MEMO

From: Neale Young

Date: 19-April-2023

Re: Early feedback on results from MON-1 & MON-2 well flow test.

Overview:

Between 2013 and 2017, three geothermal wells were drilled in the Weekes area, between Salem and Plymouth as shown in Figure 1. MON-1 and MON-2 exploration wells were successfully drilled, installed, and tested in 2013 - 2014. MON-3 was drilled in 2016 to confirm the three-dimensional model of the reservoir, but was not completed or tested due to well complications.

In November 2022, the Government of Montserrat (GoM) contracted JRG Energy Consultants to carry out works to maintain the integrity of the wellhead equipment on 3 geothermal wells: MON-1, MON-2, MON-3. Included in the scope of work was to attempt flowing MON-1 and MON-2 with locally available equipment to see if:

1. The wells could still sustain flow after a ~9yr hiatus
2. Provide a basic output test to compare current well performance versus the results obtained in 2014.

The servicing of the three wellheads and an initial MON-1 flow test attempt were carried out from the 12th to the 17th of December 2022. Flow testing activities were carried out for MON-1 only due to the time constraint. Equipment limitations and project time restraints halted operations, with a second phase planned for Q1 2023. In late March -2023, the JRG Energy team returned to continue the phase 2 scope of work, including attempting discharge of MON-1 and MON-2.

The following communication provides an initial interpretation of the results from the Mon-1 and MON-2 well flow tests carried out between Saturday 1st April to Sunday 9th April.

Methodology

To lift each well a total of 19 x 32ft strands of 1.9" diameter pipe (608 ft run depth), were run into the well to lift a water column recorded at 226ft on MON-1 well and 170ft on MON-2. This meant that approximately 382 ft of well fluid was lifted on MON-1 and 438ft of well fluid was lifted on MON-2 to initiate flow. Mon-1 well flowed on the first lifting attempt and was left in lifting mode until visible signs of temperature and steam observed at surface indicated that well could sustain flow unassisted and reached a steady state. MON-2 took a little more effort though did come online on 4th attempt and flowed for the full 48hrs planned well flow period. Both wells were initiated in a similar manner to the well testing conducted in 2013.

What follows are the summary of results from MON-1 and MON-2 wells initiated in 2023.

Mon-1 Well Performance Summary

After initial signs of flow, MON-1 well continued to increase production and reached steady state at approximately 178 DegC with a well head pressure of 130psi (8.97 barg).

The well flow rate was estimated from recording test pit fil rate and was recorded at 12.43 ft^3/min (352 liters/min), at 178 degC and 130psi (8.97 barg) well head pressure.

Analysis of Results

The 2013 MON-1 flow-test results were compiled by ThermoChem and detailed in the Well Completion Report MON-1 and MON-2. The results suggested MON-1 had the following measurements and calculated values for geothermal development and are compared to the 2023 results for steady state on 100% open throttle valve as follows:

Description	ThermoChem Results 2013[1]		2023 Results
James Tube Size	4”	6”	3”
Wellhead pressure (bar)	7.04	3.94	8.97
Flowing WHT (DegC)	166	145.2	177.9
Weir Mass Flow (kg/sec)	12.6	14.4	5.2[2]

Table 1: Comparison of results from 2013 and 2023.

Due to lack of adequate testing equipment, results of the 2023 flow-test adopt a higher inherent error. However, some critical values can still be used and with certain underlying assumptions, a comparative analysis can be drawn:

- The stabilized flowing wellhead pressure during the 2023 test was 130psi or ~8.97 barg. This stabilized wellhead pressure seems to align with the production curve established in 2013. According to the data in the 2013 report, a 3” James Tube produced ~7.97 barg and 14.3 kg/s Total Mass flow, with a calculated enthalpy of 1064 kJ/kg.
- Once at steady state the throttle valve was 100% open as per summary in appendix A – MON-1 Test Data, and managed to sustain flow through the remainder of the test with no indication of reduction.
- Flow rate was calculated by estimating test pit fill over time as well as filling a container with a known volume (5 gallon bucket). While both methods adopted more inherent error than the weir box method in 2013, the results are still similar. Based on the Total Mass flow and steam fraction calculated in 2013 for a 3” James Tube, we would expect a Brine flow rate of ~10 kg/s, however, the estimated flow-rate in 2023 was between 5-7kg/s. The difference here should be considered error more than changes in the wellbore/reservoir due to the somewhat consistent wellhead pressure and temperature recorded.

