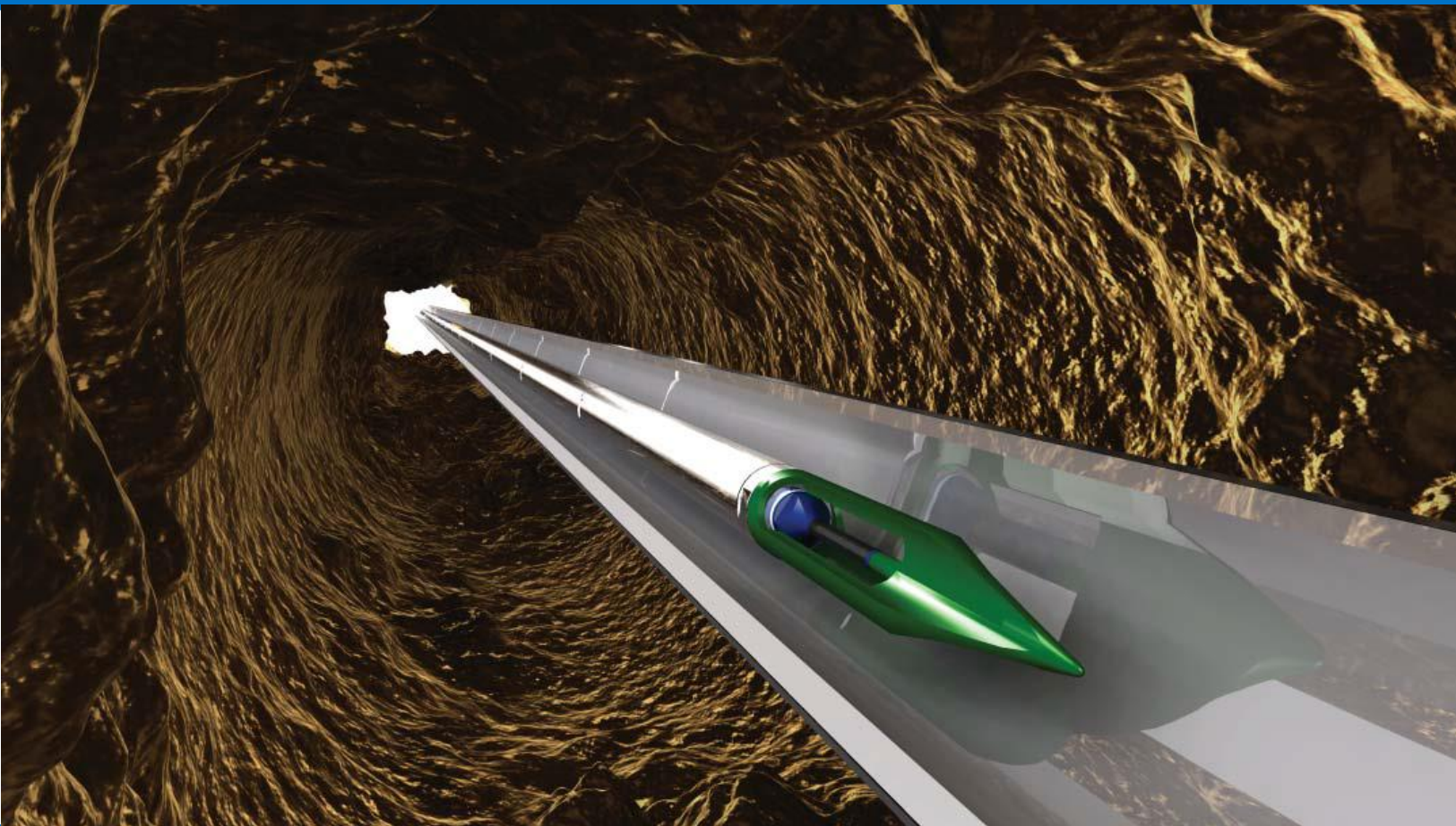




Field Experience with a Redesigned Electronic Downhole Corrosion Monitoring System and Coupon Module

White Paper



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ABSTRACT

A redesigned Rohrback Cosasco Systems (RCS) in situ monitoring probe (RCS DCMS™ - Downhole Corrosion Monitoring System) was evaluated in the East Texas and Colorado regions of North America. A large inhibitor supplier had determined through advanced modeling equations that at certain depths, corrosion rates up to 500 mpy were indicated on certain wells, if left untreated. Case studies were undertaken on those wells, as well as new untreated wells to confirm downhole corrosion at those depths with the DCMS. The results were unexpected, but the data were confirmed with a DCHA-9 company coupon module correlated with two MWT-3905-MDL-0 company surface tools. The three corrosion monitoring methods not only allowed for correlation of data, but also an understanding of a cost-effective treatment of the well. The results further demonstrated that while corrosion modeling can be very useful in some scenarios, it may not be accurate in others, and cannot be depended on by itself, whereas an in-situ probe element and coupon can better represent the environment to be monitored.

INTRODUCTION

With costs of oil and gas production increasing due to global demand and deeper explorations, ageing wells are becoming more of a maintenance issue for companies combating the various forms of corrosion. The problem is complex, whether it is reducing operating costs and limiting shutdowns for an older well, or finding data that can characterize a shared shale formation for new wells. The continued goal of an end user has always been to pursue a way to cost effectively treat and maximize the well life.

The original Rohrback Cosasco Systems (RCS) monitoring product (DCMS™ - Downhole Corrosion Monitoring System), designed in the late 90's, was recently reengineered as part of a complete overhaul for today's downhole corrosion monitoring challenges. The redesigned improvements focused on updated electrical components, enhanced battery performance, and a more compact design. The goal was to rejuvenate and remind the oil and gas industry that options remain for downhole corrosion monitoring applications. Additionally, new tools such as the RCS Downhole Coupon Holder Assembly (DCHA) were added to help validate those results. The original DCMS had been extensively tested in Prudhoe Bay, Alaska. Recently the company worked with end users on field trials in Texas and Colorado, with the redesigned DCMS in applications of chemically treated and untreated wells.

Originally, the study targeted monitoring depths selected by the results from an inhibitor modeling study. The modeling estimated corrosion rates up to 500mpy corrosion rate at these depths. This caused concern for the end user to find a way to validate those rates and develop the appropriate treatment to be applied. The primary plan was for a bacterial study with swab sampling from coupon at the depths of concern. The DCMS was integrated into the test plan to assess the efficiency of the current chemical treatments in Texas, and to find a target treatment for the untreated wells in Colorado. Material selection and other inhibitors were key questions to address once some baseline corrosion data was found. The potential benefits for the study vastly outweighed the risks and costs. For wells being over treated, the savings could be high, and if undertreated, the savings could be enormous by minimizing unscheduled shutdowns while increasing the longevity of their assets.

1. CHARACTERISTICS OF THE TOOLS

The DCMS is a battery-powered data logging system which collects continuous corrosion data. The instrument is comprised of probe – (RCS CORROSOMETER®), and a cylindrical body of 1.25" X 46" constructed to satisfy NACE MR0175 requirements by use of 17-4 PH stainless steel. The device stores

up to 120 days of data at 4 hour (1024 readings) and operates in very high temperatures. Figure 3 shows a standard schematic of the DCMS.

The DCHA is a coupon module designed to hold up to nine coupon assemblies in any configuration of corrosion coupon, tensile specimen coupon, or NACE TM0177-2005 comparable Bent Beam corrosion coupon. The coupons are typically made out of the same material as the tubing, but can be of any required alloy. The DCHA can operate in temperatures up to 250°C (482°F) and can support anywhere from three to nine coupon holder assemblies, nine being the most common. Figure 5 shows an example of a three-coupon assembly. The RCS Microcor[®] Datalogger is a high resolution electrical resistance (ER) surface instrument used to correlate downhole corrosion and effectiveness of treatment, with the corrosion response at the surface.

The tools have been designed to affect the downhole flow minimally and can be applied for casing or tubing schemes, but not in pumping rod applications.

