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MEOR Success in Southern California

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Abstract

A Microbial Enhanced Oil Recovery (MEOR) process was successfully applied to a mature waterflood in Southern California, using indigenous microbes that normally remain dormant during the producing life of the field. Certain indigenous microbial species can be activated in waterflood reservoirs by introducing the correct blend of nutrients. Once activated, the microbes multiply when the nutrients deplete, then migrate to immobile oil in search of a food source. The microbes break up this residual oil saturation into smaller micro-droplets that can flow through pore throats and be swept to producers, yielding an increase in oil recovery. The application on a producing well led to an increase in well tests from 20 to over 80 BOPD. Following this encouraging test, the nutrients were applied in three batch treatments on each of the waterflood injectors. At peak response a thirty percent oil rate increase was seen in the offset producers. Because this process uses indigenous microbes, there are no compatibility issues with reservoir fluids or concerns about survival in a foreign environment. The results from this field application demonstrate that managing a reservoir's indigenous microbes can yield significant incremental oil production in a mature waterflood with a minimal investment.

Introduction

The Beverly Hills field has two major producing horizons, the Hauser and the Ogden. The Hauser has been waterflooded since the mid-1980's, although producers in the field are commingled in both the Hauser and the Ogden formations. All water injection is into down-dip Hauser completions on the northeastern flank of the reservoir in the proximity of the original oil water contact. Oil gravity averages 22.5° and ranges from 22 to 26° API. The field has fourteen active producers and three active injectors with well spacing of approximately 10 acres. Field production is currently about 400 BOPD, 2,000 BWPD and 300 MCFD (Figure 1). All produced water is reinjected into Hauser (Figure 2).

The results reported in this paper are based on well tests. Allocation of metered oil from the lease by well test is usually within 10% of the well tests. As in many fields, water cut data is limited as there is no provision for continuous sampling during well tests. Water cuts are based on wellhead samples taken by hand while the wells are being tested.

Oil Release Mechanism

Unlike many previous attempts at MEOR, this process does not attempt to introduce microbes into the oil-producing reservoir (Sheehy, A. 1990). Instead, through a sophisticated analysis of field oil and water, microbes that are naturally indigenous to the oil reservoir are identified and quantified. Based on laboratory analysis, a reservoir-specific mixture of environmentally benign nutrients is formulated and released into the reservoir via water injection. The water injection becomes the transport medium for the designed nutrient formulations. The reservoir is treated with a targeted and unique nutrient formula. By activating certain species of microbes, changes in the flow characteristics of the oil are affected and induce the reservoir system to release additional oil to the active flow channels (Town, K. 2009). In higher permeable portions of the reservoir, newly released oil, water and microbes may interact to form a transient (temporary) micro-emulsion which effectively alters the sweep efficiency of the injected water as it moves through the reservoir to improve current production and ultimate recovery. In a waterflood, this process can recover up to an additional 10% of the original oil in place. (Davis C. P. 2009)

Steps in the MEOR Process

The Beverly Hills Field MEOR treatment program began in 2007. The application of this process typically consists of five steps: 1) Initial field screening, 2) Well sampling and laboratory analysis, 3) In-situ Microbial Response Analysis (ISMRA), where the nutrient formula developed in the lab is applied to a producing well to determine the microbial response is maximized, 4) Pilot testing (if applicable) and 5) Full-field application. In this case the ISMRA, a single nutrient application in the producing well, was performed on well OS-1. Because this field only has three injectors, the pilot was skipped and full-field application immediately followed the successful ISMRA. The application was expanded to the full-field by performing nine water injection well treatments in the three active injection wells, OS-9, OS-10 and OS-14 and two additional producing well treatments, OS-8 and BH-15. See Field Diagram, Figure 3

ISMRA Treatment Specifics

With a nutrient solution designed from the laboratory analysis of the field produced fluid samples, the ISMRA was conducted on producer OS-1 on July 2, 2007. A small volume (less than 8 barrels) of nutrients was injected into the well to check the reaction and behavior of in-situ microbes in the reservoir. The nutrient concentrate was mixed with 100 barrels of produced water and displaced with 350 barrels of injection water. The well was then shut-in for three days to allow targeted indigenous microbes to grow and multiply as a result of nutrient stimulation.

Pretreatment production from OS 1 was 20 BOPD and 95 BWPD. After peaking at 130 BOPD and 32 BWPD, well tests average 82 BOPD and 80 BWPD for the first three months after treatment as shown in Table 1.

Table 1. OS 1 Well Test Data

	Date	Gross	Cut	Water	Oil
Well Tests before Treatment					
(Normal well production)	3/6/07	110	87	96	14
	3/11/07	105	82	86	19
	3/28/07	130	79	102	28
Average:		**115**	**83**	**95**	**20**
Well Tests after Treatment	7/9/07	177	56	99	78
	7/17/07	182	50	91	91
	7/24/07	162	57	92	70
	8/6/07	162	20	32	130
	8/14/07	156	61	95	61
	9/4/07	158	66	104	54
	9/26/07	134	34	44	88
Average:		**162**	**49**	**80**	**82**

Over a year later, OS-1 was still producing 33 BOPD and 80 BWPD, although production was likely supported by treatment of offset injection wells as described in this paper. This single producing well application yielded over 3,000 barrels of incremental oil with a decrease in water produced (Figure 4).

Injection Well Treatments

Following the extraordinary performance of this initial application, the project was expanded to the full field by treating the field's three water injection wells, OS-9, OS-10 and OS-14, with three treatment cycles each for a total of nine treatments over a seven-month period from November 2007 to May 2008. On November 29, 2007, an 8-barrel tote of highly concentrated chemical nutrient solution was mixed with 250 barrels of injection water, injected into well OS 9 and displaced with 250 barrels of water. Giving the microbes time to incubate and populate, the water injection rate into OS-9 was limited for the next 8 days. Each injector was given three similar treatments on the schedule listed below.

Well	Injector Batch Treatment Dates
OS-9	November 29, 2007, January 11 and March 20, 2008
OS-14	December 20, 2007, February 16 and April 15, 2008
OS-10	January 31, March 1 and May 1, 2008

Between July and September 2008 oil production increases were seen in the five active front-line producers, OS-1, OS-3, OS-4, OS-12 and OS-13. The targeted species of microbes grew and reproduced as nutrients migrated from injector to producer, freeing oil along the way.