[1] Results from 2013 taken from ThermoChem data from completion report, pages 191 and 193 for 4” James tube and 6” James tube data respectively.
[2] Weir box reading not available for MON-1 well. Data taken from test pit fill averaged over time.

Mon-2 Well Performance Summary

After several failed attempts to get MON-2 to flow, the well unexpectedly came online and built up quickly and very loudly in comparison to MON-1. This could be attributed to the fact there was no James tube in the line choking flow. Initial returns were dark brown before turning to grey and as such, the well was left on clean up, bypassing the weir box for some time until the production fluid was clear.

The well flow rate was estimated from recording test pit fil rate and was recorded at 22.78 ft^3/min (645 liters/min), over a defined period. This compares to the weir box measurements with the following results shown in Table 4 below.

Date and Time	Pressure (psi)	Temperature (DegC)	Throttle Valve Position (% Open)	Q (liters/sec)	Q (liters/min)
09/04/2023 17:00	15	121.7	0.25	8.67	520.47
09/04/2023 17:15	20	126	0.25	7.38	442.92
09/04/2023 17:45	30	133.6	0.125	5.16	309.71
09/04/2023 18:00	35	135.6	0.125	4.68	280.78
09/04/2023 18:15	20	127.4	0.125	2.68	160.73
09/04/2023 18:30	15	121.4	0.125	2.06	123.51
09/04/2023 18:45	0	103	1	4.23	253.54
09/04/2023 22:45	10	120.7	0.5	10.09	605.65

Table 2: Volume flow rate over the Weir.

Note that both methods are best estimates with the equipment available and should be considered as a guide only. There are a number of inherent possible errors in the recording methods that will be discussed more fully in the full "End of Well Report".

Analysis of Results

The 2013 MON-2 flow-test results were compiled by ThermoChem and detailed in the Well Completion Report Montserrat – 1 and 2. The results suggested MON-2 had the following measurements and calculated values for geothermal development and are compared to the 2023 results for steady state on 100% open throttle valve:

DescrParameteription	ThermoChem Results 2013[3]		2023 Results
James Tube Size	4"	3"	~5" (TV 50% open)[4]
Wellhead pressure (bar)	4.9	7.1	0.7
Flowing WHT (DegC)	Not Available	Not Available	120.7
Weir Mass Flow (kg/sec)	7.36	6.91	10.09

Table 3: Comparison of results 2013 vs. 2023.

[3] Data compiled from ThermoChem Inc and taken from page 172 of the well completion report.
[4] Estimate of effective James Tube size by having the 10" throttle valve at 50% open.

Due to lack of adequate testing equipment, results of the 2023 flow-test adopt a higher inherent error. However, some critical values can still be used and with certain underlying assumptions, a comparative analysis can be drawn.

- MON-2 Well with less of a restriction at 50% open on the throttle valve exhibits a lower well head pressure and higher flowrate than what was achieved in 2013 well flow test results from a 4" and 3" James tube restriction. This is somewhat consistent with the well output curve generated in 2013, however with a lower than expected WHP. Based on the output curve generated in 2013 with a Brine flow of ~10 kg/sec, a calculated Total Mass flow would be ~16.9 kg/sec with a wellhead pressure ~3 barg[5]. The cause of the reduced WHP is unknown but will be further explored in the final report.
- The data for flow rate over the weir was used for a throttle valve setting of 50% open to compare to similar sized flow restrictions provided by the James Tube in the 2013 results. For a full record of results see appendix B – MON-2 Test Data.
- Based on the short-term test and instruments available, MON-2 appears to be able to sustain flow with managed WHP (throttling or by using a choke). It is expected with lengthen duration of discharge; the well may increase production/whp as debris is omitted from the reservoir.