The targeted applications for the tool include:

- Inhibitor Selection/Effectiveness and Film Persistence
- Material Selection/Effectiveness
- Determining General Corrosion/Erosion effects
- Bacterial Swabbing of Probe after retrieval (Figure 9)
- Pitting Analysis of Probe after retrieval

Probe Spans: T10 - 5 mils, T20 - 10 mils	Memory Capacity: 1024 Measurements
Resolution: 0.1% of Probe Span	Shock Tested: 3 axes, 25g, 11mS pulses
Power Source: Lithium battery	Vibration Tested: 20-50Hz, 50 m/S ² , 30 min each axis
Typical Battery Life: 90 days, reading once every 2 hours	Measurement Intervals: 1, 2 or 4 hours
Maximum Operating Pressure: 10,000 psi (69 MPa) Maximum	DCMS Weight: 30 lbs. (13.6 kg)
Maximum Operating Temperature: 302°F (150°C)	

Figure 1
DCMS Specifications

Environment: Oil, Gas, Water Production	Main Components:
Temperature: 302°F (150°C) maximum (mated to DCMS Tool)	• Downhole Coupon Holder Assembly Body
Pressure: 10,000 psi (69 MPa) maximum	• 9 Individual Coupon Holder Assemblies (may include Strip, Cylindrical, or Bent-Beam)
Body Material: 316 Stainless Steel	• Bull-Nose Sucker Rod Connection, 5/8" Sucker Rod Connector, and 5/8" Sucker Rod Adapter
Thread Attachment: 5/8" API Sucker Rod Connection Spec.	

Figure 2
DCHA Specifications

¹ Microcor is a registered trademark of Rohrbach Cosasco Systems, Inc.

² Corrosometer is a registered trademark of Rohrbach Cosasco Systems, Inc.

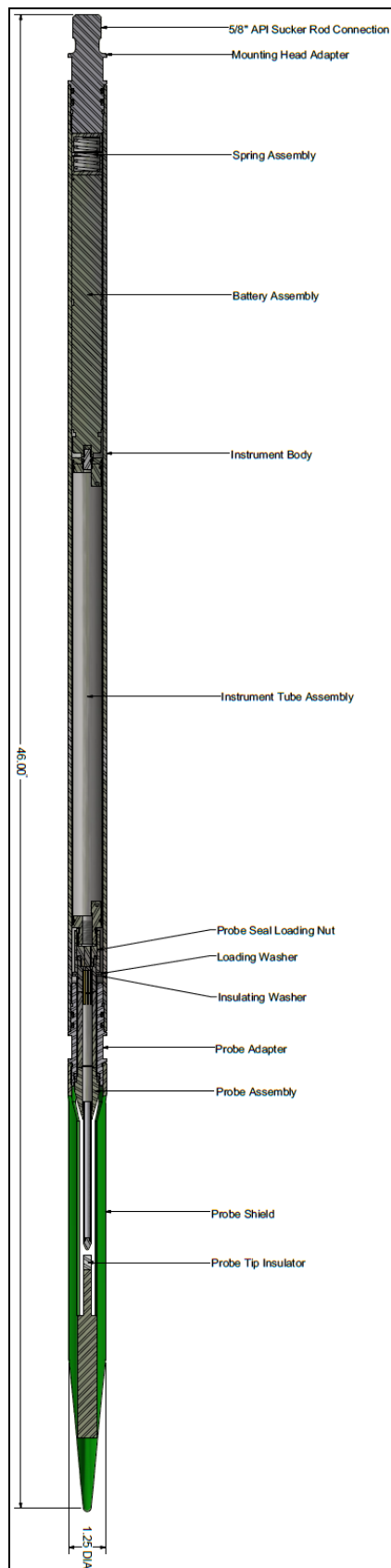


Figure 3
Cross sectional view of DCMS



Figure 4
Field Installed DCMS

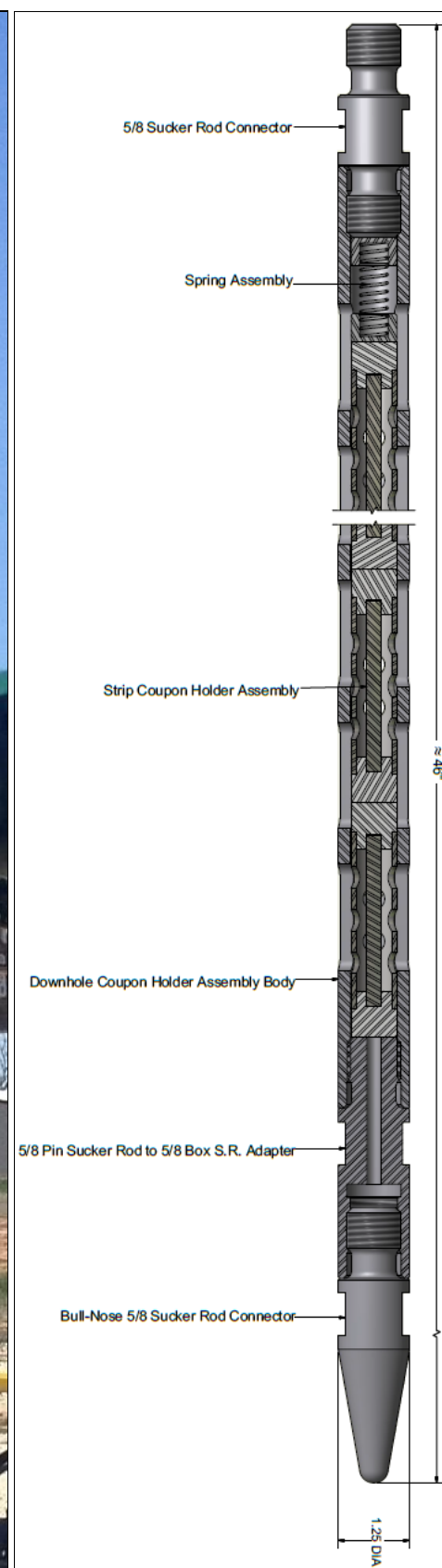


Figure 5
Schematic view of DCHA

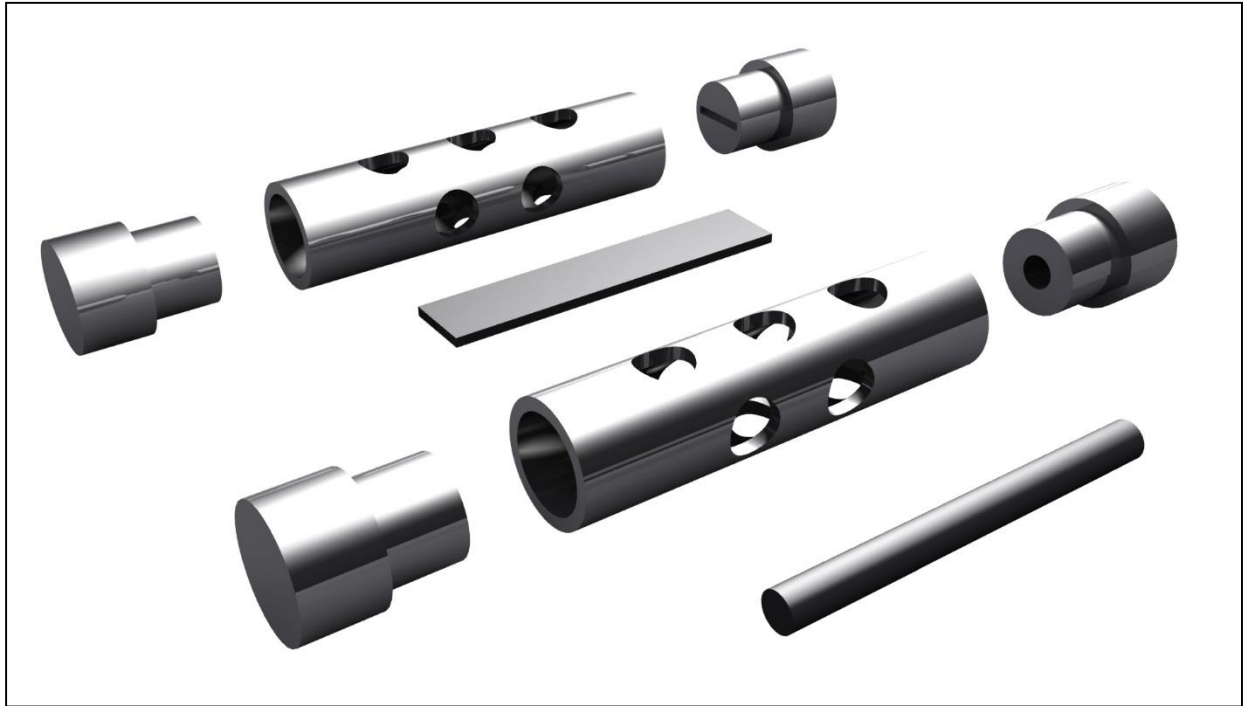


Figure 6
Strip Corrosion Coupon and Tensile specimen rod Coupon Holder



Figure 7
Pre-Stressed Bent-Beam Coupon Holder

DHT Programmed Measurement Interval	Approximate Operating Time (with a new Battery Assembly)
30 min.	22 days
1 hr.	45 days
2 hr.	90 days
4 hr.	150 days

Figure 8
DCMS Operating Duration

2. FIELD TESTING

2.1.1 TEXAS FIELD STUDY

The field trials in Texas were spearheaded by an asset integrity team that had concerns on the predicted 500 mpy corrosion model for some of their wells. The initial study was to be an in depth bacterial analysis of swabbing samples from a gauge ring, but was expanded to include the in situ probe data logging instrument.