Produced fluid samples taken on June 12 from the front line producing wells indicated high concentrations of microbes were present in four of the five adjacent producers, OS-1, OS-3, OS-4 and OS-13. This was consistent with improved well tests seen on these four wells. The June 12 sample taken from OS-12 did not show any microbe activity, which was consistent with its well tests at the time. In July, OS-12 experienced a jump in oil production and another produced fluid sample was taken in August to determine if the oil production increase was coincident with improved microbial activity. Laboratory results confirmed an increase microbial response with the increased oil seen in the well tests.

The front line producers made more oil as a result of these treatments. From June through August 2008, the first 3 months of response, the front line producers averaged 206 BOPD and 1,480 BWPD. These wells averaged 179 BOPD and 1,490 BWPD from March to May. Also, base production estimated in January of 2008 for these wells was 179 BOPD. These wells produced an average 27 BOPD over their base for the three months, June to August 2008 (See Figure 5). The front line producers averaged 217 BOPD in July. The well tests peaked at 232 BOPD and 1,669 BWPD. This is 53 BOPD over the base of 179 BOPD, a 30% increase. The front line producers accumulated about 2,500 barrels of incremental oil through August. As a result of these treatments, incremental oil continued to be produced above the baseline.

Based on the improved well tests and the advance seen in microbe activity in the other front line producers, well OS-2 was returned to production on June 18, 2008. It had been shut in since April 2003 when it tested 2 BOPD and 217 BWPD. It tested no oil until November 2008 when it tested 11 BOPD and 142 BWPD. Well tests eventually peaked at 46 BOPD and 243 BWPD after the well's lift equipment was optimized (Table 2).

Table 2, OS 2 Well Tests

Well ID	Date	BOPD	BWPD	MSCFD	%WC
O.S. 2	4/17/03	2	217	0	99%
	6/18/08	RTP			
	7/9/08	0	180	0	100%
	7/21/08	0	166	0	100%
	8/19/08	0	128	3	100%
	9/22/08	0	99	1	100%
	11/19/08	11	142	2	93%
	11/21/08	13	132	2	91%
	12/3/08	8	160	5	95%
	1/10/09	10	191	5	95%
	2/9/09	8	150	4	95%
	3/28/09	20	158	5	89%
	5/17/09	6	185	5	97%
	5/20/09	46	243	5	84%
	5/22/09	20	222	5	92%
	5/23/09	42	222	5	84%
	5/27/09	29	235	5	89%
	5/28/09	15	238	5	94%
	5/30/09	26	236	5	90%
	7/9/09	33	224	5	87%
	7/20/09	25	221	10	90%
	8/13/09	23	203	10	90%
	8/25/09	2	234	18	99%
	9/24/09	31	228	18	88%
	10/8/09	22	250	18	92%
	11/6/09	22	226	10	91%
	12/17/09	16	66	10	80%
	1/15/10	31	224	12	88%

Because all the completions commingle Ogden and Hauser production, it was decided to do some zone isolation work to determine the source of oil. The Ogden and Hauser zones were isolated and swabbed separately in both OS-2 and OS-3 during routine well service jobs, with similar results. The swab tests indicated that most of the oil is currently produced from the Ogden formation. This was surprising in that the Hauser reservoir is being waterflooded and the reservoir pressure is higher in the Hauser. With over two decades of water injection in the Hauser, all mobile oil around both OS-2 and OS-3 has apparently been swept and produced. The current oil production from the Ogden in OS-2 is probably related to stopping offset water injection in the Ogden in 2002, just before OS-2 was shut in. It is now believed that water is channeling through fractures from OS-10 to OS-2 and injected nutrients made their way into the Ogden, stimulating microbial growth and the oil release. The microbial activity was elevated in produced fluid samples from the Ogden, but it is difficult to prove that this activity is the main source of the Ogden oil.

Hall Plots and derivative Hall Plots of the three injectors indicate that transmissibility has changed over time (Ozgec, B. 2009). See Hall Plots and Derivative Hall Plots, Figures 6 to 8. Wells OS 10 shows a decrease in injectivity for a short time after the first treatment. This is a possible formation of a temporary emulsion. Sometimes an emulsion forms when oil, water and microbes are present; this emulsion tends to plug the higher permeability paths and improve the sweep efficiency of the waterflood. All three injectors show a slight increase in injectivity with the nutrient treatments. These indications of increased injection match the field's increase in produced water from about 2,100 bwpd to 2,500 bwpd during our project.

Additional Producer Treatments

Based on the results of this ISMRA, two producers, BH 15 and OS 8, were treated on April 18 and May 5, 2008, respectively. Each well was treated with an 8-barrel tote of chemical nutrient solution mixed with 100 barrels of injection water. Displacement volume in the BH 15 was 400 barrels (200% of annular volume) and in the OS 8 the displacement volume was 700 barrels (150% of the annular volume). Giving the microbes time to incubate and populate, both wells were shut in for 4 days (Figures 9 and 10).

OS 8

In both cases microbe populations increase, but neither well followed the normal pattern that was seen after treating OS 1 and other producing well applications. In the OS 8 well, the bacteria showed the normal increase in population. However, the microbes did not move as rapidly into the starvation state as usual. The first month of produced fluid samples showed that the microbes were still in the growth stage, because nutrients remained plentiful. After seeing a production increase, additional samples taken on June 10, showed that the bacteria was moving into a starvation stage. This is a delayed transition to the starvation stage as compared to OS 1. Not only did OS 8 see a delayed oil production increase it saw no oil for some time. Initial well tests showed no oil. Oil was not seen until the May 22 well test, 13 days after the well had returned to production. At this time the well had a cumulative production of about 850 barrels, which is about the treatment volume. No oil was seen until the entire treatment volume was recovered. As the microbes began to respond, the well started producing incremental oil. On June 9, it tested 37 BOPD and 28 BWPD, 43% water cut. In September OS 8 tested 33 BOPD and 30 BWPD, 48% water cut. Since the well averaged 29 BOPD and 36 BWPD, 55% water cut before it was treated, it made some incremental oil. See Figure 11, OS 8 Results Summary.

