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AEDC SURFACTANT EOR TREATMENT

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ABSTRACT

A surfactant flood consisting of a series of water and water/surfactant slugs was implemented for enhanced oil recovery at the Naval Petroleum Reserve No. 3 (NPR-3). The project in the Shannon Sandstone Member of the Upper Cretaceous Steele Formation was a joint test between American Energy Development Corporation (AEDC) and the Rocky Mountain Oilfield Testing Center (RMOTC) to test AEDC's ERA-3 chemical. ERA-3 had previously been shown to be effective for cyclic stimulation of oil wells at NPR-3.

The injections alternated weekly between the two injection wells and consisted of three phases: water injection, surfactant injection, and water injection to displace the surfactant into the reservoir. A total of 4,605 bbls of fluid was injected during the 122-day injection sequence. The injected volume was only one-thousandth of the pore volume in the treatment area.

No significant increase in oil production was observed. However, around Day 64, the oil/water ratio for both down-structure producers began to increase. The cause for the increase appears to be a decrease in the water production and not an increase in the oil production. Despite the negligible change in oil production and small injection volume, the surfactant did change the character of the production in a positive manner by reducing water production.

A third party conducted resistivity mapping of the project area during the test that indicated subtle changes in the fluid characteristics and migration direction. This indicates that either the injection volume was too small or that additional time was necessary for the effect of the surfactant to be observed.

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EXECUTIVE SUMMARY

American Energy Development Corporation (AEDC) and the Rocky Mountain Oilfield Testing Center (RMOTC) jointly conducted a test of AEDC's ERA-3 chemical in a surfactant flood of the Shannon Sandstone Member. A surfactant flood consisting of a series of water and water/surfactant slugs was implemented for enhanced oil recovery (EOR). The project was located at the Naval Petroleum Reserve No. 3 (NPR-3), and occurred in the Shannon Sandstone Member of the Upper Cretaceous Steele Formation.

The objective was to demonstrate AEDC's ERA-3 chemical as an EOR flood surfactant. ERA-3 had previously been shown to be effective for cyclic stimulation of oil wells at NPR-3.

The injections alternated weekly between the two injection wells for four weeks of water, followed by nine weeks of a surfactant mix, then pushed by five more weeks of water injection. For the injections, a total of 4,605 bbls of fluid was injected during the 122-day injection sequence. The injected volume was only one-thousandth of the pore volume in the treatment area.

No significant increase in oil production was observed. To analyze the data, the oil/water ratio was determined for each sampling period. Around Day 64, the oil/water ratio for both down-structure producers began to increase until the end of the second water injection phase. The cause for the increase does not appear to be an increase in the oil production but a decrease in the water production. Despite the negligible change in oil production and small injection volume, the surfactant did change the character of the production in a positive manner by reducing water production.

Resistivity mapping, conducted by hydroGEOPHYSICS, Inc., of the project area during the test indicated subtle changes in the fluid characteristics and migration direction. This indicates that either the injection volume was too small or that additional time was necessary for the effect of the surfactant to be observed.

INTRODUCTION

The Rocky Mountain Oilfield Testing Center (RMOTC) is located at the Teapot Dome Oilfield, also known as the Naval Petroleum Reserve No. 3 (NPR-3). The field is about 35 miles north of Casper, Wyoming (Figure 1). RMOTC is operated by the Department of Energy as a test site for new and developing oil, gas, and renewable energy related technologies.

