}{2} = 30.5\%$$

$$\Sigma_{ws} = 73.5; \quad \Sigma_{wf} = 22.6$$

* ϕ_e = Effective porosity from sonic log and Δt vs. core ϕ correlation

Σ_{ws} = capture cross section of brine

Σ_{wf} = capture cross section of fresh water

Σ_{fs} = capture cross section of formation with brine

Σ_{ff} = capture cross section of formation with fresh water

TABLE 5

APPARENT S_{or} FROM LOG-INJECT-LOG TEST ON MPP-3

Depth	Σ_{fs} (c.u.)	Σ_{ff} (c.u.)	$\Sigma_{fs} - \Sigma_{ff}$ (c.u.)	ϕ_e^* (%)	Apparent S_{or} (%)	Net Pay	Gross Sand
4586	21.4	21.1	0.3	0			
4586	21.7	21.1	0.6	0			
4590	22.8	21.2	1.6	0			
4592	24.4	22.5	1.9	0			
4594	25.3	23.1	2.2	0			
4596	26.1	22.2	3.9	0			
4598	27.0	22.5	4.5	23.3			
4600	24.8	19.9	4.9	20	51		
4602	25.2	18.3	6.9	22	37		
4604	27.3	19.1	8.2	23.3	30		
4606	26.5	18.0	8.5	28.3	40	Net Pay	Gross Sand
4608	24.9	17.3	7.6	26.7	43		
4610	25.3	19.9	5.4	21.7	50		
4612	27.6	27.1	0.5	19.3	95		
4614	29.8	29.3	0.5	23.3			
4616	29.3	28.7	0.6	0			
4618	29.7	29.3	0.4	0			
4620	29.8	30.5	-0.7	0			

$$\text{Avg. } S_{or} = (30 + 40 + 43)/3 = 38\%$$

$$S_{or} = 1 - \frac{\Sigma_{fs} - \Sigma_{ff}}{\phi(\Sigma_{ws} - \Sigma_{wf})}$$

$$\Sigma_{ws} = 72 \quad (132,000 \text{ ppm})$$

$$\Sigma_{wf} = 22$$

Equivalent NaCl conc. of brine samples

$$(130,239 + 133,537)/2 = 131,888$$

* ϕ_e = Effective porosity from sonic log and Δt vs. core ϕ
correlation $\phi = (\Delta t - 60)/1.5$

TABLE 4

AVERAGE Σ VALUES RUNS 1 & 2 LOG-INJECT-LOG TEST MPP-3

FROM DUAL NEUTRON LIFETIME LOG

 Σ (c.u.) Run 1 (Fresh Water)

<u>Depth</u>	<u>Pass #1</u>	<u>Pass #2</u>	<u>Pass #3</u>	<u>Pass #4</u>	<u>Pass #5*</u>	<u>Average</u>
4586	21.5	20.5	20.5	21.5	21.5	21.1
4588	20.5	21.5	20.5	21.5	21.5	21.1
4590	21.0	21.0	21.0	21.5	21.5	21.2
4592	22.5	22.5	22.5	22.5	22.5	22.5
4594	23.0	23.5	23.5	22.0	23.5	23.1
4596	22.0	22.0	23.0	21.5	22.5	22.2
4598	23.0	21.5	23.0	22.5	22.5	22.5
4600	20.0	20.0	20.0	20.0	19.5	19.9
4602	18.5	18.0	17.5	18.5	19.0	18.3
4604	19.0	18.5	18.0	20.0	20.0	19.1
4606	18.0	17.5	18.0	18.5	18.0	18.0
4608	17.5	17.0	17.0	17.0	18.0	17.3
4610	20.0	21.0	19.5	19.0	20.0	19.9
4612	27.5	28.0	26.0	26.0	28.0	27.1
4614	29.5	30.0	30.0	28.0	29.0	29.3
4616	29.5	28.5	29.0	29.0	27.5	28.7
4618	29.0	28.0	29.5	31.0	29.0	29.3
4620	29.0	30.0	29.5	32.0	32.0	30.5

 Σ (c.u.) Run 2 (Brine)