BH 15

On the first day of production after being shut in for four days, the bacteria in BH 15 showed an extraordinary increase in population as expected. On the second day of production bacteria decrease substantially and the high bacteria count did not repeat. A similar varied oil production response was seen. BH 15 saw an early increase in oil production and decrease in water cut followed by a disappointing decline in oil production and increase in water cut back to its base production. See Figure 21, BH 15 Well Test. During the first week, three well tests were taken and BH 15 was averaging 97 BOPD and 105 BWPD, 52% water cut. This initial high production is probably flush production from the well being shut in. Then the BH 15 dipped to 58 BOPD and 80 BWPD, 58% water cut in September 2008. Since the well averaged 70 BOPD and 110 BWPD, 61% water cut, the well did not appear to make any incremental oil for the first few months. This is not surprising since microbes were not significantly stimulated. See Figure 12, BH 15 Results Summary.

Discussion of Results

Based on both biological indicators and production data, the field showed a positive response to nutrient treatments. As of the end of August 2008, adjacent producers appear to be positively affected with a combined current production increase from five wells of over 30 barrels of oil per day—a production increase of as high as 30% over the base rate of the "front-line" of producing wells and an overall production increase of about 6% of total field production.

In general producing well treatments had excellent microbial response, but only the OS 1 showed significant incremental oil response. It appears that the large volume of displacement fluid in treating

OS 8 temporarily hurt production from OS 8. The treatment may have temporarily changed the relative permeability near the well bore. It took about 13 days to recover the treatment water, when first oil was reported on a well test. It took another 18 days before incremental oil was seen on June 9. This relative permeability problem was seen again following a tubing leak repair. The well was down from June 22 to July 15 due to a tubing leak. When the well was returned to production, its first well test on July 20 showed no oil. By August 8 the well returned to making incremental oil when it tested 37 BOPD and 41 BWPD, 53% water cut.

To get a successful MEOR treatment, the four components (oil, water, microbes and nutrients) must make contact. In BH 15, since the microbes did not respond to the injection of nutrients, the nutrients may not have come in contact with the microbes. One possibility is that the nutrient didn't go in the oil zone. Reviewing BH 15, it is noticed that the gas oil ratio, GOR, on this well is much higher than the field average. Below is Table 3 comparing GORs among the key producing wells.

TABLE 3 Gas Oil Ratios

Well	GOR: SCF/STB	Comment
OS 1	550	
OS 3	760	
OS 4	655	
OS 5	1,000	
OS 7	1,700	Structurally second highest producer
OS 8	857	
OS 11	915	
OS 12	400	
OS 13	160	Structurally lowest producer
BH 15	1,700	Structurally highest producer

It is possible a secondary gas cap formed and the nutrients were injected into the gas cap. Another possibility is that the nutrients were injected into one zone and the well produces predominantly from another. There is no way to know where the nutrients are injected with multiple intervals open.

CONCLUSIONS

The nutrient application targeting specific microbes was proven for this field in the successful application at OS 1. There is no doubt that the production response was a direct result of the nutrient stimulation. Similar nutrient treatments in the three injectors proved that microbes were stimulated throughout the reservoir, releasing incremental oil to the front line producers. Mixed or at least delayed results in the other producing wells, OS 8 and BH 15, indicate that large displacement volumes and secondary gas caps should be avoided.

ACKNOWLEDGEMENTS

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Figure 1. Beverly Hills Field Production History.

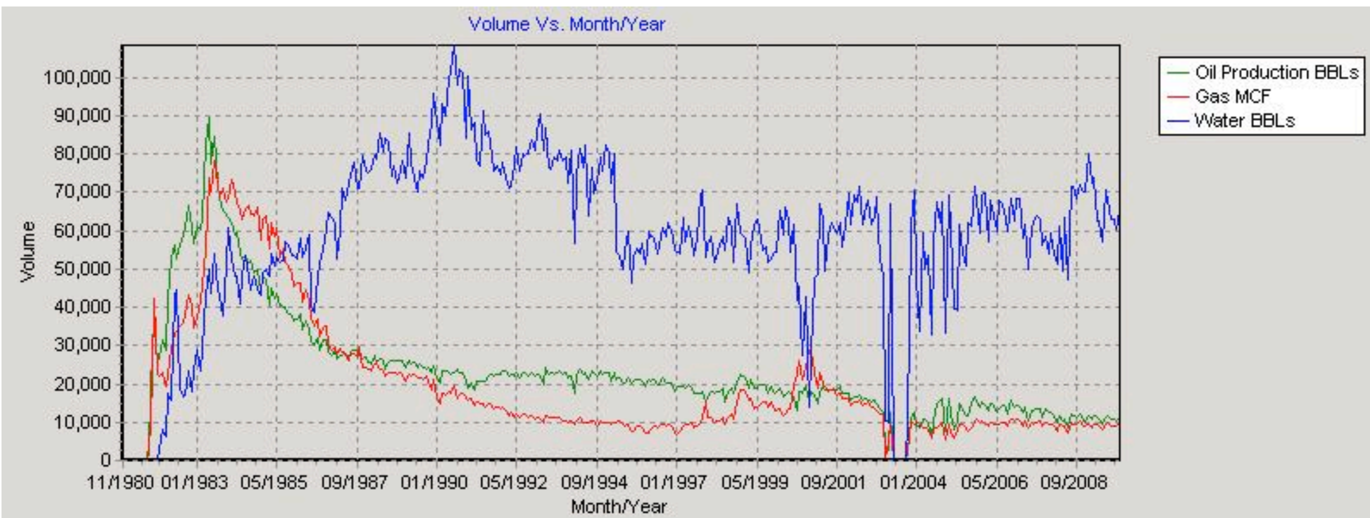

Figure 2. Beverly Hills Field Injection History.