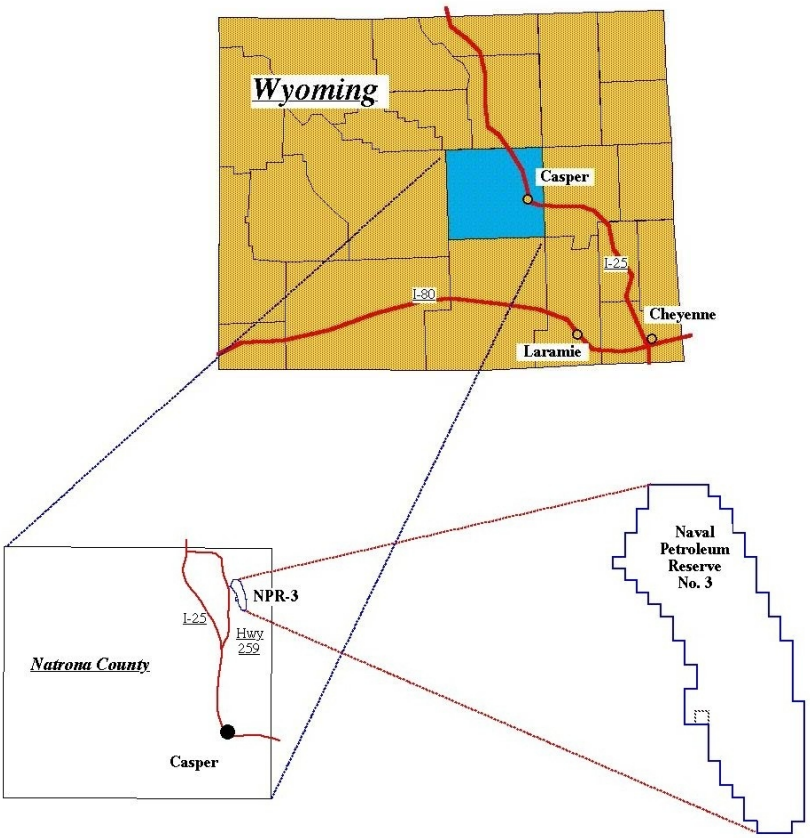

Figure 1. Location map for Rocky Mountain Oilfield Testing Center

The 9,481-acre field test site is also an operating oil field offering a full complement of associated facilities and equipment on site. There have been 1,319 wells drilled in the field with 589 of them plugged. Of the 730 remaining well bores, 680 are producing wells in nine producing reservoirs ranging in depth from 250 to 5,500 feet; 40 are non-producing wells utilized as RMOTC test wells; and 10 are shut-in.

The shallowest reservoir, the Shannon reservoir, has produced approximately 23 MMBO and 35 MMBW. The remaining oil-in-place in the Shannon is estimated to be 93% OOIP. An EOR project such as surfactant flooding could improve recoveries by 10-20%.

The project goal was to treat the Shannon Sandstone reservoir in Section 34 of NPR-3 with a surfactant to mobilize residual oil. The surfactant would alter the surface tension of the rock surfaces, thereby allowing the reservoir fluids to more readily move in the reservoir. Field testing consisted of three primary phases: baseline data acquisition, water treatment, and surfactant treatment.

The project was conducted within a structural compartment dipping gently to the northeast and bounded on the north and south by curvilinear down-to-the-south normal faults striking east-northeast, Figure 2. The faults exhibit less than 100 feet of dip-slip, and likely a small amount of strike-slip. Fault planes typically dip about 45°-55° and are smeared with bentonitic clays. The bentonite smear is expected to cause fault sealing. Two wells, 63-S-34 and 65-S-34, were used as injectors and four wells, 54-S-34, 55-S-34, 73-S-34, and 84-S-34, were used for production monitoring.

In conjunction with this project, two other projects were conducted to help monitor the surfactant injection project. Under a Memorandum of Understanding, Aflotech Pressure Monitoring conducted down-hole pressure monitoring in wells 72-2-SX-34 and 75-S-34 to observe pressure communication across faults. A Cooperative Research and Development Agreement (CRADA) was developed with hydroGEOPHYSICS, Inc. (HGI) to use High Resolution Resistivity (HRR™) subsurface monitoring to detect fluid movements and changes in fluid composition and to map the process progression. The HRR™ process used the test wells and several surrounding wells as electrodes to measure the resistance changes in the reservoir with time. For a complete discussion of the HGI work, see Fink, et.al., 2007.

