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Steam Chemistry Monitoring the Navy I Area of the Coso Geothermal Field

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ABSTRACT

Steam chemistry is used to monitor the wells that supply steam to the Navy I power plant at the Coso Geothermal Field. Almost all of the wells are dry steam wells that are part of a steam cap. Analysis of the Non-condensable gas is used to calculate reservoir temperature steam saturation using the Methane breakdown and pyrite-H2S reaction. Reservoir vapor saturation or Y values are calculated between 5-15 percent. With calculated reservoir temperature from 220 to 270 Degrees C. Reservoir Temperature calculations vary more than the than the calculated Y fraction. Variable Non- condensable gas concentrations monitor the influx of fluids that mix in the reservoir. Specifically changes in H2S to the Navy I area as a whole. Sustained stable steam flowrates have been produced to the Navy I power plants the last four years. A State of equilibrium between natural recharge, injection and production now exists resulting in a very low decline rate. The Navy I production wells are the shallowest in the field and steam contributions from other parts of the field and the margins contribute to the steam produced from the steam cap.

1. INTRODUCTION

More than half the production wells at the Coso Geothermal Field are dry steam wells, the Navy I area has the majority of the dry wells that make up the steam cap. They number 30 wells. Monitoring the steam using non-condensable gas analysis has been routine for 20 years. Along with gas analysis the steam phase is monitored for line pressure, temperature and flow rate. Applying the gas analysis to the Fischer-Tropsch and Pyrite H2S gas equilibrium reactions produce a reservoir temperature and saturation or Y value. Often these are depicted in graphical form as FT-HSH y-t spider web plots, an example is in Figure 1. Plotting the numerical number produced from this procedure over time monitors changes in saturation and reservoir temperature. The large spikes that occur are thought to be periods of recharge, these happen at irregular intervals. As field pressure lowers recharge can be introduced from fluids adjacent to the field. Addition of these fluids and injection, regardless of the source of injection fluid, help keep the decline rate in the Navy 1 Area low. Augmentation fluid from off site has not been available to the Navy I site for most of the last four years, yet the Navy I power plants flow rates have been stable. The difference between winter and summer injection rates with more condensate available in the winter has also not effected the main-steam flow rates at Navy I. The injection wells are not off-set from the production area to avoid reinjection breakthrough they are immediately adjacent and intermingled with the production wells, as shown in figure 2.

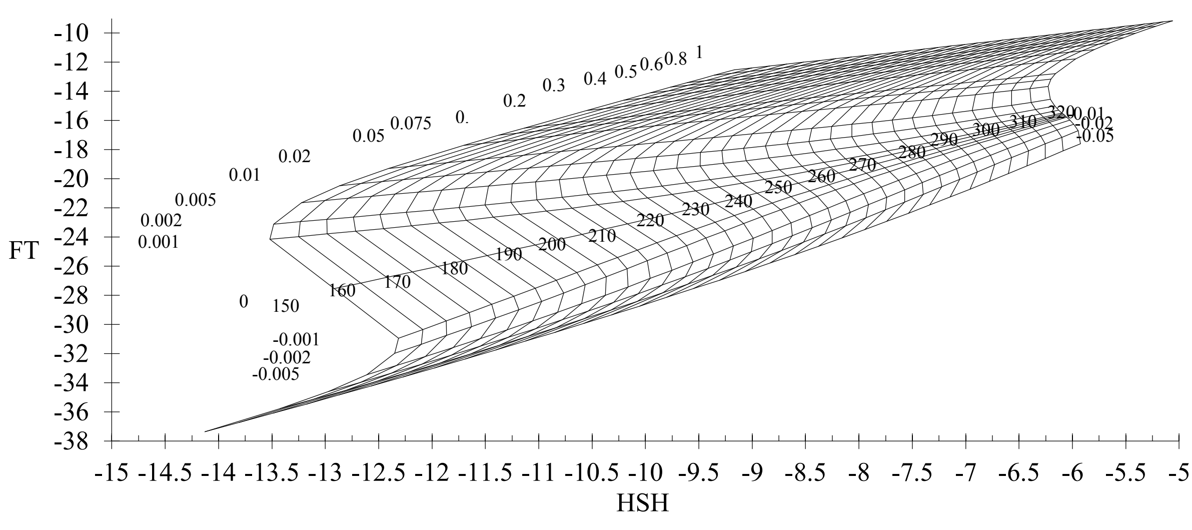

Figure 1: Example of y-t plot used at Coso from 1997, calculations by Giggenbach, D'Amore and Truesdell.