5 Estimated using the data and deliverability curves on pg 242-247 of the 2013 well completion report

Appendix 1 – MON-1 Test Data

Date	Time	Time Interval between Readings (mins)	Cum Time Intervl between Readings (mins)	Pwh (psi)	Temp (DegC)	Pit Freeboard (ft)	Notes
01/04/2023	13:50:00	0	0	10	33	7	
01/04/2023	14:00:00	10	10	15	38.3	7	
01/04/2023	14:10:00	10	20	10	45.6	7	
01/04/2023	14:20:00	10	30	10	56.3	7	Closed Throttle valve 19 turns to choke back flow.
01/04/2023	14:30:00	10	40	10	59.2	6.9	
01/04/2023	14:40:00	10	50	15	80	6.8	
01/04/2023	14:50:00	10	60	20	96.7	6.8	
01/04/2023	15:00:00	10	70	30	112.6	6.7	
01/04/2023	15:10:00	10	80	40	124.9	6.6	Opened Throttle valve 1/8th (19 turns, 77 total) throttle valve now half open.
01/04/2023	15:20:00	10	90	50	117.8	6.6	Opened Throttle valve 1/8th (19 turns, 96 total).
01/04/2023	15:30:00	10	100	60	137.5	6.5	
01/04/2023	15:40:00	10	110	70	146.7	6.4	Opened Throttle valve 1/8th (19 turns, 115 total).
01/04/2023	15:45:00	5	115				Isolated air compressor. Well lifting unassisted.
01/04/2023	15:50:00	5	120	65	150	6.3	
01/04/2023	16:00:00	10	130	80	158.1	6.3	
01/04/2023	16:10:00	10	140	90	167.2	6.3	
01/04/2023	16:20:00	10	150	95	168.9	6.2	
01/04/2023	16:30:00	10	160	100	168.9	6.1	
01/04/2023	16:40:00	10	170	110	170	6.05	
01/04/2023	16:50:00	10	180	110	172.8	6.05	

01/04/2023	17:00:00	10	190	110	172.8	6.025	Opened Throttle valve 1/8th (19 turns, 134 total).
01/04/2023	17:10:00	10	200	110	173	6	
01/04/2023	17:20:00	10	210	110	171	5.95	
01/04/2023	17:30:00	10	220	110	175	5.9	Opened Throttle valve 1/8th (20 turns, 154 total). Throttle valve fully open.
01/04/2023	17:40:00	10	230	110	173	5.9	
01/04/2023	17:50:00	10	240	110	173	5.8	
01/04/2023	18:00:00	10	250	115	174	5.8	
02/04/2023	08:00:00	840	1090	125	176	0	
02/04/2023	08:30:00	30	1120	125	176	0	
02/04/2023	09:00:00	30	1150	125	176.3	0	
02/04/2023	09:30:00	30	1180	125	178.1	0	
02/04/2023	12:00:00	150	1330	125	176.3	0	
02/04/2023	15:00:00	180	1510	130	177.9	0	
02/04/2023	18:00:00	180	1690	130	177.5	0	
03/04/2023	09:00:00	900	2590	130	177.8	0	
03/04/2023	09:30:00	30	2620	130	177.9	0	