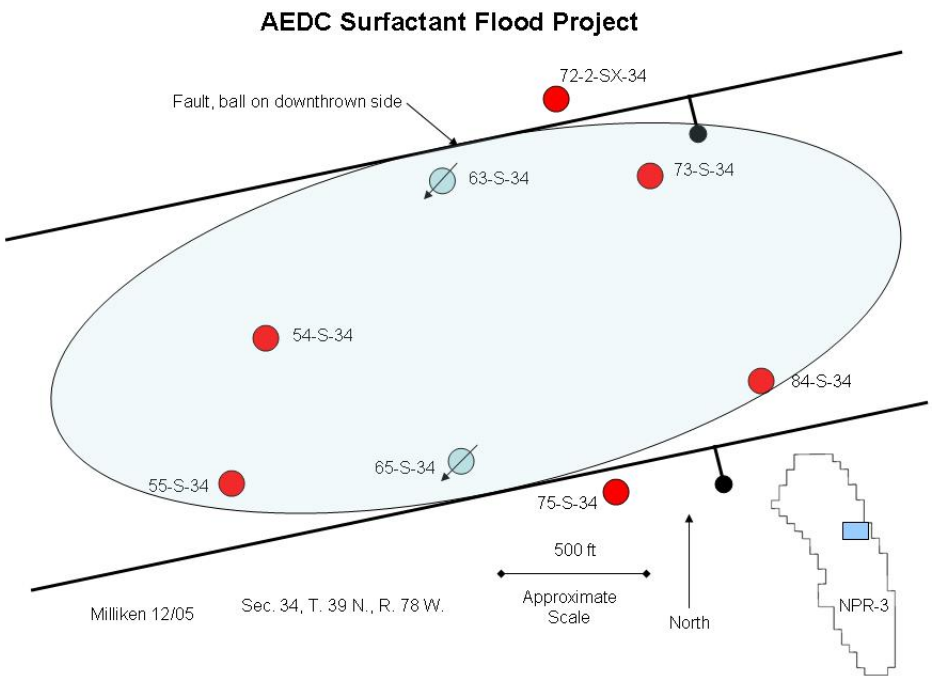

Figure 2. Project area

Surfactant Properties

The AEDC ERA-3 surfactant is a form of silicon hydride in an aqueous solution that is miscible with both oil and water. The chemical solution reduces both the surface tension of oil adhering to the rock matrix and fracture walls, and the interfacial tension between immiscible fluid phases (oil/gas and oil/water). Reduced interfacial tensions result in increased relative permeability characteristics for a given pore structure.

The surfactant characteristics make it applicable to enhanced oil recovery (EOR), paraffin mitigation, and water and soil remediation. The initial use of the chemical in the oil field has been encouraging; AEDC looked to RMOTC to conduct an independent testing series involving soak treatments and EOR floods.

The surfactant was used in prior testing at RMOTC for the cyclic stimulation (soak) of oil wells (Milliken 2005). Several wells were treated by injection of a dilute solution, 1.5% to 1.9%, into wells followed by a predetermined soak period. The wells were then

returned to production. The positive results from these tests, both increased oil/water ratio and fluid rates, led to the present project.

Testing Methodology

The surfactant field testing used six wells. Wells 63-S-34 and 65-S-34 were the injection wells with 54-S-34, 55-S-34, 73-S-34, and 84-S-34 as production wells. The accompanying projects used wells 72-2-SX-34 and 75-S-34 for pressure monitoring wells and 14 more wells for resistance measurements. Field testing consisted of three primary phases: baseline data acquisition, water injection, and surfactant injection. Following are added details for the phases:

<u>Baseline study</u>

- Measure fluid rates and levels and oil cuts for all wells using test satellites or portable testing tanks.
- Pull and lay down all test wells, check for fill, run scraper, repair as needed.
- Leave rod string out of the injection and pressure monitoring wells.

<u>Water injection</u>

- Conduct water injection using water dump (70 BWPD) at wells 63-S-34 and 65-S-34. The injection would be over a one-month time period with the injection alternating on a weekly basis between the two injection wells. Therefore, each injection well would receive two weeks of water injection.
- Monitor bottomhole pressure at 72-2-SX-34 and 75-S-34.
- Monitor oil cuts and fluid rates at wells 54-S-34, 55-S-34, 73-S-34, and 85-S-34 at the T-2-34 test satellite or with portable 17 bbl tanks.
- Maintain daily records of all data.

<u>Surfactant treatment</u>

- Conduct surfactant injection using a dump at 70 BSPD of a dilute surfactant mix per well. The mixing ratio was one drum of surfactant concentrate per 70 bbl of water for a 1.5% surfactant concentration. The one-month surfactant injection schedule followed the same alternating schedule as the water injection.
- Monitor oil cuts and fluid rates at wells 54-S-34, 55-S-34, 73-S-34, and 85-S-34 at the T-2-34 test satellite or with portable 17 bbl tanks.
- Monitor bottomhole pressure at 72-2-SX-34 and 75-S-34.
- Maintain daily records of all data.