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2. MONITORING AND H2S

For many years the method developed by Truesdell and D'Amore using the Fischer-Tropsch and pyrite-H2S equilibration reaction monitor the steam phase reservoir conditions, one component of the calculation is the H2S concentration measured in the gas analysis. At irregular intervals at Coso the H2S concentration drops while the total gas concentration remains unchanged. This happens for multiple wells at the same time. The H2S is sensitive to temperature change, Blamey (2006), and spikes in the graphed data depict periods of recharge from either injection breakthrough or from liquids adjacent to the field or both. The steam well flow rates remain steady during the spikes in calculated saturation and the enthalpy at the surface also does not change significantly either. The boiling from a liquid at depth of between 15-20% is not changing that much it is just that new fluids are being added. Selective oxidation of the H2S by fluids from out-side the reservoir at or near the boiling interface is certainly possible explanation. An independently buffered H2S would react separately at point of mixing compared to the rest of the gases produced.

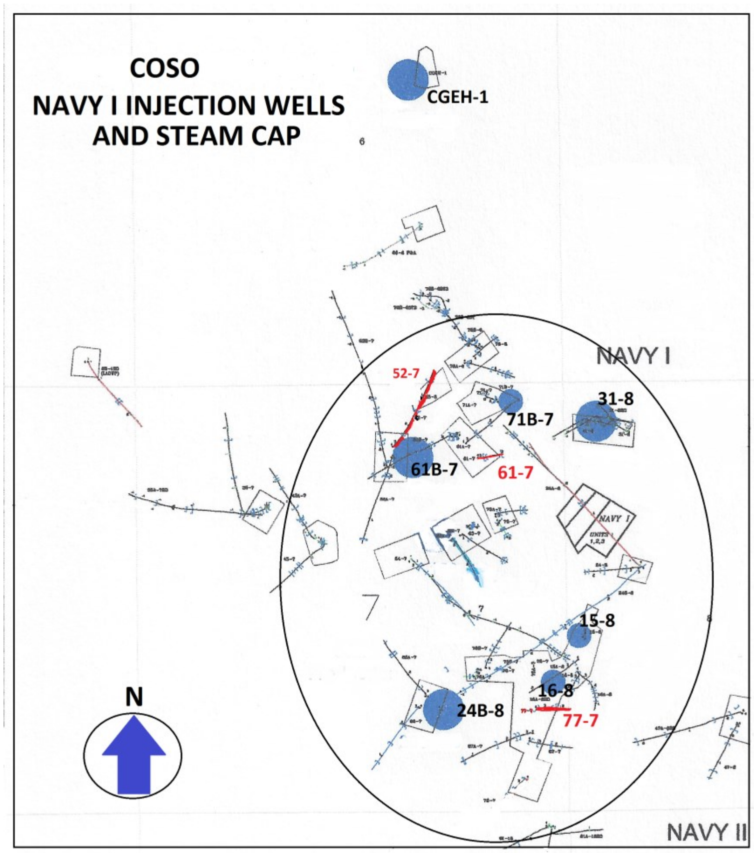

Figure 2: Map of the Navy I Area blue circles are injection wells, the oval outline is location of the steam cap.

3. ENTHALPY

To maintain the steady production rate steam is assumed to originate from boiling water zone of large capacity and then passes through an area of rock that is dry so that additional heat can be added to the steam to create the higher enthalpies in the steam cap. The longer the steam is in contact with the dry rock the more heat can be added. The enthalpy of steam from just flashing from a liquid body is expected to top out at 1204 btu/lb but most wells in the steam cap range from 1208 to 1220 btu/lb. A liquid body having a salinity of greater than 20% would be needed to create the elevated enthalpy values the steam cap wells have. Unlikely at Coso, the few brine wells in the Navy I area have TDS of less than 5000 ppm and have been at a steady concentration for over 20 years.