After the first run of tests, the DCHA was used as a supplementary tool for validating and correlating results. It consisted of nine metal loss coupons: seven corrosion strip coupons and two pre-stressed bent beam. Two of the corrosion strip coupons were stainless steel, with the remaining coupons were carbon steel.

In addition to monitoring downhole, the probes at the surface also monitored electrical resistance downstream of the wells with the high resolution RCS Microcor Datalogger to correlate data from the in situ downhole device and data from the surface instruments.

The wells were specifically selected based on modeling done by the inhibitor supplier. Although these wells were 15,000 – 20,000ft deep, the depths selected for installation were approximately 3000ft, with expected pressures to be 2000 – 3500 psi. The measurement interval was configured on the DCMS at 1hr. Lower producing test wells were selected in order to challenge the tools. The wells were also slightly deviated, so using the appropriate tools such as centralizers and knuckle joints in the right places was critical. The tubing application was one of the typical sizes of 2 3/8". The effective temperatures were in the range of 150-200°F. The CO₂ content was in the area of approximately 5% for the tested wells. Further details were unavailable for the wells under study.

2.1.2 OBJECTIVE

The primary focus was to verify if the corrosion simulations were accurate, Secondary objectives, once a baseline for corrosion analysis had been achieved, were to:

- Determine bacterial influence on wells
- Validate simulated corrosion rate of up to 500 mpy determined at 3000ft
- Determine effectiveness of corrosion inhibitor
- Determine length of effectiveness of corrosion inhibitor and the different injection methods (continuous or batch)



Figure 9
Bacterial analysis from DCMS probe

2.1.3 PREPARATION

In planning for the downhole study, RCS and the client had studied various well characteristics before determining the correct wireline parts for each respective well. Selecting the correct wireline tools for the DCMS is critical and information needed to be checked with the wireline team if soft setting or shock absorbing wireline equipment was not available. Influences such as pressure, temperature, diameters, lengths, element type, and sensitivity are some of the variables to take into account when planning to run a tool downhole. The probe depth should be predetermined with installation being done via slick line.

In addition to the DCMS toolkit, other consumables need to be properly accounted for when preparing for the current or future installs and retrievals. Typical consumables include the following:

- Batteries (Non-Rechargeable)
- Seals
- Probes
 - T20 (10 Mil Span Probe) or T10 (5 Mil Span Probe)
(Depending on sensitivity needed)
- Coupons

- Bent Beam
- Cylindrical
- Strip
- Element Material

Typically, all parts are assembled and tested for at least a few readings before running downhole. The ideal preparation would be to leave the DCMS running over night to validate measurements after complete assembly.

2.1.4 TEST PLAN

The client required an accelerated five-week study for each well. One week with no treatment, one week with chemical at 0.5x their recommended dose rate, one week at recommended rate, and finally at 2x the recommended rate. The bacterial analysis was to be done first after a scraper tool was run to collect solids from the wellbore for scale depositions. The scraper tool is also recommended to be run prior to any DCMS or DCHA installation, to clear out of any potential debris that could get the tools caught while running in the hole. Bacterial analysis of samples taken from the DCMS probe would also be taken (Shown in Figure 9), once retrieved from downhole.

2.1.5 WIRELINE

Wireline tools are a critical part of the DCMS and DCHA installation. Using “soft setting” tools is a bit of an art itself, so knowledgeable and skilled personnel must be hired for this portion of the job. Although most of the previous findings have shown little flow restrictions from wireline tools, it is critical to select the slimmest outer diameters of tools and minimize any pressure drops. Typically, there are three runs for a complete installation from start to end on a single well. First, the well is cleaned by a gauge ring (cutter) tool string, followed by the setting and installed tool string of the tools to be left downhole. The final step would be the retrieval tool string, used to remove the installed tool string so that data can be analyzed on the surface. Depending on variables such as anticipated corrosion rates, flow and pressure, the amount of safety tools in the tool string can vary. There is no one size fits all type of wireline tools, but there are many common parts used in addition to the well dependent components.

2.2.1 COLORADO FIELD STUDY

The second field trials in Colorado benefitted from the previous experience in Texas. Tubing displacement records indicated that most of the general corrosion occurred in the 1000ft range, suggesting the targeted depth for the test. The study for the Colorado wells involved the use of two DCMS tools at different depths of the tubing, approximately 50ft apart. The DCHA was attached just behind the upper DCMS, shown in Figure 12. The surface ER probes were installed just downstream of the well, one probe in the vertical position, and the other is in the horizontal position.

The Colorado trials were to determine the existing corrosion rate on the first run, followed by a second run to examine the effectiveness of a new treatment. The well details were limited since these wells were completely untreated with no prior data recorded of the wells. The only expectations from the selected well was that results should demonstrate a high corrosion rate.

The trials were run, both using Figure 12 configuration. The initial trial used standard coupons for the DCHA, mostly carbon steel. The second trial had many more unique alloys in the coupon holder. The decision there was to see how different alloys react to the type of corrosion in the well, and then using this well to characterize other wells in the area. The second trial on this well is currently in progress at the time of this report.

3. RESULTS AND DISCUSSION

3.1.1 TEXAS RESULTS AND DISCUSSION

On completion of the first five-week trial, the bacterial results were inconclusive, whereas the DCMS and Microcor surface corrosion indicated rates were both consistent. The data correlated for both instruments: surface and downhole showed that the corrosion rate was low at the chosen depths, and in contradiction with the modeled rates at that point. This left doubt about the results, so the following trial was planned in more detail.

For the next downhole test, a larger window was set for each period of treatment. Leaving the wells untreated for about two weeks, plus an initial two weeks prior to installation so the DCMS acclimates with no residual effects from prior chemical treatment. This also allowed more time for the 9 coupons in the DCHA to get more acclimated to the downhole environment.

The second cycle of five week testing for the same wells produced similar results. This time, the DCHA was also included directly attached behind the DCMS, and was able to validate the data recorded by the DCMS. Figures 10 and 11 clearly indicate a corrosion rate of < 10 mpy for those particular trials. The coupon analysis validated with an average corrosion rate of < 3 mpy. As expected the stainless steel coupons were more corrosion resistant than the carbon steel coupons. The temperatures were fairly consistent near 200°F (≈93°C).

The DCMS clearly revealed the limits of having only a coupon holder. Figures 10 and 11 of the DCMS data demonstrated a more interactive response and reaction of the chemical treatment and dosage from week to week.

All three sets of monitoring (DHT, DCHA and Microcor Datalogger) correlated, putting any lingering doubts to rest. Subsequently, this allowed the end user to scale back treatment accordingly, while proceeding with their study on other untreated wells in Colorado.