TEST RESULTS

Injection

The actual injection sequence varied from that which was planned by the addition of a longer surfactant injection period and then a second water injection period following the surfactant. During the entire fluid injection period, the weekly alternating between the two injection wells was maintained. The first water injection phase was conducted as planned for a one-month period. During this time, 545 bbls and 560 bbls of water were dumped into 63-S-34 and 65-S-34, respectively. It should be noted that a 70 bbl dump injection took 15 to 20 minutes. The surfactant injection phase was extended from four to nine weeks with 1,330 bbls and 1,050 bbls of the 1.5% surfactant-in-water mixture dumped into 63-S-34 and 65-S-34, respectively. The surfactant phase was followed by a second water injection phase to push the surfactant further into the reservoir. During the five-week period, 490 bbls and 630 bbls of water were dumped into 63-S-34 and 65-S-34, respectively. A total of 4,605 bbls of fluid was injected during the 122-day injection sequence. Injection data is given in the Appendix.

Production

Production from the four production wells was monitored throughout the project. Production from 54-S-34 and 55-S-34 were combined and measured in test battery T-2-34 because the individual flows were too small for accurate measurements in the test separator. Production from 73-S-34 and 84-S-34 were individually monitored in 17 bbl test tanks. No significant increase in oil production could be observed. All production data are given in the Appendix.

To analyze the data, the oil/water ratio was determined for each sampling period and the results were plotted (Figures 3-5). There was no observed change in the production from the combined 54-S-34 and 55-S-34 (Figure 3), but the other two production wells showed a change in the oil/water ratio. Around Day 64 of operations, the oil/water ratio for both 73-S-34 (Figure 4) and 84-S-34 (Figure 5) began to increase until the end of the second water injection phase. The red line on Figures 4 and 5 represent an average for the oil/water ratio. The cause for the increase appears to be a decrease in the water production, not an increase in the oil production.