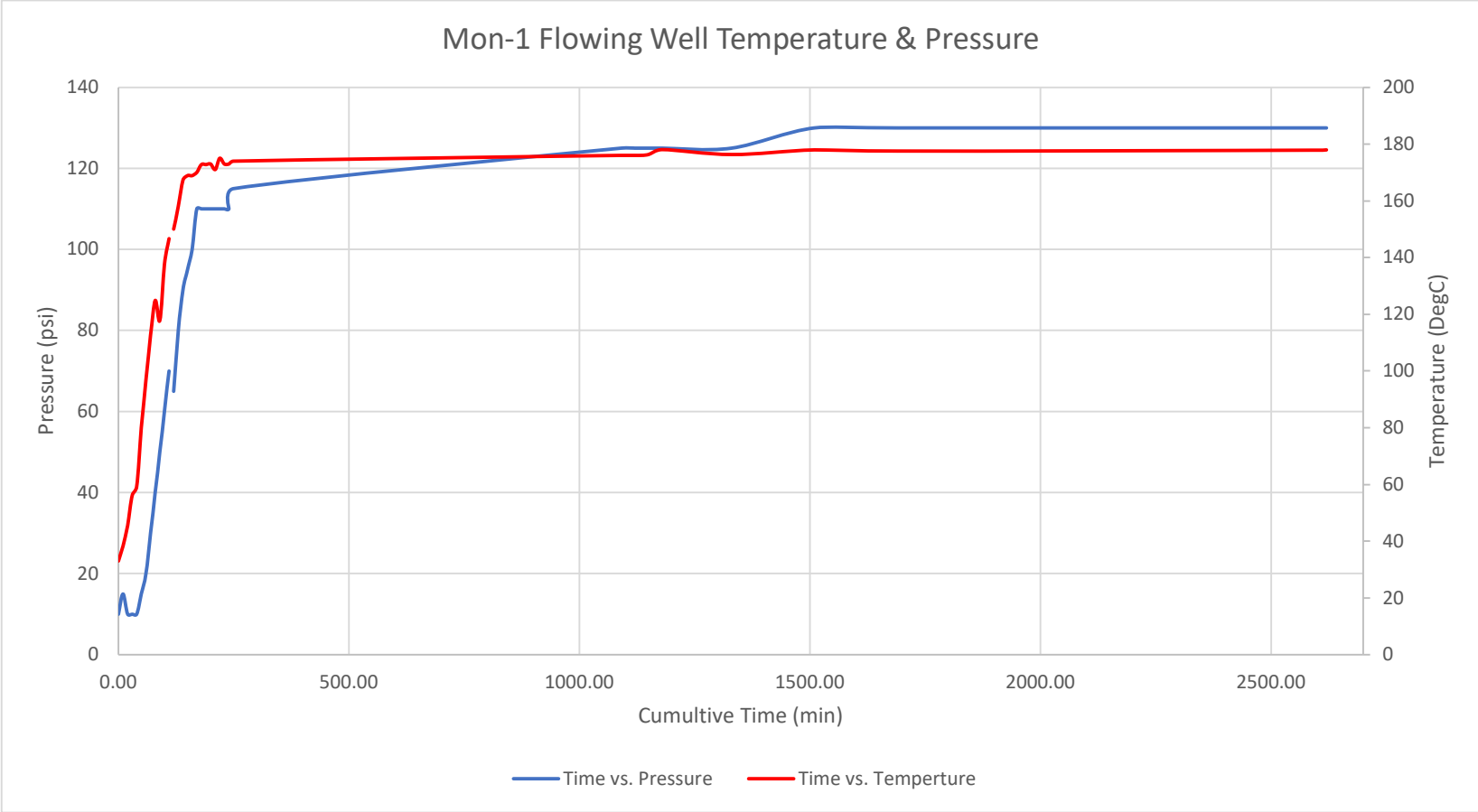

Figure 1: Well Head temperature / pressure profile MON-1 well test.