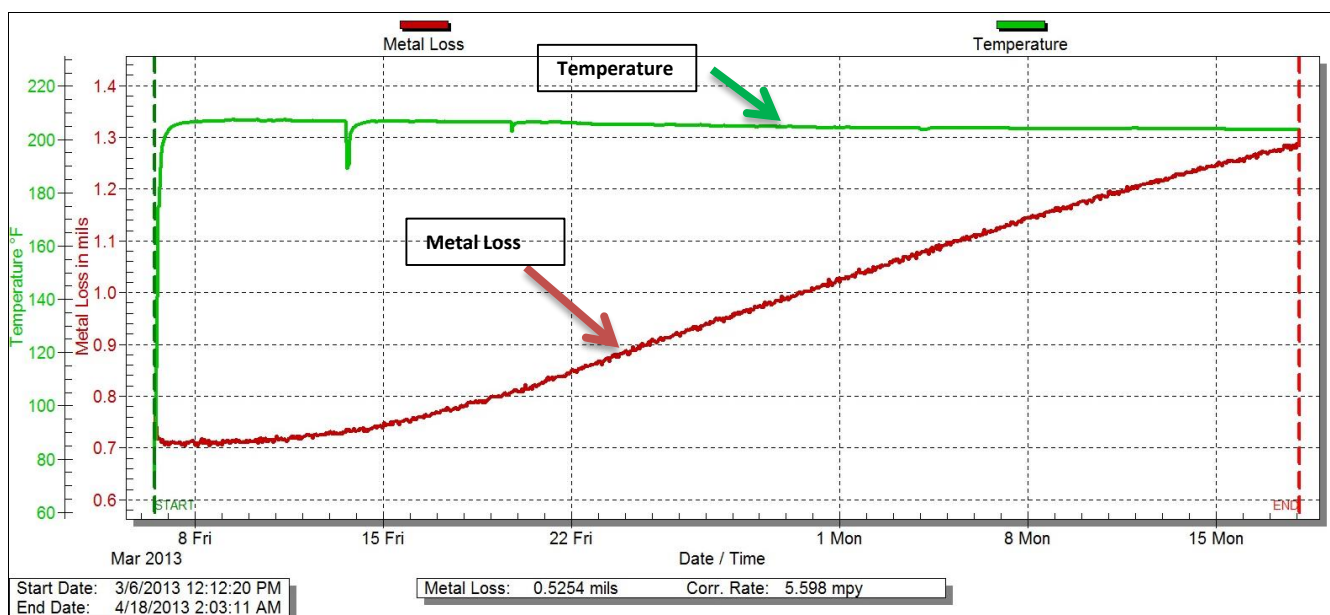


Figure 10

Texas DCMS - Metal Loss & Temperature vs. Time

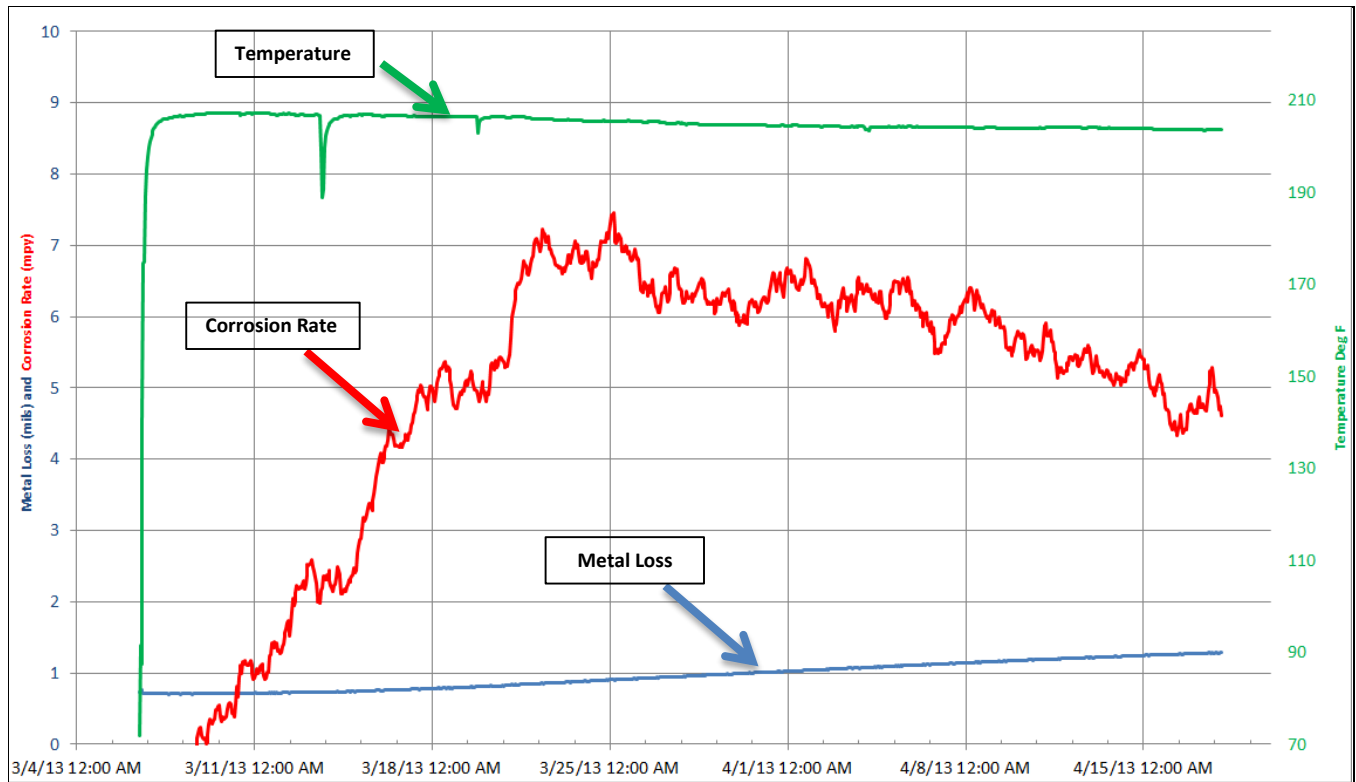


Figure 11

Texas DCMS 5 Mil Probe Span - Corrosion Rate, Metal Loss, and Temperature vs. Time

Bent Beam Coupons - Carbon Steel (G10180)										
	Coupon ID	Install Date	Remove Date	Expose Time Days	Expose Time Hours	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Corrected Weight Loss (g)	Corrosion Rate (mpy)
1	HL884	5-Mar-13	23-Apr-13	49	1176	3.8533	3.8001	0.0532	0.0484	2.143
2	HL885	5-Mar-13	23-Apr-13	49	1176	3.8385	3.7529	0.0856	0.0808	3.578
Strip Downhole Coupon - 410 Stainless Steel										
	Coupon ID	Install Date	Remove Date	Expose Time Days	Expose Time Hours	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Corrected Weight Loss (g)	Corrosion Rate (mpy)
3	HL888	5-Mar-13	23-Apr-13	49	1176	11.4555	11.4273	0.0282	0.0255	0.439

4	HL889	5-Mar-13	23-Apr-13	49	1176	11.4672	11.4407	0.0265	0.0238	0.409
Strip Downhole Coupon - Carbon Steel (G10180)										
	Coupon ID	Install Date	Remove Date	Expose Time Days	Expose Time Hours	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Corrected Weight Loss (g)	Corrosion Rate (mpy)
5	HL892	5-Mar-13	23-Apr-13	49	1176	11.8678	11.6848	0.183	0.1754	2.951
6	HL893	5-Mar-13	23-Apr-13	49	1176	11.937	11.8444	0.0926	0.0853	1.435
7	HL894	5-Mar-13	23-Apr-13	49	1176	11.9085	11.767	0.1415	0.01342	2.258
8	HL895	5-Mar-13	23-Apr-13	49	1176	11.7925	11.6263	0.1662	0.1589	2.674
9	HL896	5-Mar-13	23-Apr-13	49	1176	12.034	11.9101	0.1239	0.1166	1.962

Table 1
DCHA Coupon Data from Texas well

3.1.2 COLORADO RESULTS AND DISCUSSION

The Colorado study indicated high corrosion rates as anticipated. The corrosion at 1000ft was found to be extremely aggressive, and at times so aggressive, it caused not only the probes to be completely consumed, but also damage to the wireline tools holding the instruments in place to corrode as seen in Figure 17.

Two separate trials were run. The first used all three instruments (DCMS, DCHA and Microcor Dataloggers on surface) arranged similar to the downhole configuration in Figure 12. The data (Figures 13-16) confirmed that corrosion was aggressive, to the extent that the probes were either completely consumed by general or localized corrosion.

For Colorado Trial 1, the corrosion was so aggressive that the setting tool dogs holding the top DCMS and DCHA tools in place. Immediately after the setting tool dogs corroded through, both tools shot up to the surface. That event was later evident, once the tools were retrieved and were noticed to be sitting near the top of the well bore. Figure 15 approximates when that upset may have occurred. Figure 16 gives a visual on an actual probe break.

Colorado Trial 2 was done in two stages. While the tool arrangements were exactly the same as for the first trial, DCMS and DCHA were both retrieved after about one month. The Figure 19 plot was truncated due to complete probe consumption. The second DCMS (Bottom) was targeted to hold two months of data. The client separated the retrievals in two parts to see the effectiveness of a treatment they were to start in the middle of the trial. The original intended date for injection was delayed by an injection problem. It was later found that even if treatment had begun as intended, it would have been too late to be monitored as the DCMS had already been consumed (Figures 18-21). The same trial is being repeated on a shorter time scale to monitor the treatment.