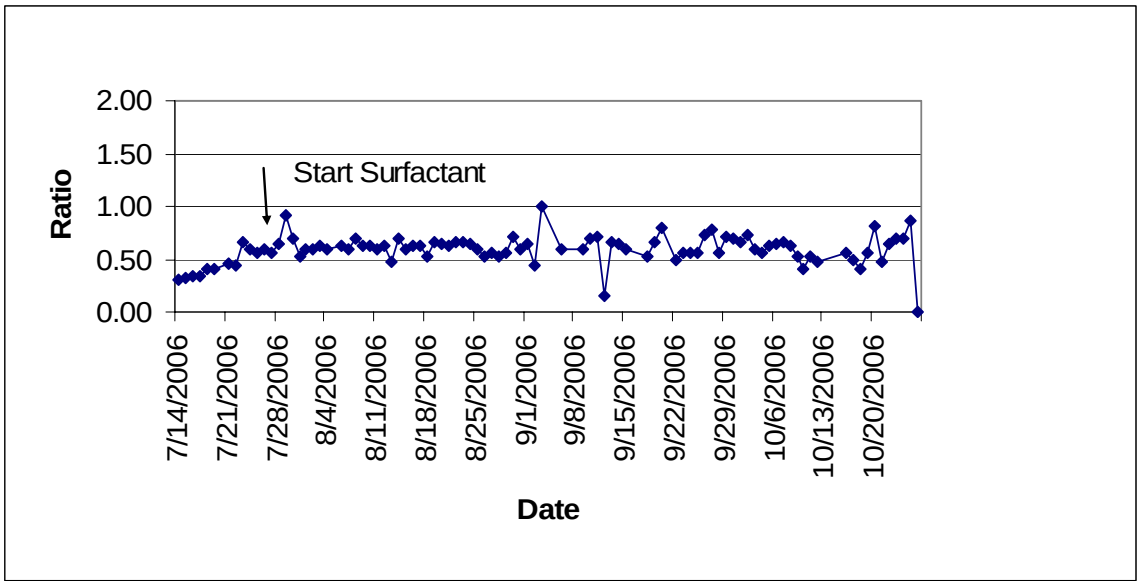

Figure 3. Oil/Water Ratio for Combined Wells 54-S-34 and 55-S-34

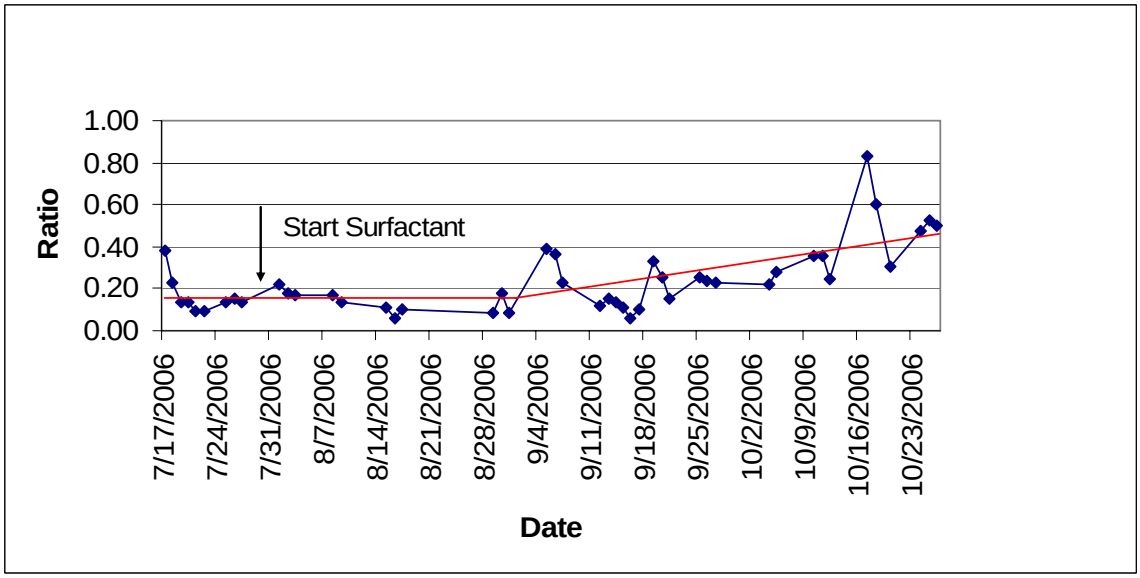

Figure 4. Oil/Water Ratio Well 73-S-34

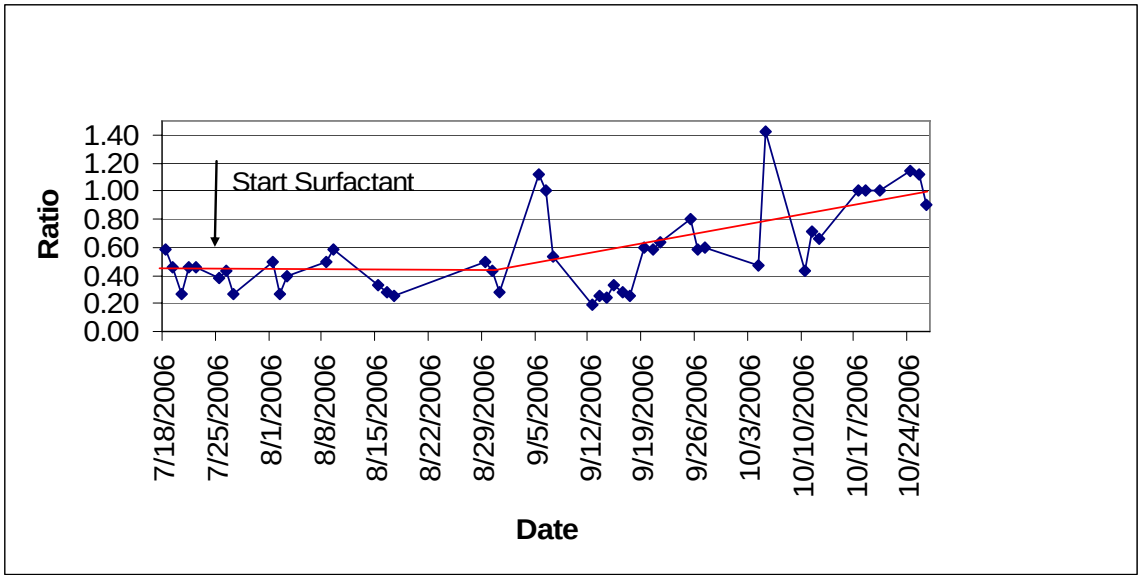

Figure 5. Oil/Water Ratio Well 84-S-34

Associated Projects

Aflotech

Bottomhole pressure monitoring indicated pressure build-up higher on the south edge of the test area then on the north edge. This indicates that the south fault is better sealed than the north fault. The bottomhole pressure monitoring was also able to see response to the individual injections by high amplitude pressure excursions.

HGI

Based on electrical response during and after, a recovery time of approximately 10 hours for well 63-S-34 and for approximately one hour 65-S-34 of was calculated. This implies that 65-S-34 is in a higher permeability area than 63-S-34. The hydraulic recovery times can be used to tailor injection for a flood.