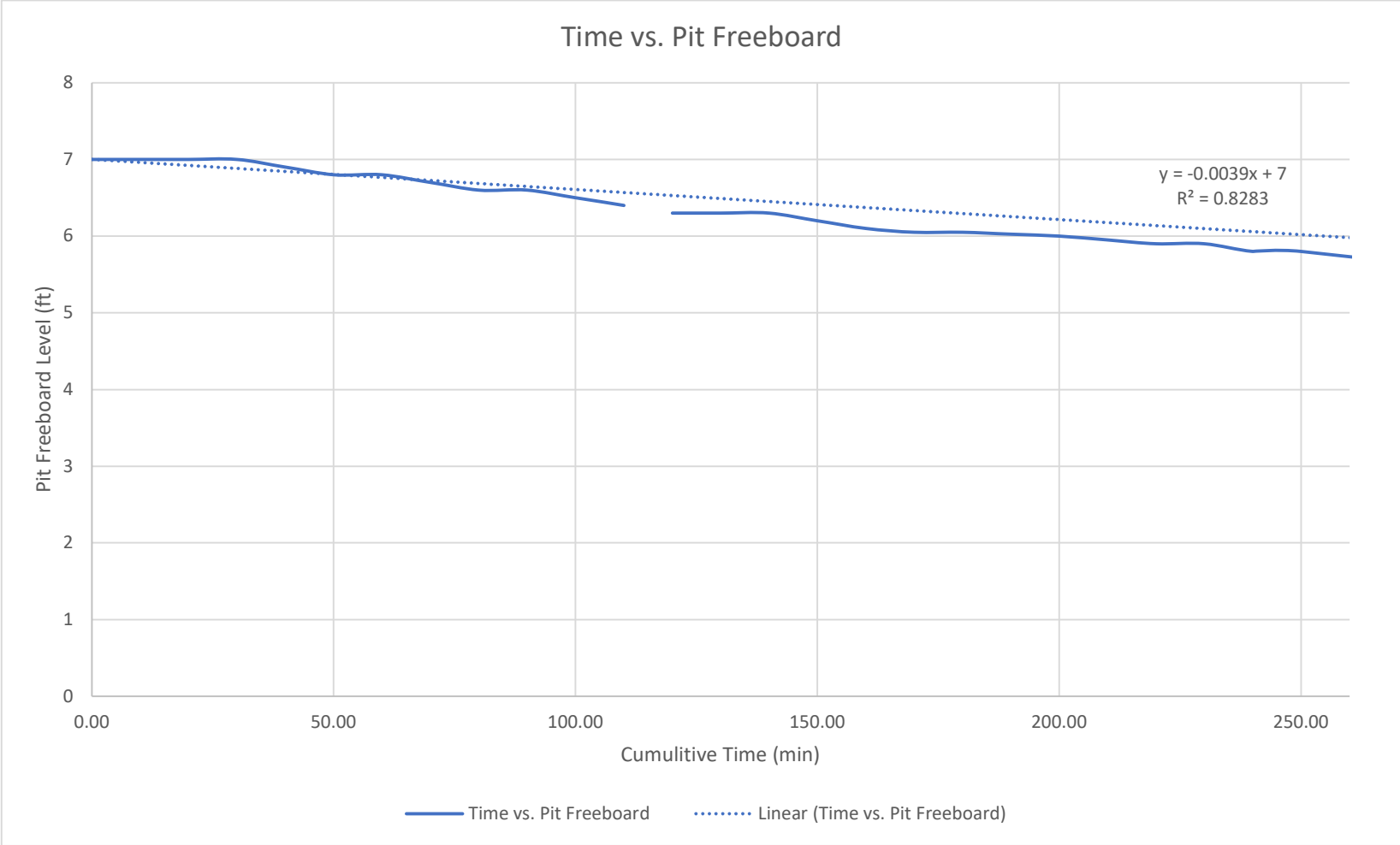

Figure 2: Test pit fill over time (XSA = 75ft x 42.5ft = 3,187.5 ft^3)..