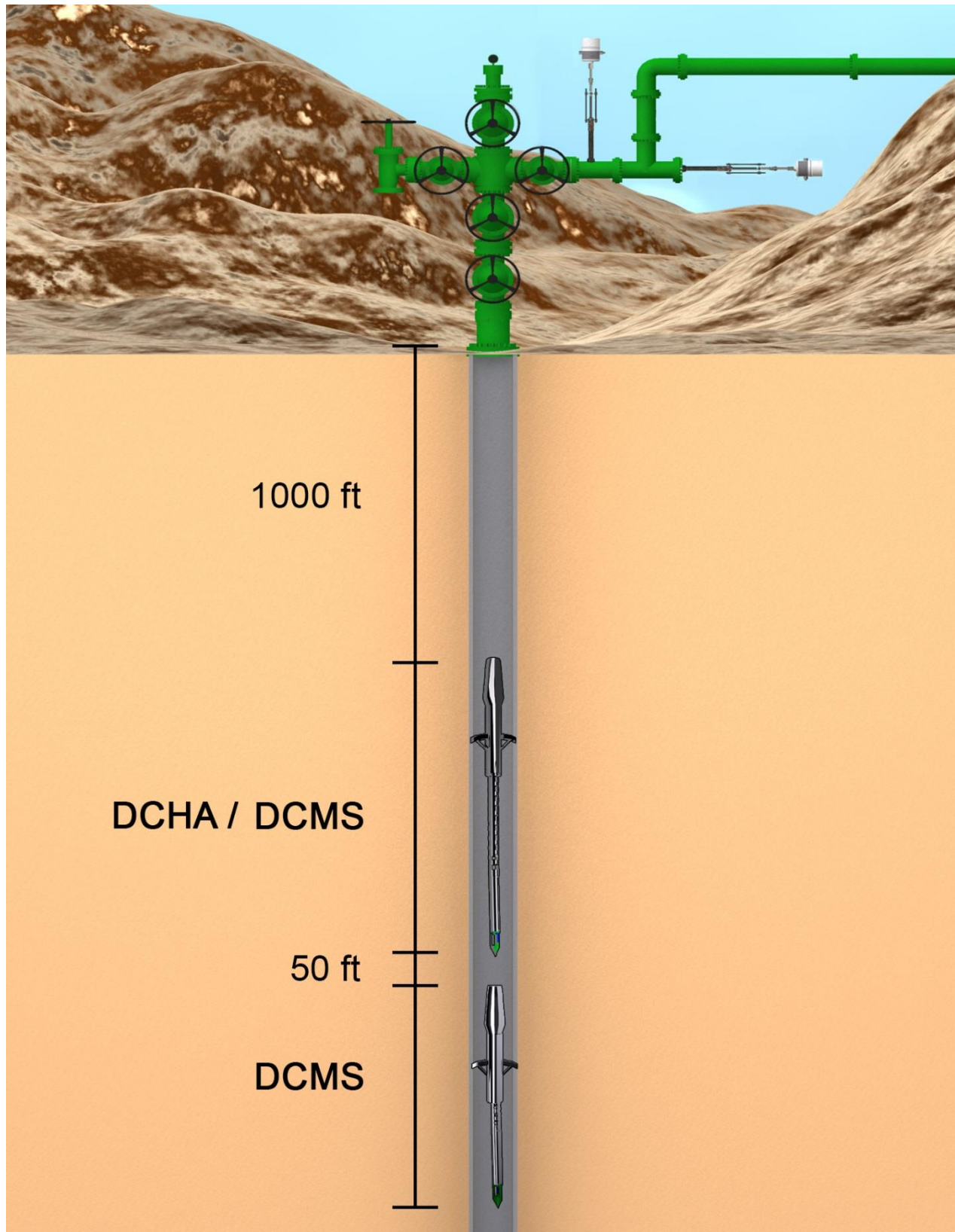


Figure 12
Colorado Downhole Configuration

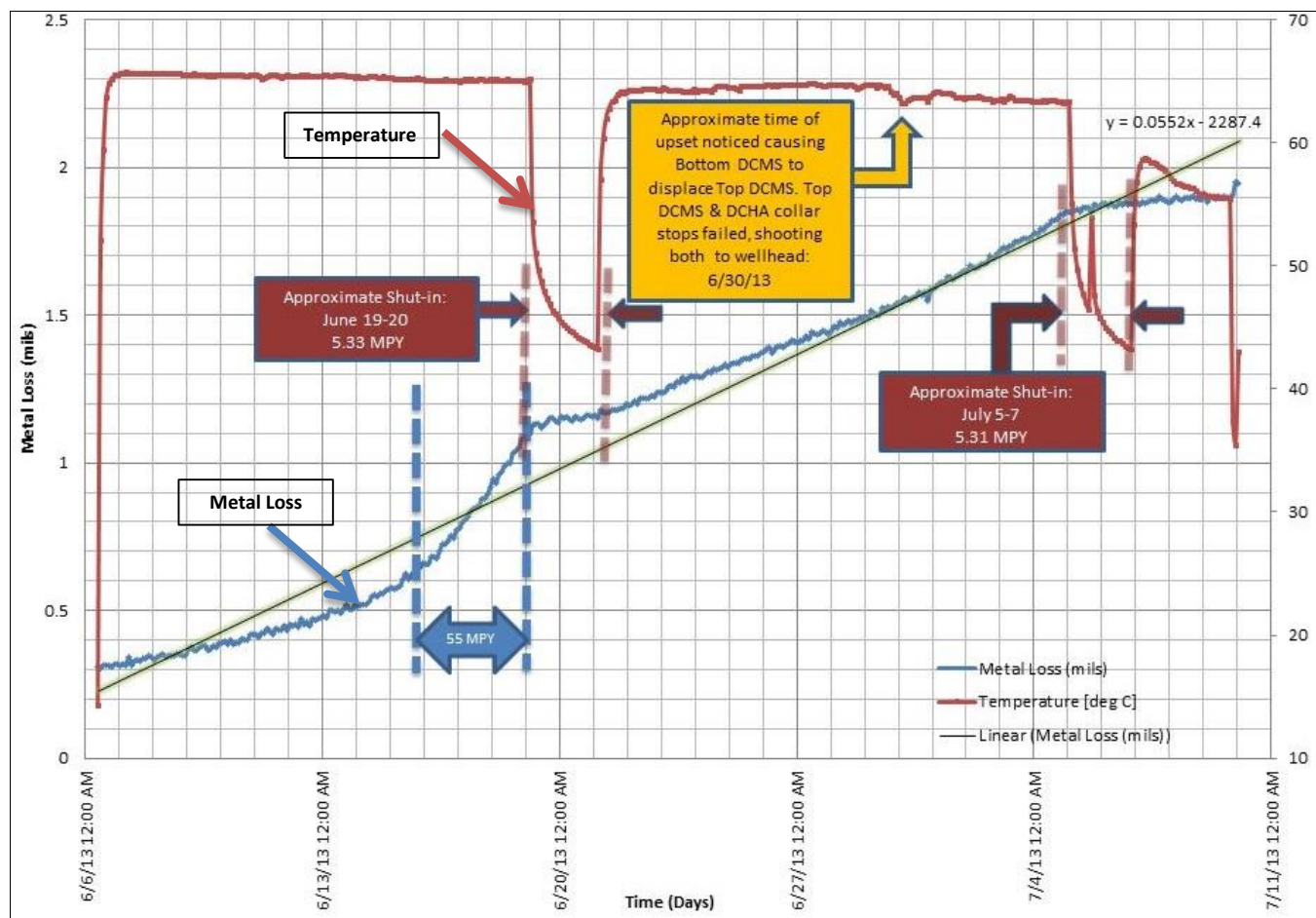


Figure 13
Colorado Trial 1 Bottom DCMS 10 Mil Probe Span – Metal Loss and Corrosion Rate vs. Time

June 6 - July 10 (5 Weeks)	
MPD	MPY
0.055216004	20.16764544
June 6-22 (3 Weeks)	
MPD	MPY
0.063559256	23.21501835
June 16-19 Pre-shut-in slope after probe acclimation	
MPD	MPY
0.150672219	55.03302805
Shut-in June 19-20	
MPD	MPY
0.014616655	5.338733073
Shut-in July 5-7	
MPD	MPY
0.014539335	5.310492232
Pitting @ Tip of T20 Probe	
Pit Depth (Mils)	35 Day MPY
0.019	198