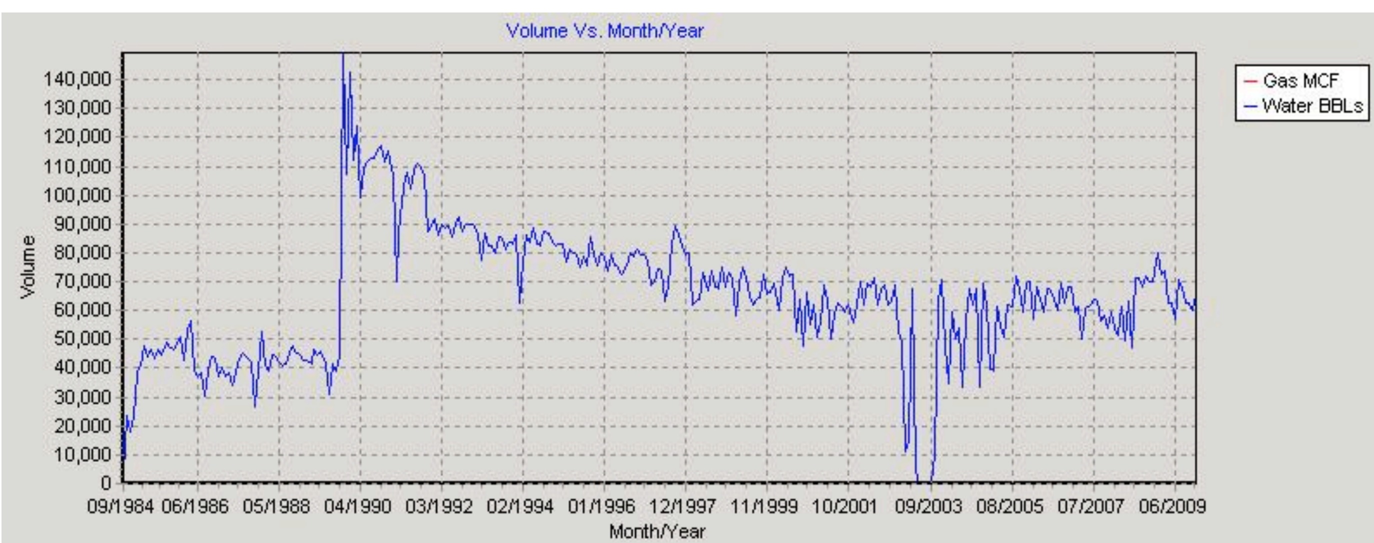

Figure 3. Field Map

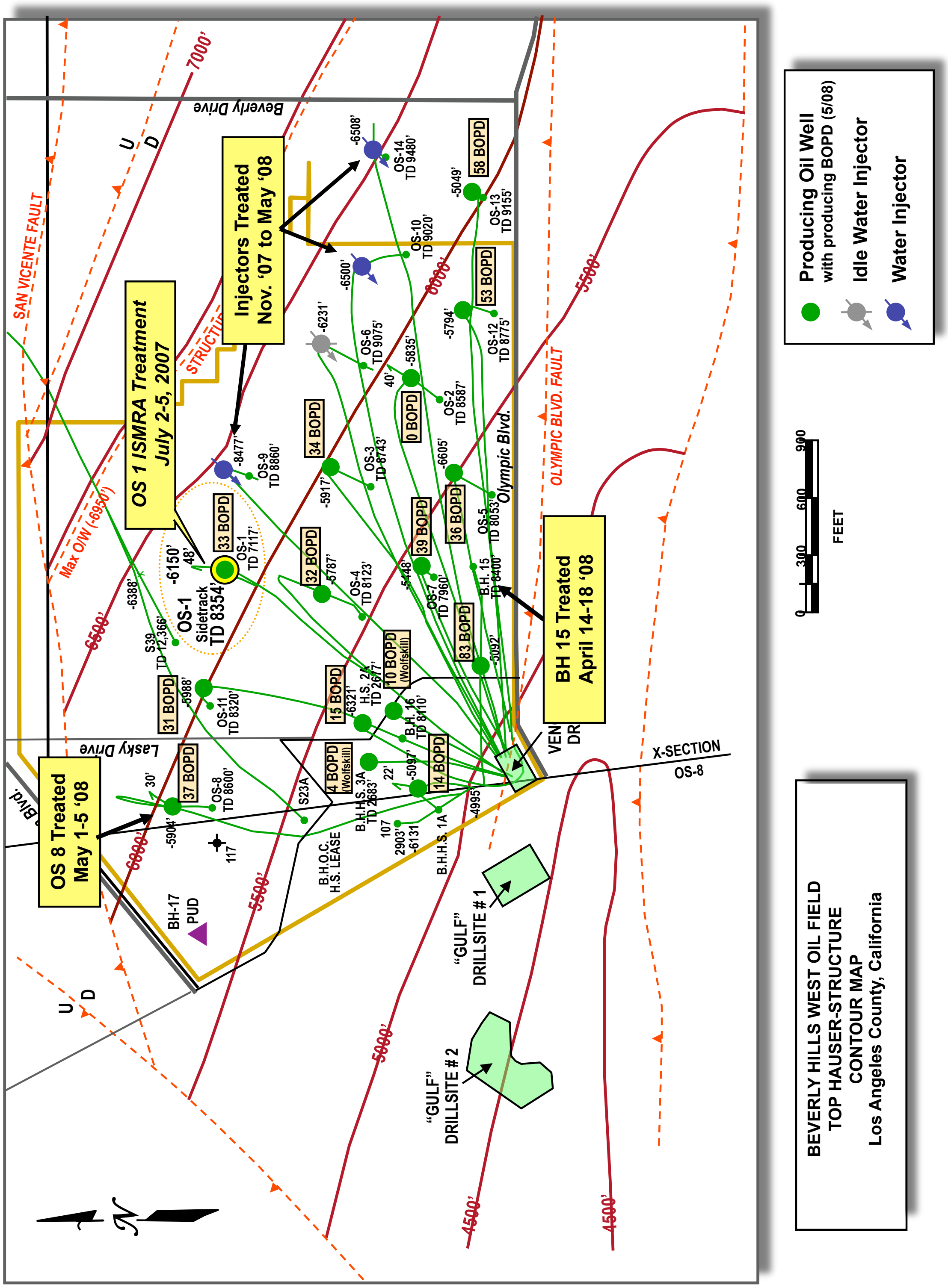

Figure 4. In Situ Microbial Response Analysis, OS 1 Well Test Results

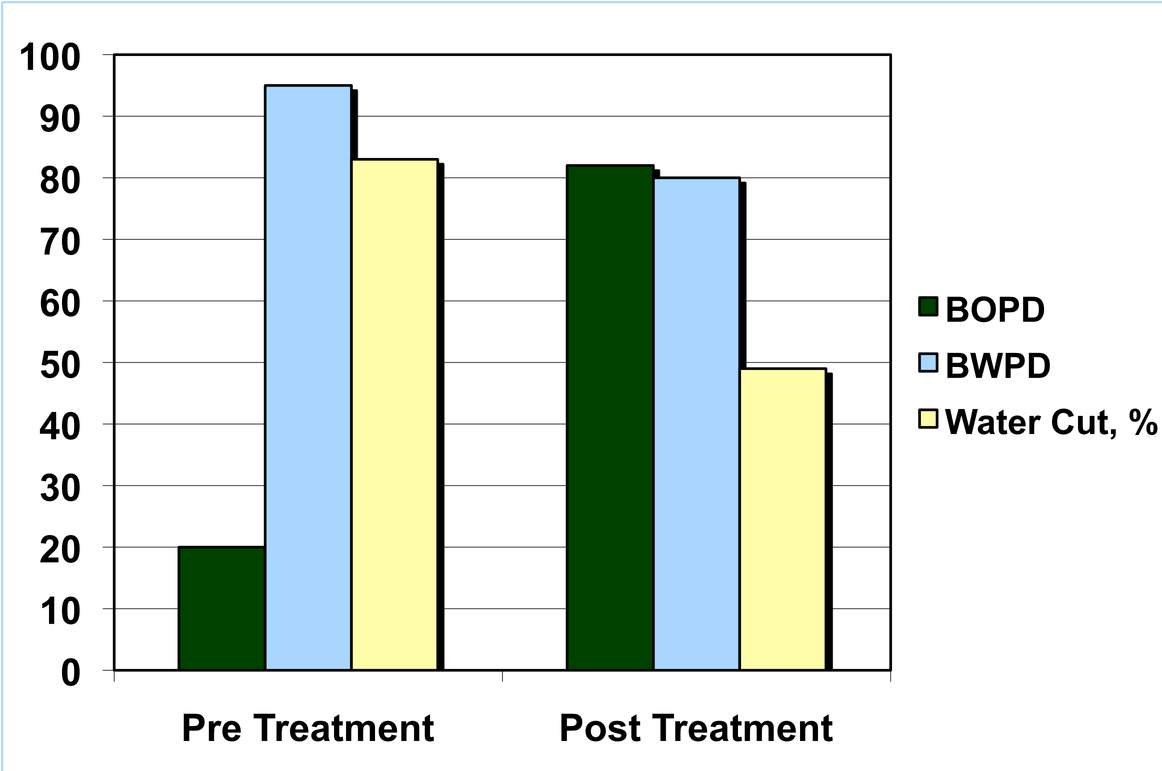

Figure 5. Well Test vs. Baseline, Front line Producers

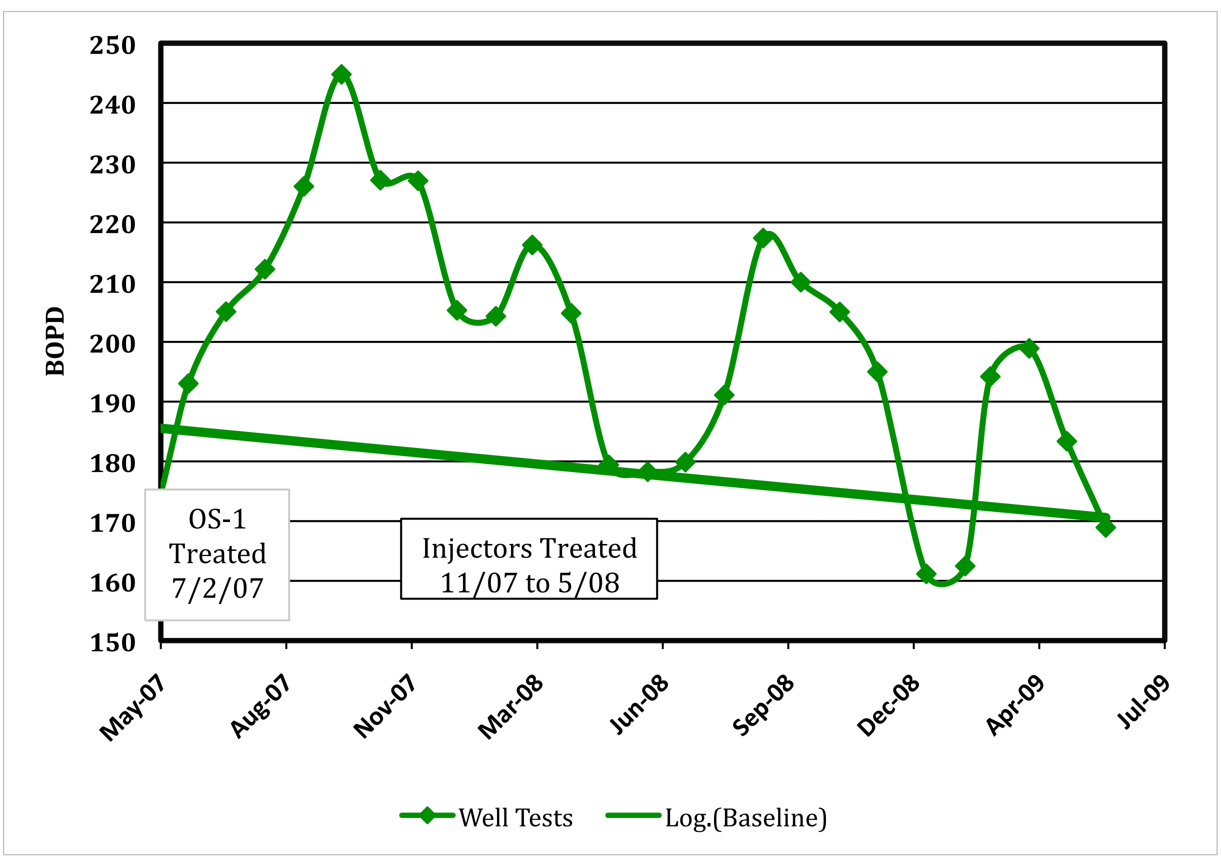

Figure 6. OS 10 Hall Plots

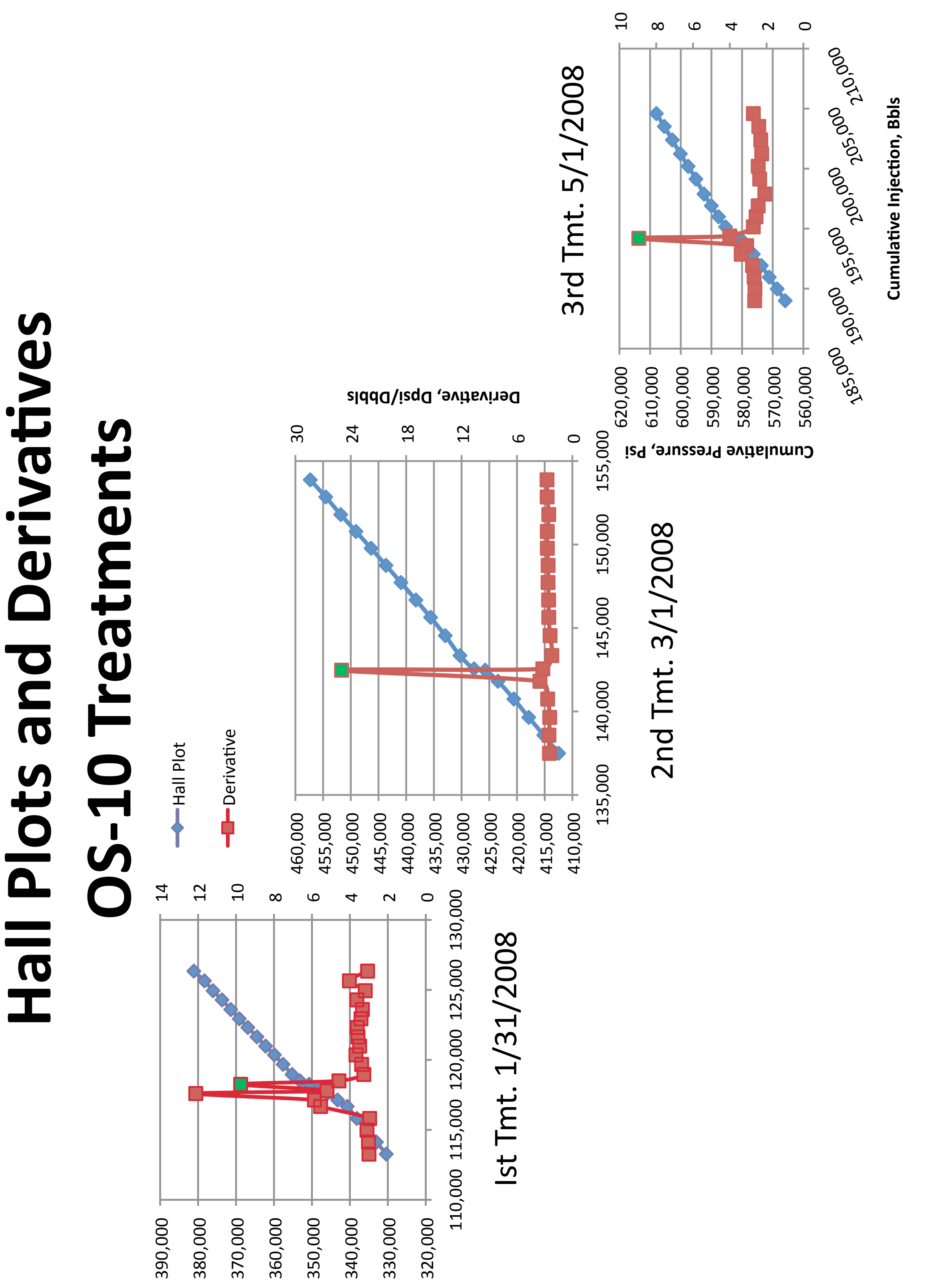

Figure 7. OS 9 Hall Plots