The HRR™ system identified subtle changes in spatial fluid flow characteristics and migration direction, but little change in production character either during the surfactant injection period or shortly thereafter. This suggests that the surfactant flood had little impact on the hydrogeologic environment.

CONCLUSIONS & DISCUSSION

During the surfactant flood test, there was no noticeable change in the oil production rate. However, there was a noticeable increase in the oil/water ratio in the down-structure production wells. This increase was from a decline in the overall water production for these two wells and not an increase in oil production. This increase in oil/water ratio was also noted in prior cyclic testing (Milliken 2005).

The poor response of the surfactant could be the result of several factors, two of which follow. The dump injection method did not permit a viable flood front to develop because the injection fluid dispersed between injection periods. It took 15 to 20 minutes to dump inject the fluid with 23-plus hours between injections. The second factor is the small injection volume of 4,605 bbl. Using the average porosity of 18% for the Shannon, a test area of 1,200 feet by 2,000 feet, and an average thickness of 60 feet, the pore volume for the area is 4,600,000 bbl. The total injection is one thousandth of the available volume. Therefore, any indication of a positive change in the production characteristics would be a plus for the project. An increase in the oil/water ratio is a plus.

To fully test this chemical, a proper displacement front would need to be established by using continuous injection and a larger total injection volume. By using continuous injection, the surfactant mixture would be displaced into the reservoir as a concentrated phase and could be tracked.

REFERENCES

Fink, James B., Richard J. Wold, Dale F. Parker, Marc T. Levitt, John B. Fleming and Lyle A. Johnson, 2007, High Resolution Resistivity Monitoring of a Surfactant Flood for Enhanced Oil Recovery. Rocky Mountain Oilfield Testing Center, U.S. D.O.E., Casper, Wyoming, DOE-RMOTC-51065.

Milliken, Mark, 2005, American Energy Development Corporation Surfactant Well Treatment. Rocky Mountain Oilfield Testing Center, U.S. D.O.E., Casper, Wyoming, DOE-RMOTC-51024.

APPENDIX

Field data

Table A1. Injection Data

Date	Time	Fluid	Volume bbls	Well
26-Jun	11:00 to 11:20	Water	75	63-S-34
27-Jun	10:00 to 10:20	Water	70	63-S-34
28-Jun	8:00 to 8:20	Water	70	63-S-34
29-Jun	11:30 to 11:50	Water	70	63-S-34
3-Jul	8:30 to 9:00	Water	70	65-S-34
4-Jul	8:00 to 8:30	Water	70	65-S-34
5-Jul	8:30 to 8:50	Water	70	65-S-34
6-Jul	9:55 to 10:15	Water	70	65-S-34
10-Jul	11:50 to 12:10	Water	70	63-S-34
11-Jul	11:32 to 12:10	Water	50	63-S-34
12-Jul	2:50 to 3:10	Water	70	63-S-34
13-Jul	9:35 to 10:55	Water	70	63-S-34
17-Jul	8:30 to 8:50	Water	70	65-S-34
18-Jul	7:35 to 7:50	Water	70	65-S-34
19-Jul	8:30 to 9:00	Water	70	65-S-34
20-Jul	8:20 to 8:40	Water	70	65-S-34
24-Jul	8:50 to 9:22	1.5% Surfactant	70	63-S-34
25-Jul	8:30 to 9:05	1.5% Surfactant	70	63-S-34
26-Jul	8:00 to 8:30	1.5% Surfactant	70	63-S-34
27-Jul	8:35 to 10:05	1.5% Surfactant	70	63-S-34
31-Jul	8:15 to 8:43	1.5% Surfactant	70	65-S-34
1-Aug	8:17 to 9:30	1.5% Surfactant	70	65-S-34
2-Aug	15:30 to 16:37	1.5% Surfactant	70	65-S-34
3-Aug	13:15 to 15:50	1.5% Surfactant	70	65-S-34
7-Aug	08:00 to 11:50	1.5% Surfactant	70	63-S-34
8-Aug	11:58 to 12:15	1.5% Surfactant	70	63-S-34
9-Aug	08:35 to 09:00	1.5% Surfactant	70	63-S-34
10-Aug	08:25 to 08:50	1.5% Surfactant	70	63-S-34
14-Aug	09:30 to 10:26	1.5% Surfactant	70	65-S-34