4. INJECTION

Three production wells are graphed covering a twelve year period of time that plot the variation in calculated saturation and reservoir temperature. The wells are 52-7, 77-7 and 61-7graphed in figures 3, 4, and 5. A plot of injection over the same number of years for the Navy I area is also provided, Figure 6. The variation in calculated steam saturation plots seem to roughly match the injection flow rates plotted over the same time frame which is expected. Natural recharge is helping maintain the steady flow rate conditions. In the last four years there has not been as much augmentation water from off- site available yet steam flow rates remain steady. It does not seem to matter the source of the water or were it comes from, as long as there is enough to maintain the current state of equilibrium. Large variations in injection flow rate occur between winter and summer without much change in production well steam flow rates. The extra water comes from the lower evaporation rate in the cooling towers during winter months. The Navy I area has the most injection wells in service compared to the rest of the field even though it has the fewest two phase wells with brine. A map is provided in Figure 2.

5. CONCLUSION

The wells that are part of the steam cap often react as a whole rather than individually. If an H2S change occurs in one well it often is seen in all the wells of the steam cap. The recent fluctuations of H2S measured in the gas analysis taken from the Navy I steam cap wells monitors reservoir processes that are not as easy to detect at the surface. In between the body of water that flashes to create the steam and the wellbore there is a body of hot dry rock that contributes heat and also buffers any of signs of liquid addition. As the pressure drops in the field over time additional water from adjacent to the field is added and when there are large enough amounts the H2S is a sensitive enough reaction to monitor the change. The saturation or Y value plots show much more variation than the actual steam flow rates and enthalpies. Studies in past have shown when too much injection fluid is added the wells in the steam cap all the components of the gas analysis decline not just H2S. Selectively lower H2S values are thought to react at a deeper depth than the steam cap itself were new fluids are mixing with an existing body of liquid near the flash zone. The changes monitored by the saturation values show the mixing of fluids from not just adjacent new fluid but by nearby steam. This mixing of these fluids suggests a balance between mass extracted and recharge from injection, natural fluids adjacent to the field, nearby steam, and the existing liquid body at depth. Even though the H2S drops off at irregular intervals the overall H2S is steady or slightly increasing in the last four years.

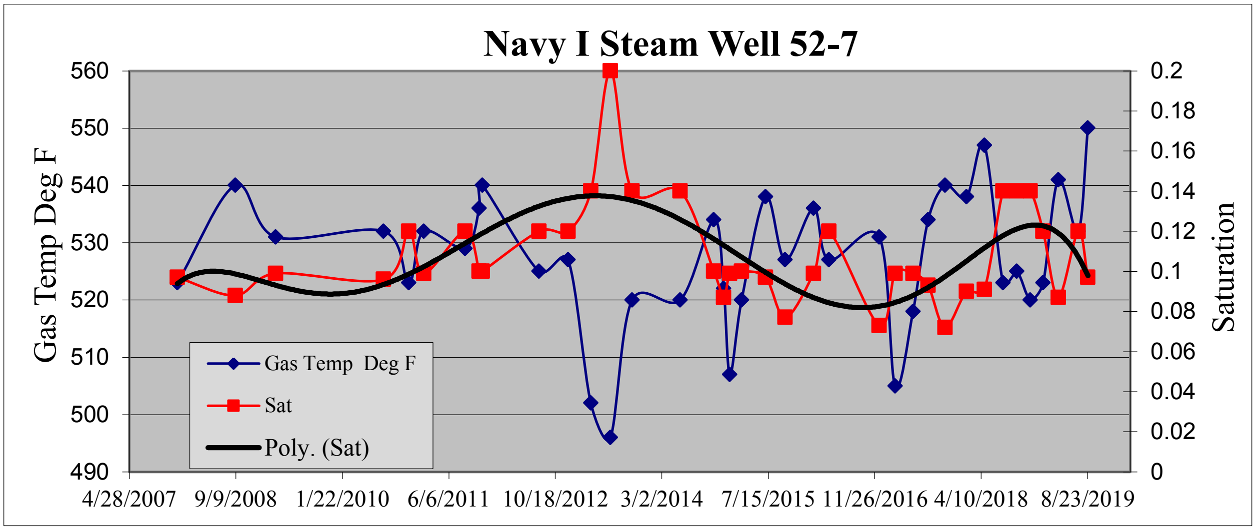

Figure 3: Well 52-7 Saturation and Reservoir Temperature plotted over 12 years.