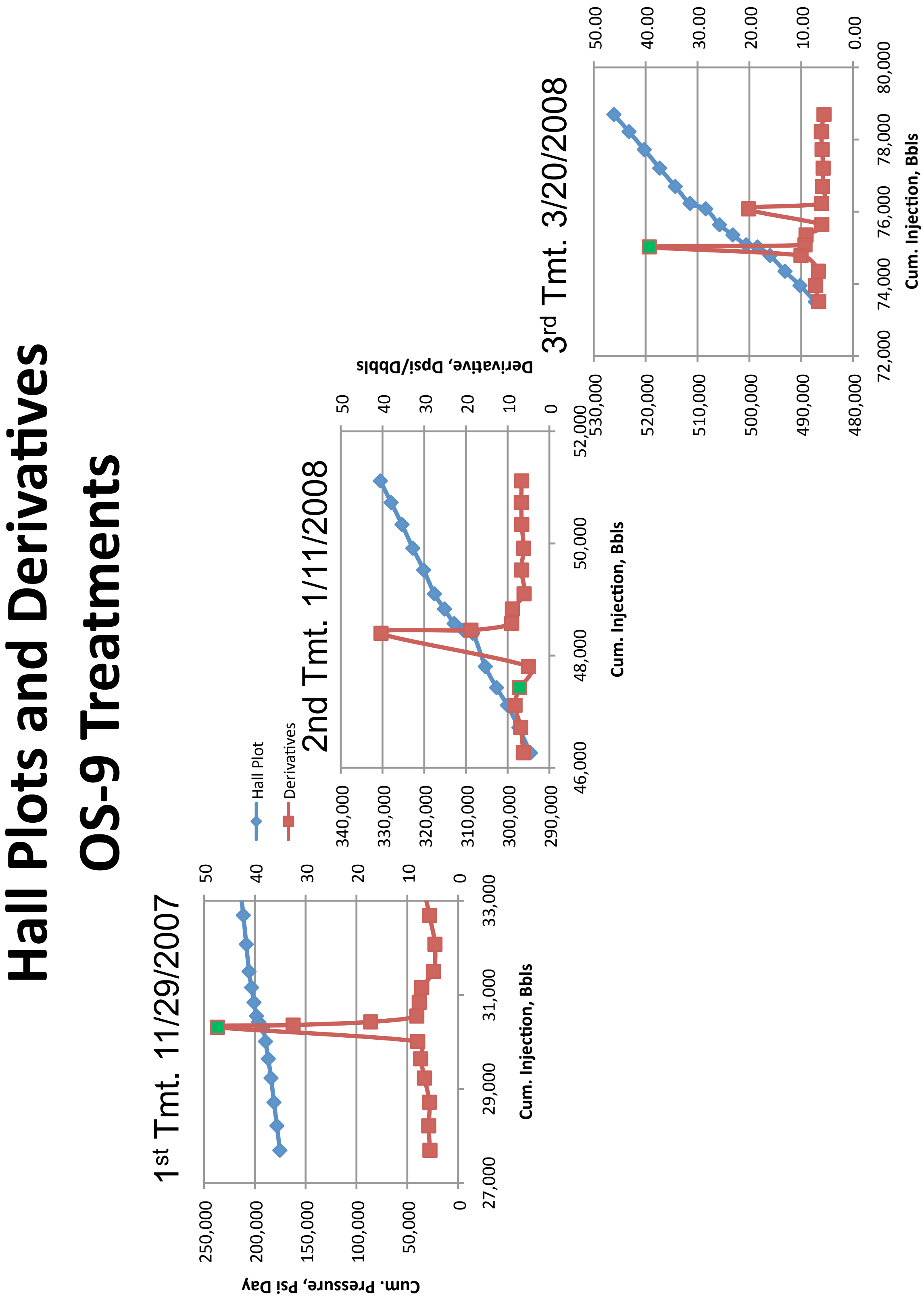

Figure 8. OS 14 Hall Plots

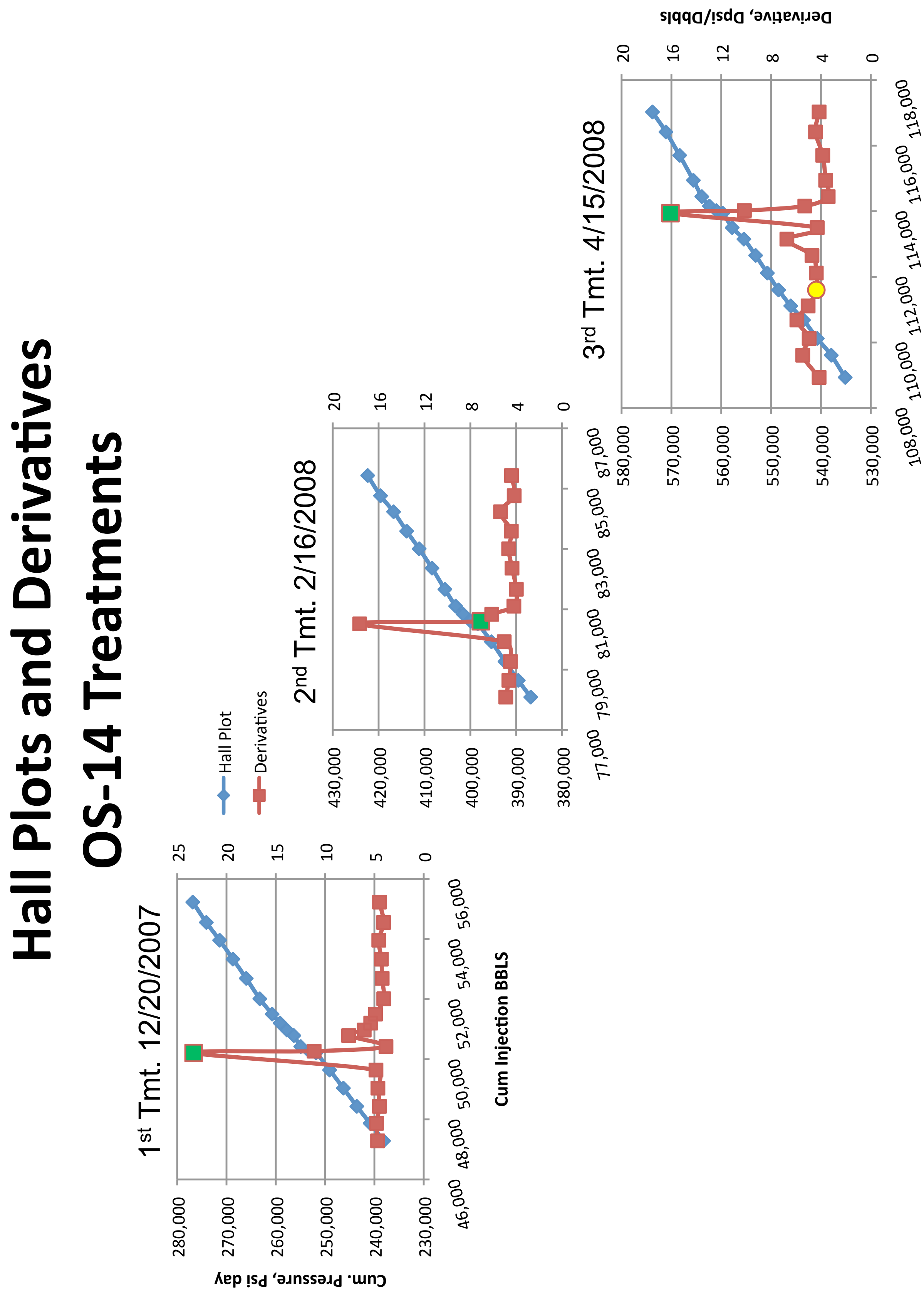

Figure 9. OS 8 Well Tests

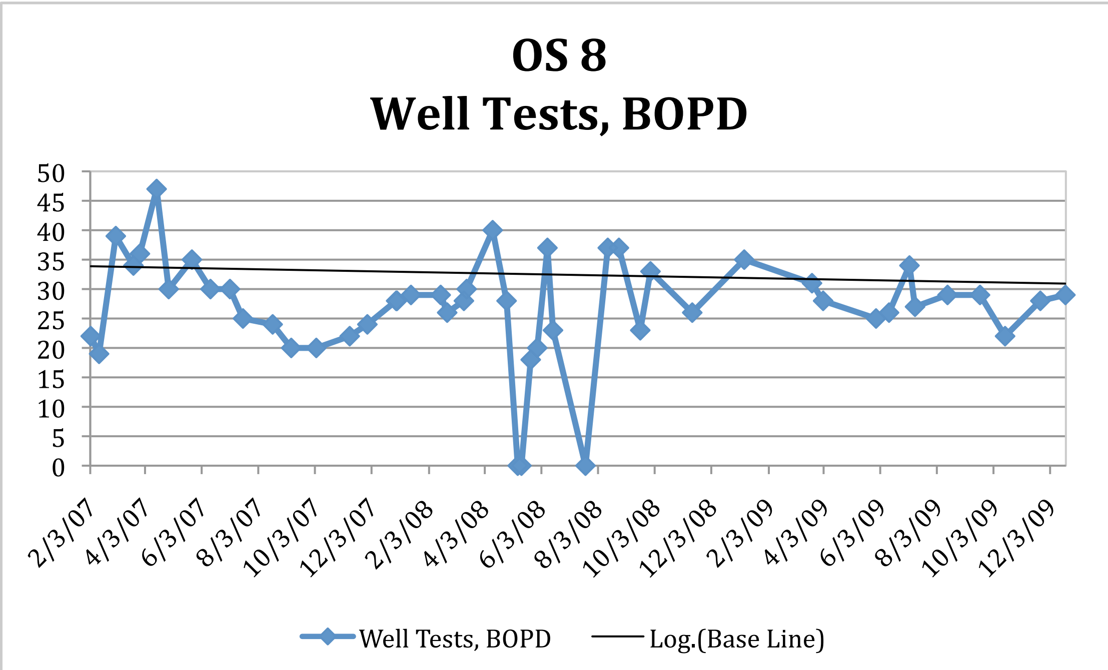

Figure 10. BH 15 Well Tests

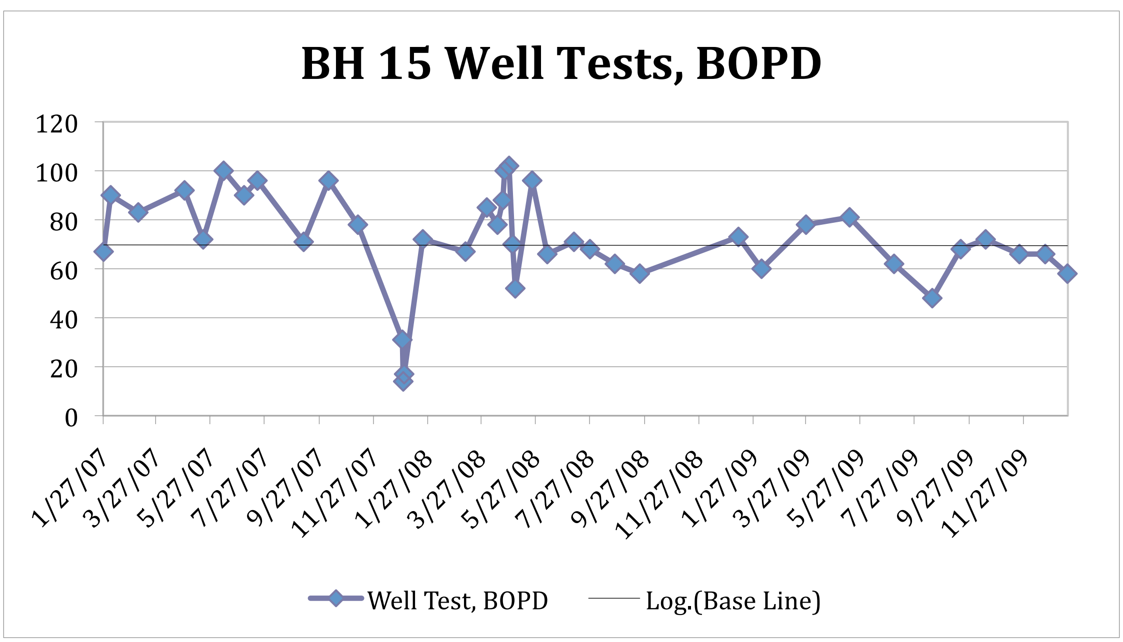

Figure 11.

OS 8
Results

Well Tests before Treatment
(Pretreatment well production)

Date	BOPD	BWPD	%WC
11/28/07	24	44	65%
12/29/07	28	32	53%