15-Aug	08:15 to 08:45	1.5% Surfactant	70	65-S-34
16-Aug	08:15 to 08:45	1.5% Surfactant	70	65-S-34
17-Aug	08:25 to 08:50	1.5% Surfactant	70	65-S-34
21-Aug	12:50 to 01:10	1.5% Surfactant	70	63-S-34
22-Aug	03:15 to 03:35	1.5% Surfactant	70	63-S-34
23-Aug	09:00 to 09:20	1.5% Surfactant	70	63-S-34
24-Aug	10:00 to 10:20	1.5% Surfactant	70	63-S-34
28-Aug	14:15 to 14:47	1.5% Surfactant	70	65-S-34
29-Aug	10:45 to 11:15	1.5% Surfactant	70	65-S-34
30-Aug	15:45 to 16:11	1.5% Surfactant	70	65-S-34
31-Aug	10:45 to 11:21	1.5% Surfactant	70	65-S-34
5-Sep	1:00 to 1:30	1.5% Surfactant	70	63-S-34
6-Sep	1:00 to 1:30	1.5% Surfactant	70	63-S-34
7-Sep	8:00 to 8:30	1.5% Surfactant	70	63-S-34
11-Sep	8:30 to 9:00	1.5% Surfactant	70	65-S-34
12-Sep	9:45 to 10:15	1.5% Surfactant	70	65-S-34
13-Sep	15:30:16:00	1.5% Surfactant	70	65-S-34
14-Sep	8:00 to 8:30	1.5% Surfactant	70	65-S-34
18-Sep	8:30 to 9:00	1.5% Surfactant	70	63-S-34
19-Sep	8:30 to 9:00	1.5% Surfactant	70	63-S-34
20-Sep	9:30 to 10:00	1.5% Surfactant	70	63-S-34
21-Sep	10:30 to 11:00	1.5% Surfactant	70	63-S-34
25-Sep	9:00 to 10:00	Water	70	65-S-34
26-Sep	weather		0	65-S-34
27-Sep	13:00 to 13:30	Water	70	65-S-34
28-Sep	8:30 to 9:00	Water	70	65-S-34

2-Oct	14:45 to 15:15	Water	70	63-S-34
3-Oct	8:00 to 8:30	Water	70	63-S-34
4-Oct	13:00 to 13:30	Water	70	63-S-34
5-Oct	weather		0	63-S-34
9-Oct	weather		0	65-S-34
10-Oct	weather		0	65-S-34
11-Oct	8:00 to 8:30	Water	70	65-S-34
12-Oct	14:30 to 15:00	Water	70	65-S-34
16-Oct	16:00 to 16:30	Water	70	63-S-34
17-Oct	8:15 to 9:45	Water	70	63-S-34
18-Oct	16;19 TO 16:48	Water	70	63-S-34
19-Oct	11:00 TO 11:23	Water	70	63-S-34
23-Oct	8:18 TO 8:48	Water	70	65-S-34
24-Oct	13:37 TO 14:06	Water	70	65-S-34
25-Oct	8:34 TO 8:58	Water	70	65-S-34
26-Oct	weather		0	65-S-34
TotalDays	122	Total Injection	4605	
		63-S-34	2365	
		65-S-34	2240	

Table A2. Production Data

Date	54/55-S-34		73-S-34		84-S-34	
	oil, bpd	water, bpd	oil, bpd	water, bpd	oil, bpd	water, bpd
12-Jul						
13-Jul						
14-Jul	0.7	2.3				
15-Jul	0.6	1.9				
16-Jul	0.6	1.8				
17-Jul	0.6	1.8	1.4	3.7		
18-Jul	0.8	2.0	2.7	11.9	0.7	1.2
19-Jul	0.8	2.0	0.7	5.2	0.6	1.3
20-Jul			0.6	4.5	0.4	1.5
21-Jul	0.9	2.0	0.4	4.4	0.6	1.3
22-Jul	0.7	1.6	0.4	4.4	0.6	1.3
23-Jul	1.0	1.5				
24-Jul	1.0	1.7				
25-Jul	0.9	1.6	0.5	3.7	0.5	1.3
26-Jul	1.0	1.7	0.6	4.0	0.6	1.4
27-Jul	0.9	1.6	0.5	3.7	0.4	1.5
28-Jul	1.1	1.7				
29-Jul	1.0	1.1				
30-Jul	1.1	1.6				
31-Jul	0.9	1.7				
1-Aug	1.0	1.7	0.7	3.2	0.6	1.2
2-Aug	1.0	1.7	0.6	3.4	0.4	1.5
3-Aug	1.0	1.6	0.6	3.5	0.6	1.5
4-Aug	1.0	1.7				
5-Aug						
6-Aug	1.0	1.6				
7-Aug	0.9	1.5				
8-Aug	1.1	1.6	0.6	3.5	0.7	1.4
9-Aug	1.0	1.6	0.5	3.7	0.7	1.2
10-Aug	1.0	1.6				
11-Aug	1.0	1.7				
12-Aug	1.0	1.6				
13-Aug	0.9	1.9				
14-Aug	0.9	1.3				
15-Aug	1.0	1.7	0.4	3.6	0.5	1.5
16-Aug	1.0	1.6	0.2	3.4	0.4	1.4
17-Aug	1.0	1.6	0.3	3.0	0.3	1.2
18-Aug	0.9	1.7				
19-Aug	1.0	1.5				
20-Aug	1.1	1.7				
21-Aug	1.0	1.6				
22-Aug	1.0	1.5				
23-Aug	1.0	1.5				