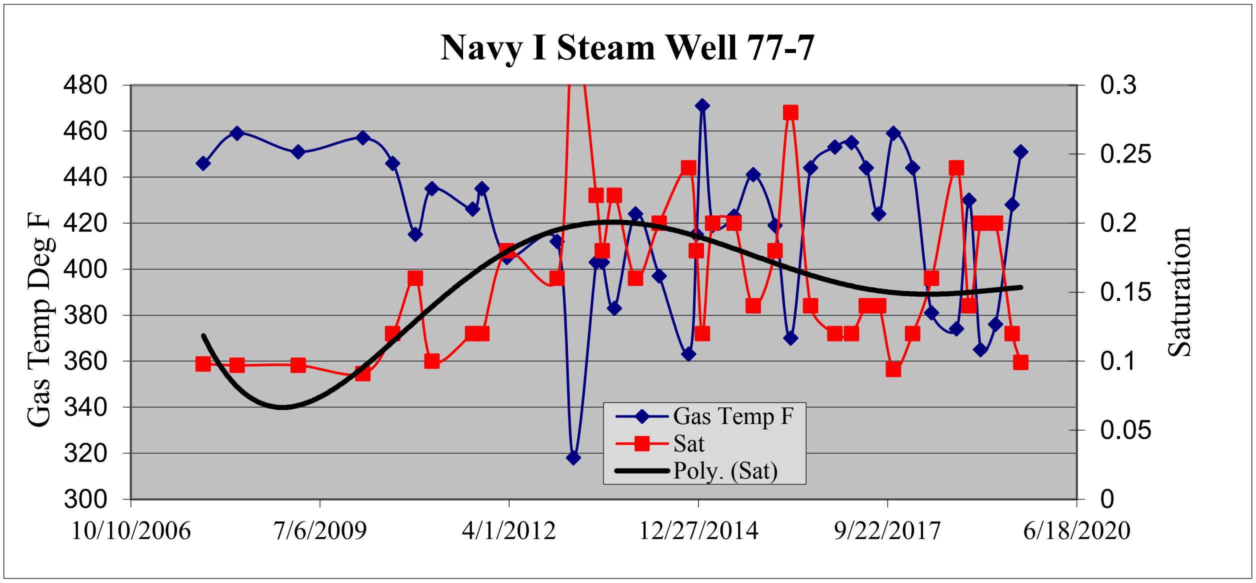

Figure 4: Well 77-7 Saturation and Reservoir Temperature plotted over 12 years.

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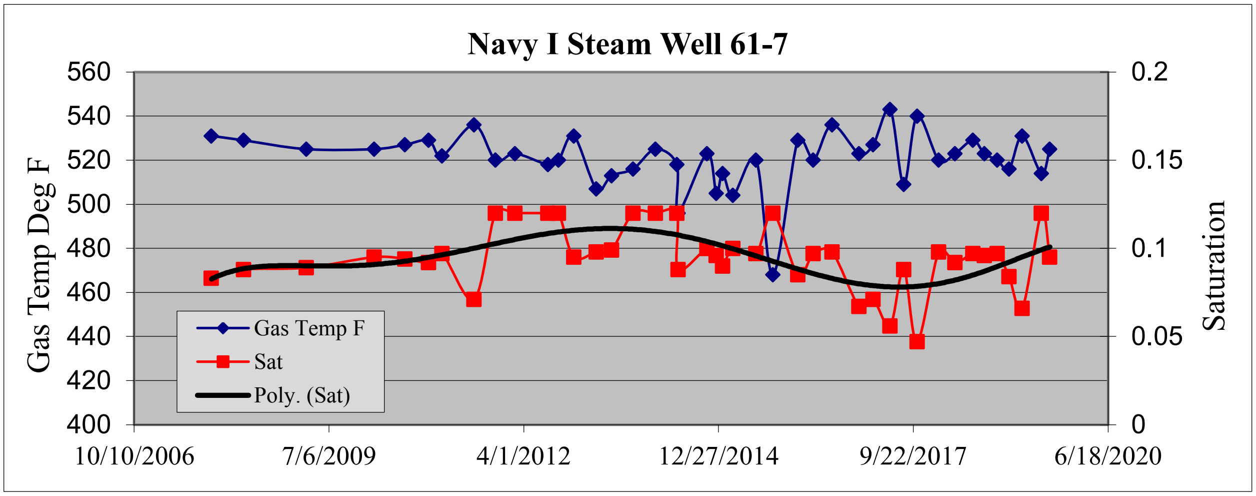

Figure 5: Well 61-7 Saturation and Reservoir Temperature plotted over 12 years.