Table 2

Colorado Trial 1 Bottom DCMS 10 Mil Probe Span Corrosion Rate



Figure 14
Colorado Trial 1 Bottom DCMS – 10 Mil Probe Span

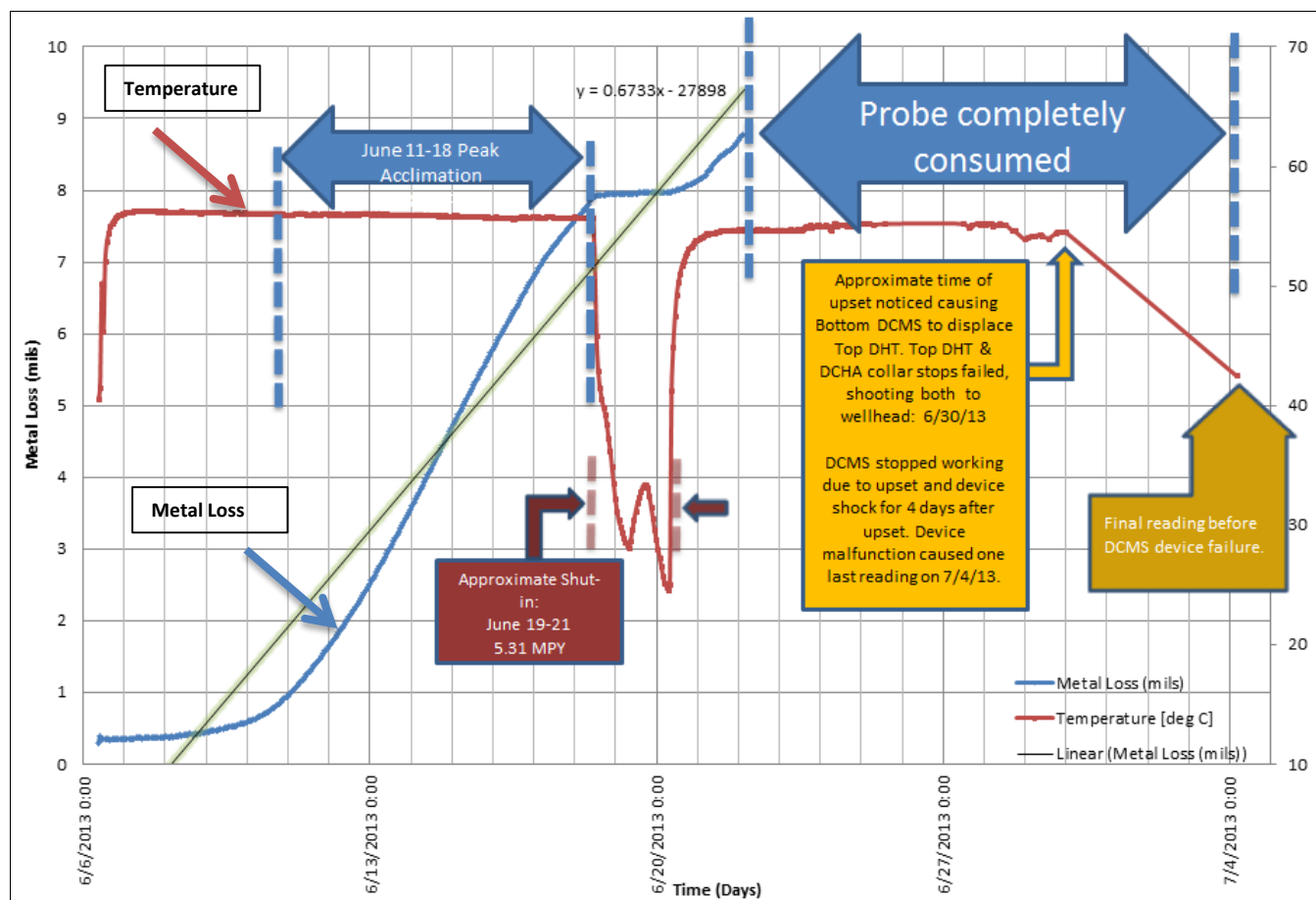


Figure 15
Colorado Trial 1 Top DCMS Mil Probe Span – Metal Loss and Corrosion Rate vs. Time

June 7 - June 22 (3 Weeks)	
MPD	MPY
0.54103742	197.6139161
Peak June 11 - June 18	
MPD	MPY
1.04322159	381.0366844
Took \approx 7 Days to Corrode 5 Mil Span Probe	
1 Year for T10	
MPD	MPY
0.013689	5
Shut-in June 19-20	
MPD	MPY
0.01944901	7.103752595

Table 3
Colorado Trial 1 Top DCMS 10 Mil Probe Span Corrosion Rate

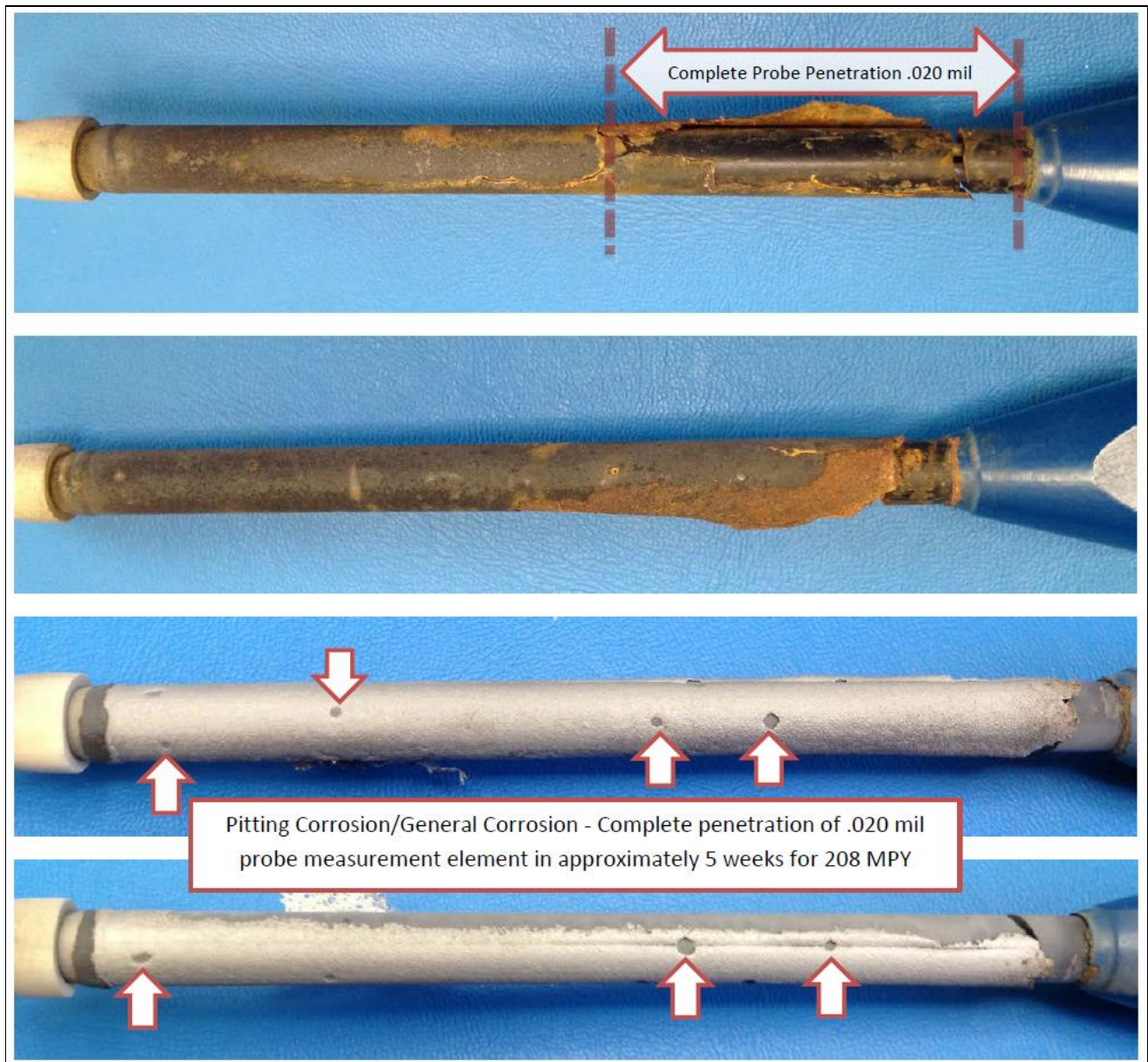


Figure 16
Colorado Trial 1 Top DCMS – 10 Mil Probe Span



Figure 17
Corroded Collar Stop Wireline Tool

Bent Beam Coupons													
Blank Start Weight		3.8611 g	Coupon Material		Carbon Steel (G10180)								
Blank End Weight		3.646 g	Coupon Density		7.86 g/cm ³								
Blank Weight Loss		0.2151 g	Surface Area		1.294 in ²								
	Location	Coupon ID	Install Date	Remove Date	Expose Time Days	Expose Time Hours	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Corrected Weight Loss (g)	Corrosion Rate (mpy)	Max Pit Depth (mil)	Pitting Rate (mpy)
1	Top of Coupon Holder	HN541	6-Jun-13	8-Jul-13	32	768	3.8492	2.8624	0.9868	0.7717	52.891	22.0	250.938
2	Second from Top	HN540	6-Jun-13	8-Jul-13	32	768	4.0078	2.9757	1.0321	0.817	55.996	BD	BD
Strip Downhole Coupon													
Blank Start Weight		18.5454 g	Coupon Material		410 Stainless Steel								
Blank End Weight		18.543 g	Coupon Density		7.74 g/cm ³								
Blank Weight Loss		0.0024 g	Surface Area		3.42 in ²								
	Location	Coupon ID	Install Date	Remove Date	Expose Time Days	Expose Time Hours	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Corrected Weight Loss (g)	Corrosion Rate (mpy)	Max Pit Depth (mil)	Pitting Rate (mpy)
3	Middle of Coupon Holder	HN546	6-Jun-13	8-Jul-13	32	768	11.4288	11.4212	0.0076	0.0052	0.137	BD	BD
Cylindrical Downhole Coupon													
Blank Start Weight		18.7389 g	Coupon Material		Carbon Steel (K03005)								
Blank End Weight		18.7346 g	Coupon Density		7.85 lb./in ³								
Blank Weight Loss		0.0043 g	Surface Area		2.454 in ²								
	Location	Coupon ID	Install Date	Remove Date	Expose Time Days	Expose Time Hours	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Corrected Weight Loss (g)	Corrosion Rate (mpy)	Max Pit Depth (mil)	Pitting Rate (mpy)
4	Second from Bottom	HM177	6-Jun-13	8-Jul-13	32	768	18.6352	17.4310	1.2042	1.1999	43.400	14.0	159.688
5	Bottom of Coupon Holder	HM176	6-Jun-13	8-Jul-13	32	768	18.6932	17.8284	0.8648	0.8648	31.280	20.0	228.125