24-Aug	1.1	1.7				
25-Aug	0.9	1.5				
26-Aug	0.9	1.7				
27-Aug	0.9	1.6				
28-Aug	0.9	1.7				
29-Aug	0.9	1.6	0.3	3.5	0.6	1.2
30-Aug	1.2	1.7	0.6	3.4	0.6	1.4
31-Aug	1.0	1.7	0.3	3.5	0.4	1.4
1-Sep	0.9	1.4				
2-Sep	0.8	1.8				
3-Sep	1.3	1.3				
4-Sep						
5-Sep			0.9	2.3	0.9	0.8
6-Sep	0.9	1.5	1.1	3.0	1.0	1.0
7-Sep			0.7	3.1	0.7	1.3
8-Sep	0.0	1.4				
9-Sep	1.0	1.7				
10-Sep	1.1	1.6				
11-Sep	1.0	1.4				
12-Sep	0.9	5.7	0.4	3.3	0.3	1.6
13-Sep	1.0	1.5	0.5	3.3	0.4	1.6
14-Sep	1.1	1.7	0.5	3.6	0.4	1.7
15-Sep	1.0	1.7	0.4	3.6	0.5	1.5
16-Sep			0.2	3.4	0.4	1.4
17-Sep			0.3	3.0	0.3	1.2
18-Sep	0.9	1.7				
19-Sep	1.0	1.5	0.7	2.1	0.6	1.0
20-Sep	1.2	1.5	0.8	3.1	0.7	1.2
21-Sep			0.7	4.7	1.2	1.9
22-Sep	1.8	3.6				
23-Sep	0.9	1.6				
24-Sep	0.9	1.6				
25-Sep	0.9	1.6	0.8	3.1	0.8	1.0
26-Sep	1.1	1.5	0.7	3.0	0.7	1.2
27-Sep	1.1	1.4	0.7	3.1	0.6	1.0
28-Sep	0.9	1.6				
29-Sep	1.2	1.7				
30-Sep	1.1	1.6				
1-Oct	1.0	1.5				
2-Oct	1.1	1.5				
3-Oct	1.0	1.7				
4-Oct	0.9	1.6	0.7	3.2	0.8	1.7
5-Oct	1.0	1.6	0.8	2.9	1.0	0.7
6-Oct	1.1	1.7				
7-Oct	1.0	1.5				
8-Oct	1.0	1.6				
9-Oct	0.9	1.7				
10-Oct	0.7	1.7	0.9	2.5	0.7	1.6
11-Oct	1.0	1.9	0.9	2.5	1.0	1.4
12-Oct	0.8	1.7	0.7	2.8	0.8	1.2

13-Oct						
14-Oct						
15-Oct						
16-Oct	0.9	1.6				
17-Oct	0.9	1.8	1.0	1.2	0.7	0.7
18-Oct	0.7	1.7	1.2	2.0	0.9	0.9
19-Oct	0.9	1.6				
20-Oct	1.3	1.6	0.8	2.6	1.0	1.0
21-Oct	0.8	1.7				
22-Oct	0.9	1.4				
23-Oct	1.1	1.6				
24-Oct	1.1	1.6	1.0	2.1	0.8	0.7
25-Oct	1.3	1.5	1.0	1.9	0.9	0.8
26-Oct			1.0	2.0	0.9	1.0