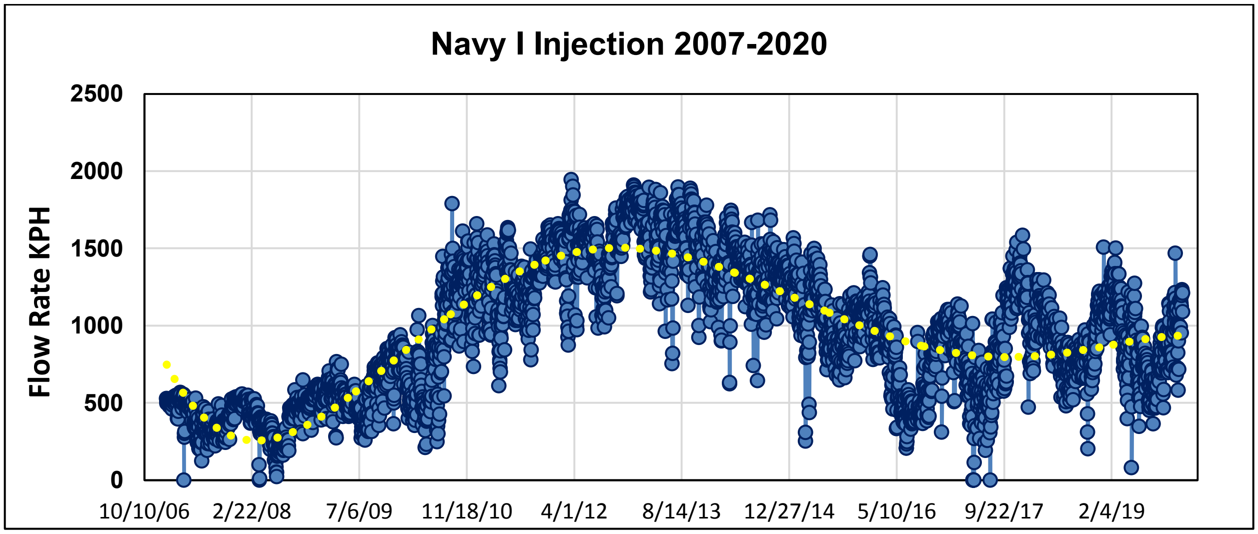

Figure 6: Navy I Injection over the last 12 years.

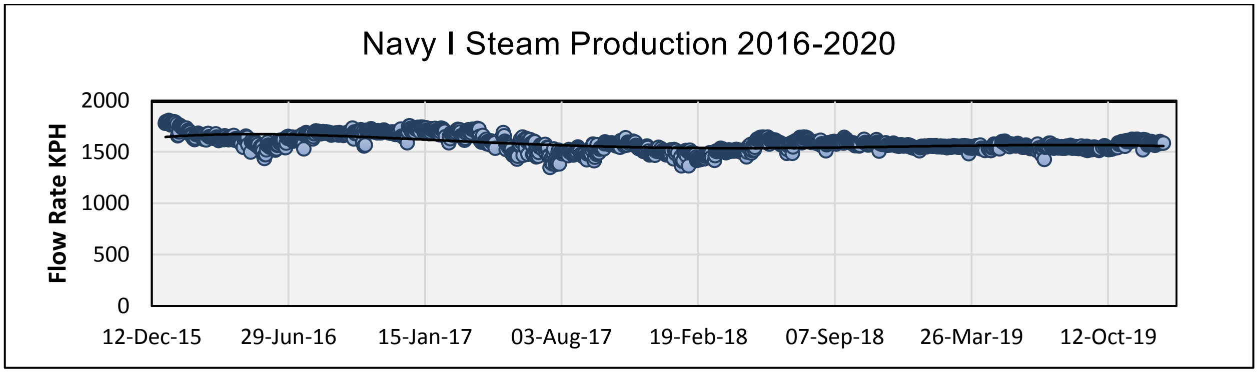

Figure 7: Navy I Steam Production 2016 to 2020.