Appendix B – MON-2 Well Test Data

Date and Time	Time Interval between Readings (mins)	Cum Time Intervl between Readings (mins)	Pwh	T	Fl / Weir	Comments
07/04/2023 18:30	0.00	0.00	20	32	7	TV opened 57 turns (37.5% Open)
07/04/2023 18:40	10.00	10.00	20	32.7		
07/04/2023 18:50	10.00	20.00	100	37.6		
07/04/2023 19:05	15.00	35.00	40	33.7		Opened TV 3 turns and observed pressure drop.
07/04/2023 19:10	5.00	40.00	35	40.1		
07/04/2023 19:20	10.00	50.00	30	40.6		Opened TV 1/8th (19 turns, 50% Open).
07/04/2023 19:30	10.00	60.00	10	44		
07/04/2023 19:40	10.00	70.00	10	51		
07/04/2023 19:45	5.00	75.00	10	54.7		Opened TV 5 turns (52.5% Open).
07/04/2023 19:50	5.00	80.00	10	60		Opened TV 5 turns (55.8% Open).
07/04/2023 20:00	10.00	90.00	10	68.1		
07/04/2023 20:05	5.00	95.00	10	72		Opened TV 10 turns (62.3% Open).
07/04/2023 20:10	5.00	100.00	10	79.2		Observed compressor pressure steady at 150 psi. Opened TV 10 turns (68.8% Open).
07/04/2023 20:15	5.00	105.00	10	87		
07/04/2023 20:20	5.00	110.00	10	89		
07/04/2023 20:30	10.00	120.00	20	105.6		Opened TV 1/8th (19 turns, 81% Open).
07/04/2023 20:40	10.00	130.00	50	147		Opened TV 1/8th (19 turns, 93.5% Open).
07/04/2023 20:45	5.00	135.00				Shut down air compressor
07/04/2023 20:50	5.00	140.00	40	144		Opened TV 1/8th (19 turns, 100% Open).
07/04/2023 21:00	10.00	150.00	25	136		
07/04/2023 21:05	5.00	155.00	20	136		
07/04/2023 21:10	5.00	160.00	15	132		
07/04/2023 21:20	10.00	170.00	15	128		
07/04/2023 21:30	10.00	180.00	10	127		
07/04/2023 21:50	20.00	200.00	10	123		Closed TV 1/4 (38 turns, 75% Open).
07/04/2023 22:00	10.00	210.00	15	125	5	

08/04/2023 08:30	630.00	840.00	5	120.5	1.5	Opened throttle valve (TV) 1/4 (38 turns, Open 100%).
08/04/2023 09:00	30.00	870.00	5	120.1	1.2	
08/04/2023 13:00	240.00	1110.00	5	118.1	0	Closed TH 1/4 (38 turns, Open 75%).
08/04/2023 16:30	27.00	1137.00	8	117	0	Closed TV 1/4 (38 turns, Open 50%).
08/04/2023 16:45	15.00	1152.00	8	118	0	
08/04/2023 17:00	15.00	1167.00	9	119	0	
08/04/2023 19:00	120.00	1287.00	15	126.2	0	
09/04/2023 08:30	810.00	2097.00	20	124.1	0	Opened throttle valve (TV) 1/8 (19 turns, open 62.5%).
09/04/2023 09:30	60.00	2157.00	15	123.42	0	
09/04/2023 10:00	30.00	2187.00	10	115	0	Closed TH 1/8 (19 turns, open 50%).
09/04/2023 10:30	180.00	2367.00	10	118.5	0	
09/04/2023 13:30	30.00	2397.00	10	114.3		
09/04/2023 14:00	30.00	2427.00	10	114.3		Closed TV 1/4 (19 turns, open 32.5%).
09/04/2023 14:30	30.00	2457.00	10	115.7	0	
09/04/2023 15:00	30.00	2487.00	15	120.5	0	
09/04/2023 15:30	30.00	2517.00	10	119.1	0	
09/04/2023 16:00	30.00	2547.00	10	118.9	0	
09/04/2023 16:15	15.00	2562.00	12	119.9		***Removed bypass for clean-up and commenced flowing through weir box.***
09/04/2023 16:45	30.00	2592.00	15	119.9		Level measured above weir = 7"
09/04/2023 17:00	15.00	2607.00	15	121.7	7	Closed TV 1/8 (19 turns, open 25%).
09/04/2023 17:15	15.00	2622.00	20	126	7.25	
09/04/2023 17:45	30.00	2652.00	30	133.6	7.75	Closed TV 1/8 (19 turns, open 12.5%).
09/04/2023 18:00	15.00	2667.00	35	135.6	7.875	
09/04/2023 18:15	15.00	2682.00	20	127.4	8.5	
09/04/2023 18:30	15.00	2697.00	15	121.4	8.75	Opened TV fully open (135 turns, open 100%). Observed instantaneous drop of pressure.
09/04/2023 18:45	15.00	2712.00	0	103	8	Closed TV 1/2 (77 turns, open 50%).
09/04/2023 22:45	240.00	2952.00	10	120.7	6.75	Closed in well, end of 48hr flow period

Table 4: Raw data collected from MON-2 well test.