Table 4
Colorado Trial 1 DCHA Coupon Data from Colorado well: June 6th – July 8th

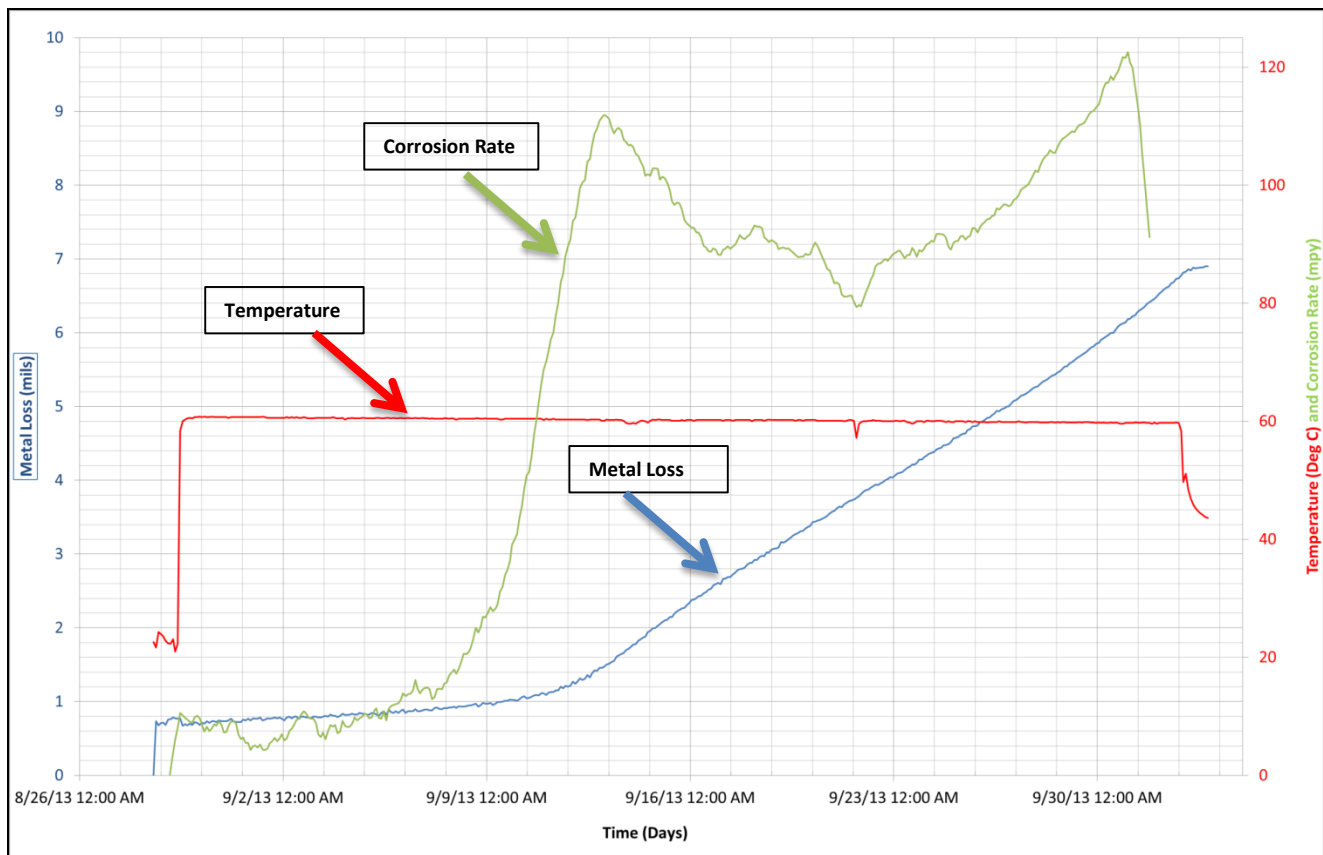


Figure 18
Colorado Trial 2 Top DCMS 10 Mil Span – Metal Loss Corrosion Rate, and Temperature vs. Time

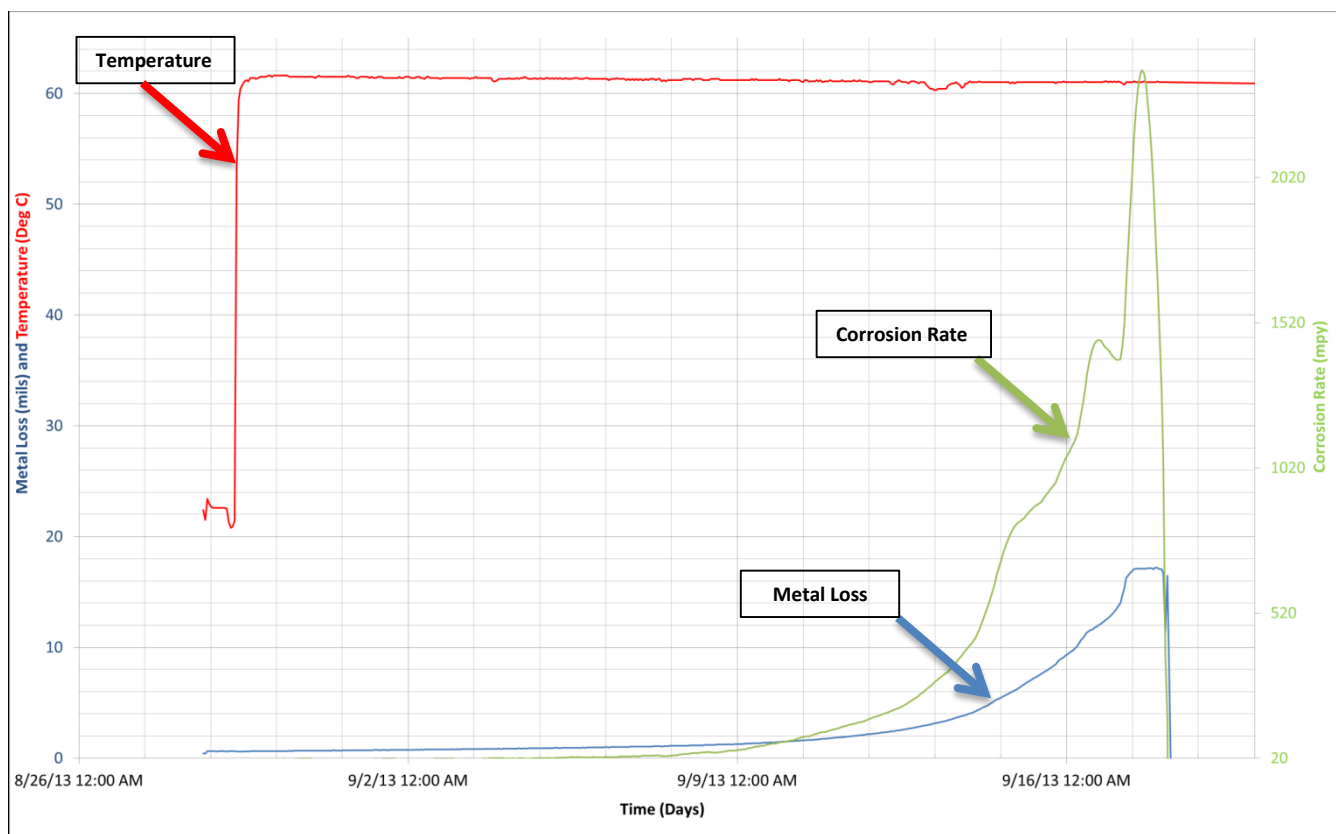


Figure 19

Colorado Trial 2 Bottom DCMS 10 Mil Span – Metal Loss Corrosion Rate, and Temperature vs. Time