Well	52-7									
	Total									
	G/S	CO2	H2S	NH3	Ar	N2	CH4	H2	Tgrid	Ygrid
Date	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	Deg F	
12/9/2007	12119	11892	201.5	2.32	0.34	17.63	0.46	3.89	523	0.097
9/6/2008	12603	12344	233.0	1.34	0.43	20.23	0.43	3.68	540	0.088
3/15/2009	13719	13465	225.1	3.61	0.49	20.14	0.49	4.10	531	0.099
8/4/2010	13690	13428	228.8	3.03	0.53	25.03	0.50	4.25	532	0.096
11/30/2010	12992	12725	230.5	3.35	0.60	26.99	0.43	4.57	523	0.120
2/8/2011	13037	12777	227.9	3.58	0.53	24.08	0.44	4.00	532	0.099
8/22/2011	13494	13219	240.8	3.04	0.53	25.41	0.46	4.53	529	0.120
10/27/2011	13742	13461	246.2	3.35	0.56	26.14	0.48	4.48	536	0.100
11/10/2011	13675	13392	250.6	3.16	0.47	24.33	0.39	4.05	540	0.100
8/3/2012	13978	13717	228.9	3.28	0.60	23.77	0.45	4.42	525	0.120
12/17/2012	14486	14214	239.5	3.48	0.53	23.39	0.58	4.68	527	0.120
4/3/2013	13480	13257	199.6	2.95	0.36	14.94	0.61	5.08	502	0.140
7/4/2013	14906	14629	246.0	3.36	0.41	19.89	0.66	6.76	496	0.200
10/14/2013	14933	14658	246.0	3.61	0.46	19.29	0.68	5.41	520	0.140
5/28/2014	13827	13550	249.6	3.40	0.43	17.49	0.67	5.51	520	0.140
11/2/2014	13890	13630	233.0	3.42	0.39	18.25	0.59	4.65	534	0.100
12/18/2014	11772	11565	186.1	3.39	0.36	12.75	0.58	3.67	522	0.087
1/16/2015	11414	11219	168.3	3.29	0.22	18.15	0.69	3.96	507	0.099
3/12/2015	12133	11892	206.6	3.25	0.62	24.58	0.86	4.60	520	0.100
7/3/2015	13843	13554	257.9	3.06	0.54	21.76	0.88	4.87	538	0.097
10/3/2015	11200	10982	193.1	3.04	0.48	16.27	0.87	3.78	527	0.077
2/13/2016	14679	14393	253.4	1.44	0.49	25.01	0.78	4.84	536	0.099
4/25/2016	15554	15275	250.0	2.71	0.42	20.14	0.73	5.17	527	0.120
12/17/2016	11117	10900	192.2	2.98	0.44	17.11	0.70	3.43	531	0.073
3/2/2017	12755	12555	168.7	2.94	0.64	23.30	1.06	4.28	505	0.099
5/25/2017	14330	14098	198.7	2.77	0.56	24.04	0.95	4.64	518	0.099
8/4/2017	14742	14478	235.0	2.83	0.61	20.28	0.99	4.38	534	0.093
10/22/2017	13943	13685	228.1	2.78	0.76	20.87	1.28	4.09	540	0.072
1/31/2018	15469	15202	240.6	2.69	0.46	18.54	0.88	4.29	538	0.090
4/25/2018	15405	15098	277.8	2.72	0.50	20.04	0.85	4.65	547	0.091
7/22/2018	15628	15336	258.3	2.86	0.50	23.33	0.79	5.61	523	0.140
9/24/2018	14871	14578	266.8	2.71	0.21	17.21	0.51	5.56	525	0.140
11/27/2018	14877	14611	240.8	2.77	0.24	16.20	0.49	4.93	520	0.140
1/26/2019	13505	13255	226.0	2.74	0.20	15.72	0.46	4.39	523	0.120
4/7/2019	13086	12821	243.5	2.79	0.19	14.25	0.57	3.97	541	0.087
7/10/2019	14051	13762	260.1	2.84	0.23	20.54	0.53	4.95	532	0.120
8/24/2019	14809	14494	289.8	2.70	0.24	17.17	0.51	4.36	550	0.097

Table 2: 52-7 gas analysis and calculated reservoir temperature and Y saturation values.