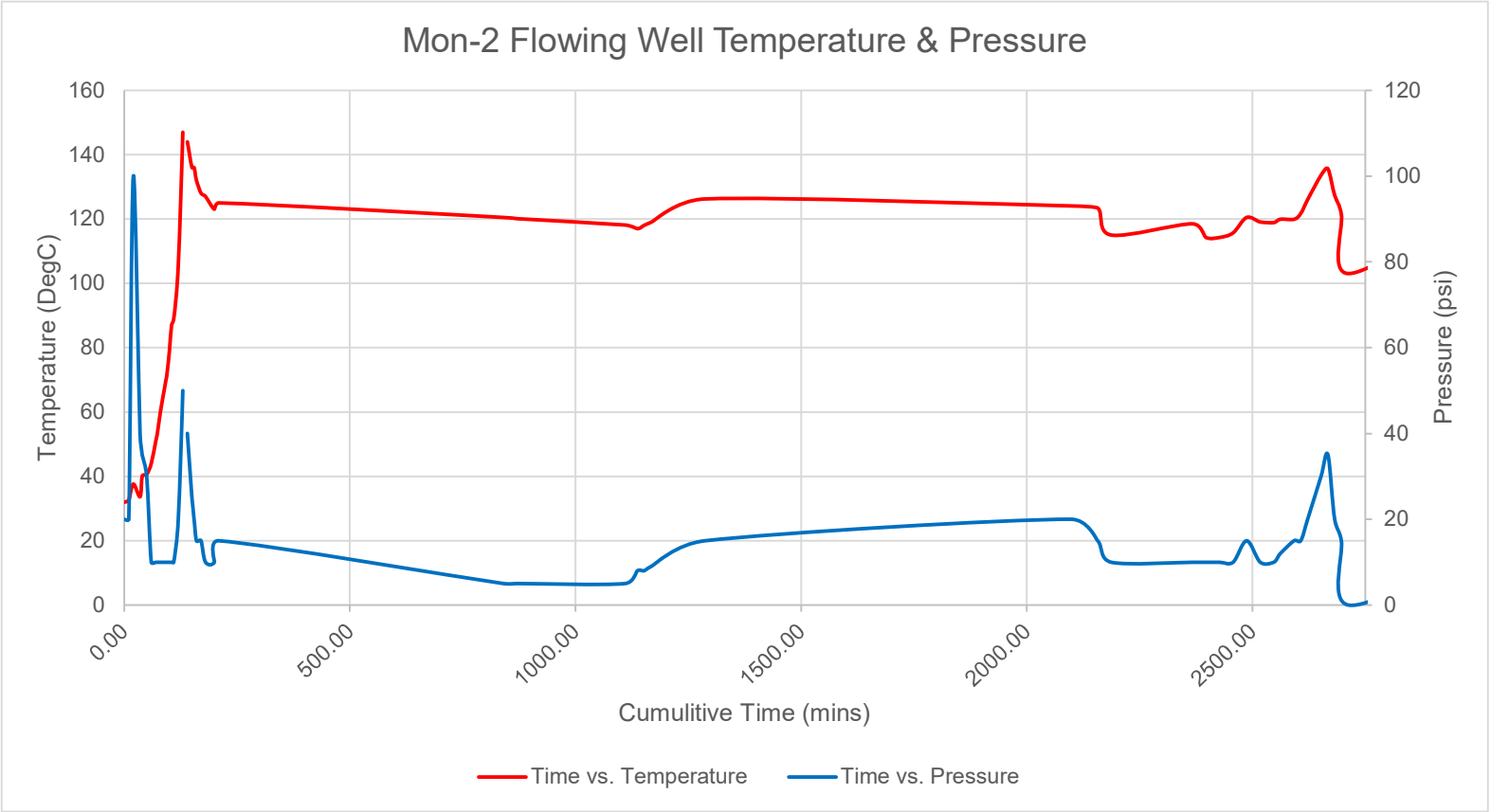

Figure 3: Graphical representation of raw data from Mon-2 well flow test. Note that MON-2 did not respond as steadily as MON-1 and required many adjustments to assess best performance of MON-2.