<u>Depth</u>	<u>Pass #1</u>	<u>Pass #2</u>	<u>Pass #3</u>	<u>Pass #4</u>	<u>Pass #5*</u>	<u>Average</u>
4586	21.5	22.0	21.0	21.5	21.0	21.4
4588	21.5	22.0	21.5	21.0	22.5	21.7
4590	22.5	23.5	22.0	23.0	23.0	22.8
4592	24.5	24.5	25.0	24.0	24.0	24.4
4594	25.5	25.5	26.5	24.0	25.0	25.3
4596	26.0	25.5	26.5	26.0	26.5	26.1
4598	28.0	26.5	26.5	27.0	27.0	27.0
4600	25.5	24.5	24.0	25.0	25.0	24.8
4602	25.0	25.5	25.0	25.0	25.5	25.2
4604	27.0	28.0	27.5	27.0	27.0	27.3
4606	26.5	27.5	27.0	25.5	26.0	26.5
4608	24.5	25.0	26.5	24.0	24.5	24.9
4610	24.5	25.5	27.0	24.0	25.5	25.3
4612	26.0	28.0	28.0	27.0	29.0	27.6
4614	28.5	29.5	31.5	29.0	30.5	29.8
4616	28.0	30.0	30.0	29.5	29.0	29.3
4618	30.0	29.5	28.5	31.0	29.5	29.7
4620	30.5	30.0	28.0	31.0	29.5	29.8

*Repeat section recorded on first logging pass during run.

FIGURE 1
MPP-1
LOG-INJECT-LOG TEST RESULTS FROM
TDT-K LOG

PC = Port Collar
PJ = Pup Joint
SC = Slotted Casing
ECP = External Casing Packer

FIGURE 2

MPP-3

LOG-INJECT-LOG TEST RESULTS FROM

DUEL NEUTRON LIFETIME LOG

PC = Port Collar
 PJ = Pup Joint
 SC = Slotted Casing
 ECP = External Casing Packer

ATTACHMENT 1

Summary of Operations During Log-Inject-Log
Test on MPP-1

(July and August, 1977)

Prior to the start of the test a 400 BBL frac tank was moved to the location and loaded with approximately 300 BBL of produced water from the Section 12 battery. A transfer pump, filter pot and Floco flow meter were connected to the tank, such that the tank's contents could be pumped down the well at a prescribed rate.

- 7-26-77 Begin injection of produced water at ~ 6 BBL/hr.
- 7-27-77 Complete first injection step (~ 150 BBL of produced formation water) and begin logging with Schlumberger TDT-K and TDT-L. Made five logging passes across interval of interest with TDT-K. TDT-L equipment failed and Schlumberger returned to Casper to repair same. Haliburton mixed 8,000# NaCl into ~ 150 BBL of water remaining in tank.
- 7-29-77 Schlumberger on location to log. Ran TDT-K tool; made five passes from TD to 7500. Ran TDT-L tool from 4052-4637; 16 stations; tool appeared to operate properly. Begin injection of brine at ~ 4 BPH.
- 7-30-77 Injecting brine.
- 8-1-77 Complete brine injection (~130 BBL) and third set of logs. Schlumberger TDT-K ran from TD to 4500, five passes. Ran TDT-L from 4652 to 4636; 17 stations. Logging equipment appeared to operate properly.
- 8-13-77 Dowell Mixed 16,000# NaCl into ~ 300 BBL of produced water from Section 12 battery. Ran Schlumberger tracer survey while injecting brine at ~ 6 BPH. Survey indicated all injection going into pay; no apparent losses above or below pay.
- 8-14-77 Injecting brine at ~ 6 BPH.
- 8-15-77 Continue to inject brine at ~ 6 BPH while running TDT-K log from TD to 4550. Made five passes across interval. Log values indicate this test may be successful.

ATTACHMENT 2

Summary of Operations During Log-Inject-Log Test on MPP-3

(August 1977)

Prior to the initiation of this test a 400 BBL frac tank was moved to the location and filled with produced water from Section 12 battery. Installation of a transfer pump, filter and Floco meter were completed so that a specified injection rate could be maintained into the well.

- 8-23-77 Begin injecting fresh water at ~ 6 BPH.
- 8-24-77 Complete injection of fresh water (~ 150 BBL). Hailburton mixed 16,000# NaCl into ~ 300 BBL produced water. Attempt to run Dresser Atlas Dual Neutron Lifetime Log. Could not get below 4600'. Sent D.A. back to Gillette. MIRUDDPU. Clean out to ~ 4640' with sand pump, fillup appears to be drilling mud. SDON.
- 8-25-77 No additional fillup over night, clean out to 4670' with sand pump. Ran Dresser NLL from TD to 4400', made five logging passes. Attempted to inject brine. Could not inject at 100 psig surface pressure, which was limit of filter pot and transfer pump capabilities. Swabbed well down to ~ 1000' KB. SDON.
- 8-26-77 No fluid entry over night. Swabbed well down to perf. SDON.
- 8-27-77 250' fluid entry over night. Swabbed well down to perf. Tagged bottom and checked TD with sinker bar. No fillup. RDMODDPU. Loaded hole with 20 BBL brine from tank. Could not pump into well with transfer pump. SDON.
- 8-28-77 Pumped into well at ~ 1/4 BPM using hot oiler. Broke down at ~ 1500 psig. Pumped ~ 110 BBL final wellhead pressure 1000 psig. Hooked up transfer pump. Pumped brine at ~ 4 BPH.
- 8-29-77 Pumped ~ 120 BBL since starting transfer pump. Continued to pump at ~ 4 BPH while Dresser ran second NLL from TD to 4500'. Made five passes with logging tool. SDON.
- 8-30-77 Ran Dresser Atlas Fluid Flow Tracer survey while injecting brine with transfer pump. Logged from 4700' to 4500'. Survey indicated no fluid loss above or below pay interval.