Well	77-7									
	Total									
	G/S	CO2	H2S	NH3	Ar	N2	CH4	H2	Tgrid	Ygrid
Date	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	DegF	
4/25/2008	21539	21441	76.7	1.30	0.31	16.82	0.56	2.18	459	0.097
3/14/2009	21186	21090	72.2	4.02	0.34	17.10	0.63	2.32	451	0.097
2/19/2010	21834	21741	72.3	2.64	0.27	14.51	0.66	2.13	457	0.091
7/26/2010	23092	22988	77.7	2.63	0.40	20.12	0.67	2.57	446	0.120
11/23/2010	22840	22743	69.3	3.00	0.35	17.38	0.87	3.09	415	0.160
2/18/2011	20786	20711	53.8	2.99	0.48	14.99	0.28	1.64	435	0.100
9/22/2011	22587	22500	59.2	2.66	0.58	21.15	0.53	2.28	426	0.120
11/10/2011	25116	24995	67.0	2.52	1.29	47.30	0.49	2.36	435	0.120
3/21/2012	28226	28087	63.8	2.58	1.98	66.70	0.81	2.95	405	0.180
12/11/2012	28071	27947	61.9	2.51	1.38	54.70	0.72	2.62	412	0.160
3/7/2013	28810	28737	32.6	2.40	1.13	33.40	0.95	3.02	318	0.340
7/5/2013	31934	31805	75.2	2.10	1.31	45.60	0.99	3.66	403	0.220
8/6/2013	29038	28908	60.5	2.58	1.83	61.70	0.68	2.72	403	0.180
10/9/2013	31032	30924	57.5	1.40	1.40	42.88	1.00	3.18	383	0.220
1/30/2014	31458	31306	76.0	2.49	1.88	67.41	1.00	3.16	424	0.160
6/3/2014	31672	31545	63.7	2.48	1.74	55.13	0.96	3.14	397	0.200
11/6/2014	30634	30495	46.7	2.57	2.15	83.19	1.22	3.12	363	0.240
12/17/2014	32951	32791	75.4	2.53	2.13	74.74	1.29	3.33	415	0.180
1/18/2015	32941	32755	114.7	2.50	1.76	62.00	1.36	3.49	471	0.120
3/12/2015	33928	33742	89.8	2.71	2.47	84.60	1.91	4.12	419	0.200
7/4/2015	35807	35636	94.6	2.89	1.83	65.74	2.06	4.25	423	0.200
10/13/2015	33660	33494	88.4	2.96	1.90	68.24	1.71	3.49	441	0.140
2/5/2016	33245	33113	79.6	2.87	1.30	43.08	1.34	3.45	419	0.180
4/28/2016	39071	38946	61.3	3.20	1.36	52.88	2.00	4.05	370	0.280
8/11/2016	33016	32887	89.3	2.99	0.81	31.90	1.26	3.22	444	0.140
12/18/2016	27843	27716	89.2	3.00	0.70	30.35	1.14	3.01	453	0.120
3/15/2017	28106	27974	91.0	3.12	0.82	32.77	1.35	3.08	455	0.120
6/2/2017	31759	31623	90.6	3.20	0.90	36.18	1.66	3.41	444	0.140
8/7/2017	29711	29600	71.3	3.11	0.74	31.06	1.41	3.17	424	0.140
10/24/2017	26147	26046	77.1	3.30	0.46	17.11	0.97	2.35	459	0.094
2/2/2018	24774	24664	78.1	3.22	0.57	24.17	0.98	2.81	444	0.120
5/13/2018	23390	23318	42.0	3.22	0.73	23.52	0.98	2.49	381	0.160
9/22/2018	22264	22173	55.4	3.42	0.57	27.54	0.77	3.25	374	0.240
11/27/2018	22633	22533	71.1	3.11	0.46	21.53	0.63	2.69	430	0.140
1/27/2019	21475	21408	40.1	3.09	0.37	19.90	0.62	2.50	365	0.200
4/15/2019	21878	21804	47.6	3.14	0.55	19.24	0.80	2.86	376	0.200
7/13/2019	21288	21193	64.6	2.98	0.44	23.26	0.82	2.69	428	0.120
8/27/2019	21343	21237	74.8	3.12	0.48	24.20	0.82	2.61	451	0.099

Table 2: 77-7 gas analysis and calculated reservoir temperature and Y saturation values .