12/30/07	28	32	53%
1/14/08	29	43	60%
2/15/08	29	28	49%
2/22/08	26	35	57%
3/11/08	28	30	52%
3/14/08	30	30	50%
4/11/08	40	26	39%
4/26/08	28	29	51%

Feb.–Apr. Weighted Average:	**29**	**36**	**55%**

Well Tests after Treatment

	Date	BOPD	BWPD	%WC
	5/8/08	0	63	100%
	5/12/08	0	66	100%
	5/22/08	18	50	74%
	5/29/08	20	68	77%
	6/9/08	37	28	43%
	6/15/08	23	45	66%
Tubing Leak 6/22 – 7/16				
	7/20/08	0	74	100%
	8/13/08	37	41	53%
	8/25/08	37	40	52%
	9/17/08	23	41	64%
	9/28/08	33	30	48%

Weighted Avg. since leak:	**22**	**54**	**70%**
Weighed Avg. since 8/13:	**33**	**38**	**53%**

Figure 12

BH 15
Well Test Data

Well Tests before Treatment
(Pretreatment well production)

Cylinder change: Jan 21.
Scale clean out: Feb. 20-25

Date	BOPD	BWPD	%WC
12/29/07	31	23	43%
12/30/07	14	46	77%
12/31/07	17	19	53%
1/21/08	72	108	60%
3/9/08	67	113	63%
4/2/08	85	138	62%
4/14/08	78	98	56%

Feb.-Mar. Weighted Avg: 70 110 61%

Well Tests after Treatment

Date	BOPD	BWPD	%WC
4/20/08	88	116	57%
4/22/08	100	106	51%
4/27/08	102	93	48%
5/1/08	70	142	67%
5/4/08	52	157	75%
5/23/08	96	85	47%
6/9/08	66	87	57%
7/9/08	71	105	60%
7/27/08	68	95	58%
8/24/08	62	92	60%
9/21/08	58	80	58%

May-Jul. Weighted Avg: 74 106 59%