APPENDIX II

40-ACRE PILOT

PATTERN CONTAINMENT AND TRACER STUDIES

I. FACIES DISTRIBUTION

- A. Characteristics of Barrier Bar/Lagoonal Facies
- B. Areal Limits of Distinct Facies

II. PATTERN CONTAINMENT

- A. Elements of Symmetry
- B. Specify Flow Field
- C. Single Phase Model
- D. Homogeneous Case
- E. Areal Variations in ϕ , k , h and Surrounding Active Wells
- F. Conclusion: 40-Acre Pilot Can Be Made "Fully Confined" By Specifying Flow Field.

III. PRELIMINARY TRACER STUDIES

- A. Tracer Injection Into MPP-3
- B. Specify Flow Field
- C. Areal Variations in ϕ , k , and h
- D. Stratification Effect Included
- E. Results:

	<u>No Stratification</u>		<u>With Stratification</u>	
	<u>190 Days</u>	<u>260 Days</u>	<u>70 Days</u>	<u>140 days</u>
C_o	19,000 ppm		19,000 ppm	
C/Co	7×10^{-4}	3.3×10^{-3}	1×10^{-4}	2×10^{-3}
C	13 ppm	63 ppm	2 ppm	38 ppm

- F. Conclusion: Breakthrough of Tracers In Detectable Concentrations Should Occur In 3 To 5 Months

TABLE 1
SUMMARY OF ULTIMATE RESIDUAL OIL SATURATION
TO WATERFLOOD FROM CORE TESTS

<u>WELL</u>	<u>UNIT</u>	<u>DEPTH (ft)</u>	<u>Sor (%)</u>
MPP-1 (1)	A	4648-4649	23
MPP-2 (2)	A	4646-4647	28
#22-9	A	(3)	33.5
#23-1	A	4645-4646	22.8
#27-3	A	(4)	34.4
#4-2	C	(5)	30.4
#12-1	D	4702-4703	31.1
#12-8	D	4722-4723	40.2
#27-3	Ranch Creek	(6)	28.4

- (1) Composite of 2 core plugs
- (2) Composite of 4 core plugs
- (3) Average of 6 samples
- (4) Average of 3 samples
- (5) Average of 8 samples
- (6) Average of 5 samples

TABLE 2
RESIDUAL OIL SATURATION
FROM OPEN HOLE LOGS, MPP WELLS

<u>WELL</u>	<u>DEPTH (ft)</u>	<u>$\phi_{\Delta t}$ (1) (%)</u>	<u>S_{xo} (2) (%)</u>	<u>ROS (3) (%)</u>
MPP-1	4643-4650	31	67	33
MPP-2	4710-4718	31.5	65.5	34.5
MPP-3	4606-4610	29	82	18
MPP-4	4684-4690	30	73	27
MPP-5	4674-4683	31	81	19
AVERAGE				26.3

(1) Porosity determined using sonic Δt and core porosity correlation

(2) Saturation determined using readings from Micro-Spherically Focused Log and resistivity of mud-filtrate

(3) $ROS = 1 - S_{xo}$

TABLE 3
TRACERS FOR MPP INJECTORS

<u>WELL</u>	<u>TRACER</u>	<u>AMOUNT INJECTED</u>	<u>DETECTABLE CONCENTRATION</u>
MPP-1	Co ⁶⁰	0.05 curies	.02 pc/ml
MPP-2	Tr	20.0 curies	2.0 pc/ml
MPP-3	NO ₃	2000 lb.	0.1 ppm
	(Co ⁵⁸	0.2 curies	0.02 pc/ml)
	(S ³⁵	0.2 curies)	
MPP-4	Co ⁵⁷	0.025 curies	0.025 pc/ml