Well	61-7									
	Total									
	G/S	CO2	H2S	NH3	Ar	N2	CH4	H2	Tgrid	Ygrid
Date	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	DegF	
11/11/2007	12870	12651	196.5	3.29	0.29	15.30	0.44	3.27	531	0.083
4/24/2008	12321	12099	201.7	1.33	0.26	14.70	0.44	3.55	529	0.088
3/12/2009	12814	12566	193.9	3.82	2.67	44.00	0.55	3.57	525	0.089
2/7/2011	13395	13126	198.6	3.77	1.35	60.96	0.54	3.98	522	0.097
7/21/2011	15081	14808	203.3	3.14	1.45	61.10	0.85	3.37	536	0.071
11/8/2011	14265	13979	219.0	4.21	1.38	56.20	0.55	4.43	520	0.120
2/17/2012	14732	14452	230.2	4.25	1.02	39.38	0.56	4.56	523	0.120
8/3/2012	16184	15915	216.6	3.86	1.12	42.71	0.67	4.57	518	0.120
9/27/2012	16051	15768	223.2	1.43	1.33	51.21	0.76	4.70	520	0.120
12/14/2012	16226	15939	224.6	3.57	1.43	52.63	0.82	4.29	531	0.095
4/9/2013	14669	14450	168.6	3.58	1.21	41.14	0.80	4.07	507	0.098
6/26/2013	15429	15192	179.3	3.64	1.33	47.32	0.76	4.17	513	0.099
10/15/2013	16924	16655	213.2	3.90	1.22	45.11	0.84	4.68	516	0.120
2/6/2014	17347	17046	243.0	4.11	1.15	45.69	1.00	5.35	525	0.120
5/27/2014	15524	15257	219.1	4.11	0.92	36.95	0.81	4.83	518	0.120
6/3/2014	12352	12204	128.1	3.90	0.27	12.06	0.56	2.97	496	0.088
10/29/2014	14400	14146	211.6	4.15	0.81	32.29	0.75	4.39	523	0.100
12/16/2014	13844	13648	159.0	4.27	0.77	26.91	0.76	3.73	505	0.096
1/17/2015	12934	12722	174.2	4.33	0.8	28.65	0.88	3.78	514	0.090
3/12/2015	13795	13579	163.7	4.33	1.23	41.74	1.10	4.08	504	0.100
7/8/2015	14568	14316	199.1	3.98	1.02	42.71	0.95	4.30	520	0.097
10/3/2015	12180	12030	112.6	4.02	0.72	28.28	0.88	3.75	468	0.120
2/7/2016	14664	14417	203.5	4.05	0.84	34.18	0.89	3.81	529	0.085
4/27/2016	15484	15246	200.2	3.67	0.63	27.73	0.86	4.41	520	0.097
8/1/2016	15447	15168	244.6	4.05	0.54	25.14	0.85	4.42	536	0.098
12/17/2016	11245	11053	165.0	4.11	0.47	18.25	0.69	3.08	523	0.067
2/28/2017	12646	12433	180.9	3.72	0.53	22.87	0.86	3.38	527	0.071
5/26/2017	13972	13740	203.9	4.11	0.49	20.31	0.85	3.00	543	0.056
8/4/2017	13900	13710	157.0	3.93	0.63	24.61	0.82	3.50	509	0.088
10/12/2017	13996	13793	174.2	3.93	0.54	21.23	0.76	2.39	540	0.047
1/31/2018	15911	15667	200.1	3.96	0.79	34.12	1.08	4.31	520	0.098
4/24/2018	16002	15755	198.7	3.99	0.96	38.84	0.99	3.98	523	0.092
7/25/2018	15749	15485	223.0	3.89	0.69	31.39	0.75	4.39	529	0.097
9/22/2018	15046	14809	203.1	4.19	0.42	24.21	0.61	4.08	523	0.096
11/27/2018	15129	14908	194.1	3.85	0.38	18.36	0.59	3.98	520	0.097
1/27/2019	13075	12880	164.0	4.29	0.45	22.37	0.52	3.19	516	0.084
4/5/2019	13602	13375	179.4	4.83	0.7	38.58	0.65	3.03	531	0.066
7/12/2019	14578	14332	208.3	3.80	0.42	27.52	0.77	4.70	514	0.120
8/24/2019	14172	13930	211.7	4.21	0.32	20.72	0.74	4.36	525	0.095

Table 3: **61-7 gas analysis and calculated reservoir temperature and Y saturation values**.

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