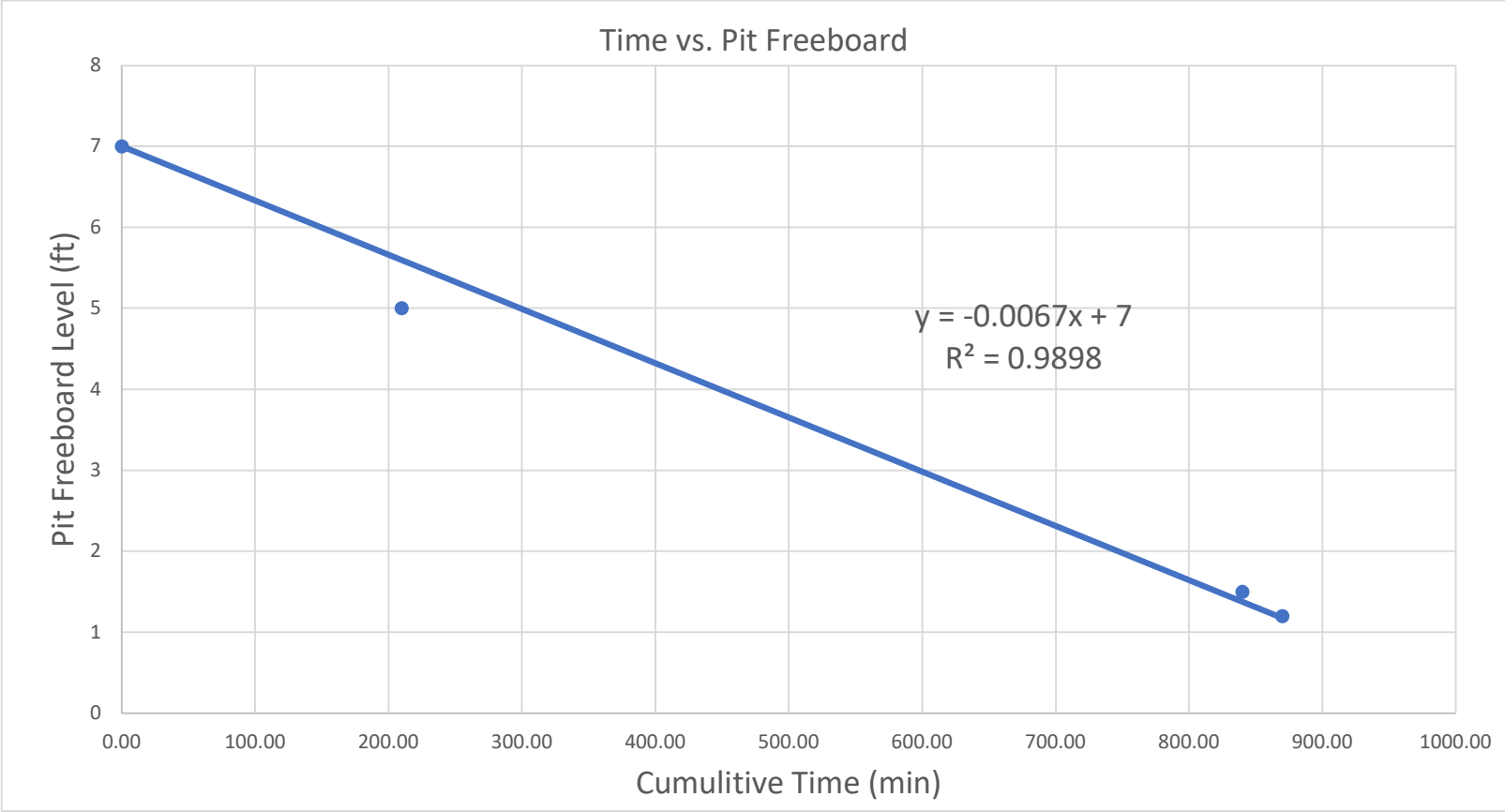

Figure 4: Trend of freeboard reduction and pit volume fill over time MON-2 (XSA = 80ft x 42.5ft = 3,187.5 ft^3).