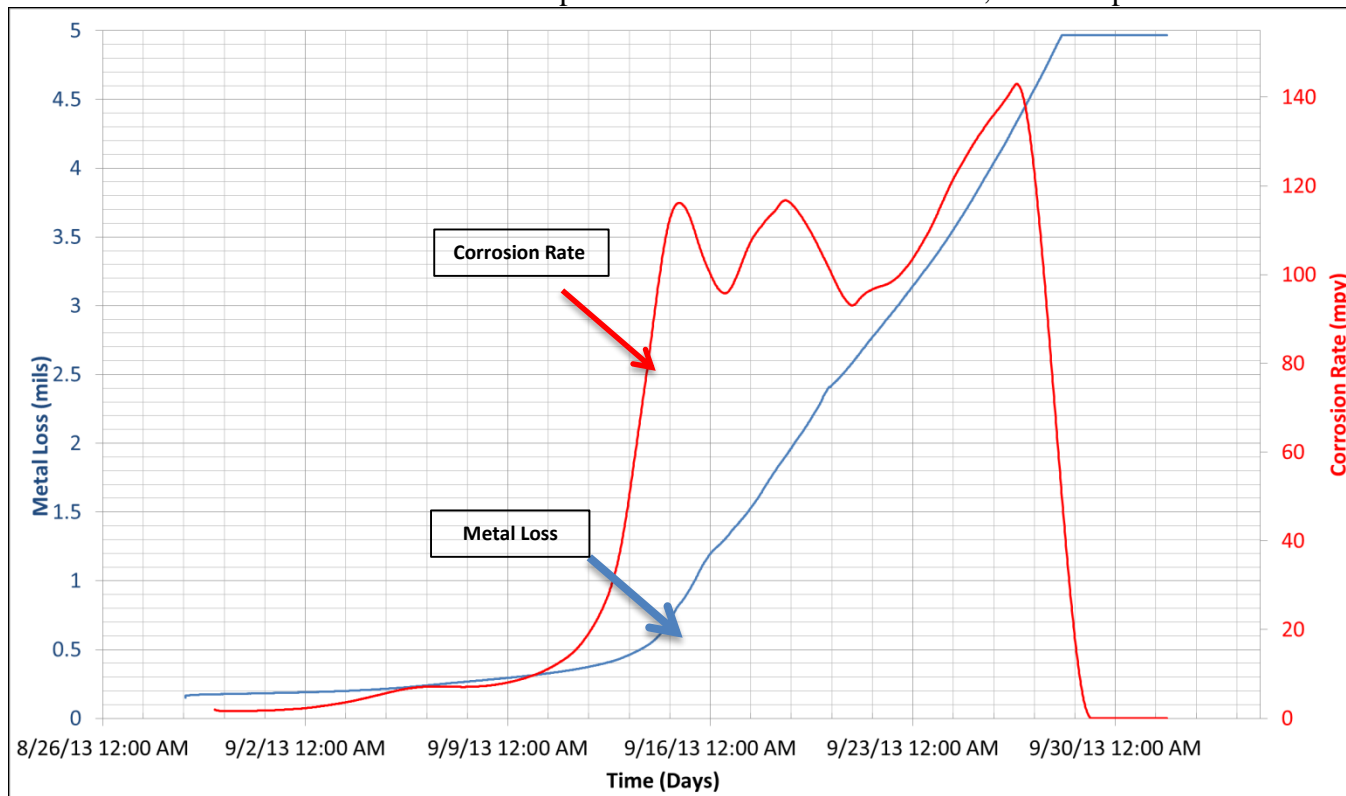


Figure 20

Colorado Trial 2 Horizontal Surface ER Probe 5 Mil Span – Metal Loss and Corrosion Rate vs. Time

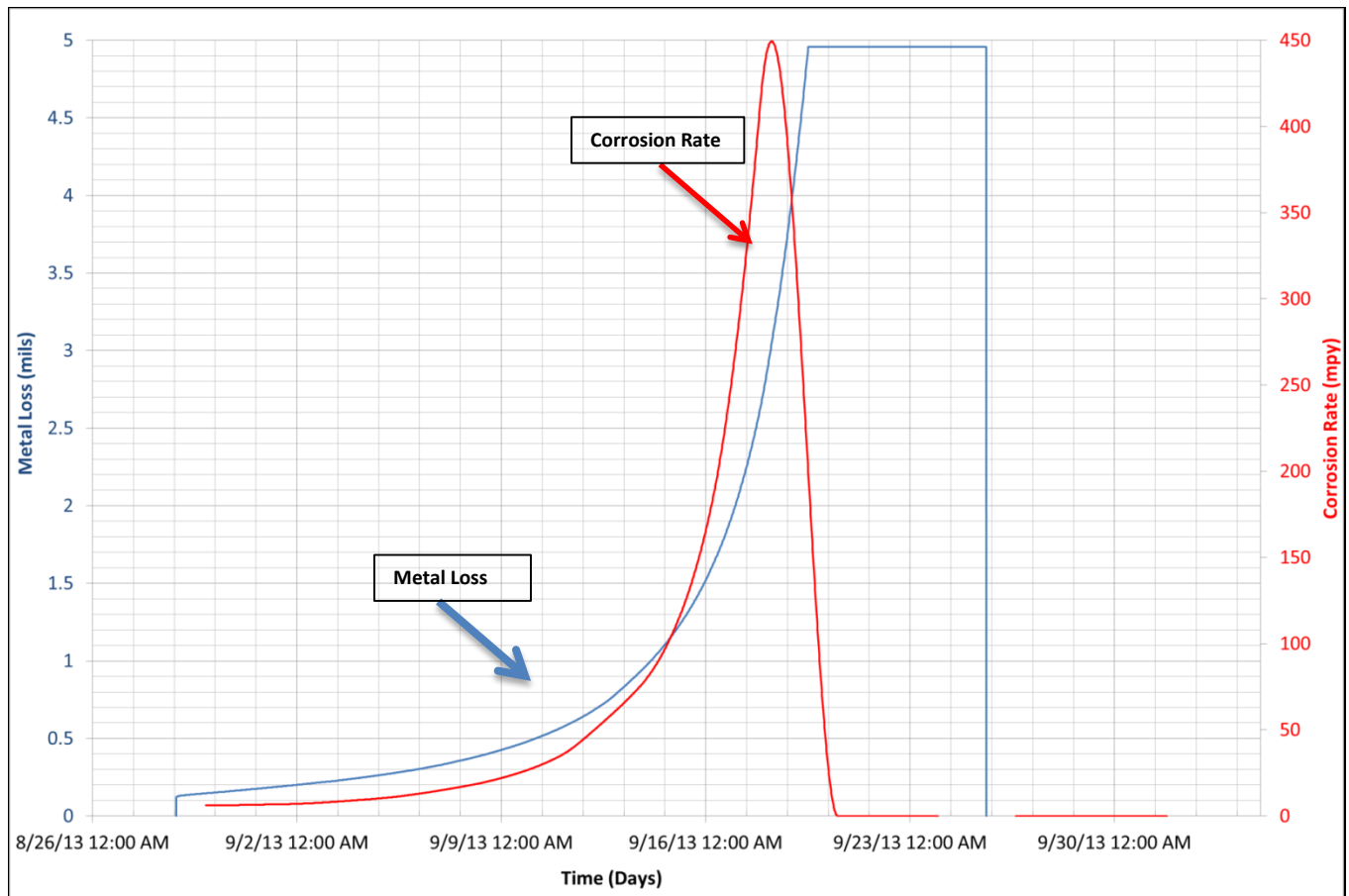


Figure 21
Colorado Trial 2 Vertical Surface ER Probe 5 Mil Span – Metal Loss and Corrosion Rate vs. Time



Figure 22
Horizontal Surface ER Probe



Figure 23
Vertical Surface ER Probe

Coupon ID	Material	Location / Description	General CR (mpy)	Maximum Pit depth (μm)	Maximum Pitting CR (mpy)
CR101	1% Chrome	Bottom #1	27.0	246	99
HN543	13% Chrome	Bottom #2	0.04	None detected	
IE302	Carbon Steel	Bottom #3	32.6	238	96.2
CR102	1% Chrome	Bottom #4	32.8	344	139
HN544	13% Chrome	Bottom #5	0.03	None detected	
IE303	Carbon Steel	Bottom #6	31.3	297	120
CR103	1% Chrome	Bottom #7	29.7	210	85

Table 5
Colorado Trial 2 Coupon Data

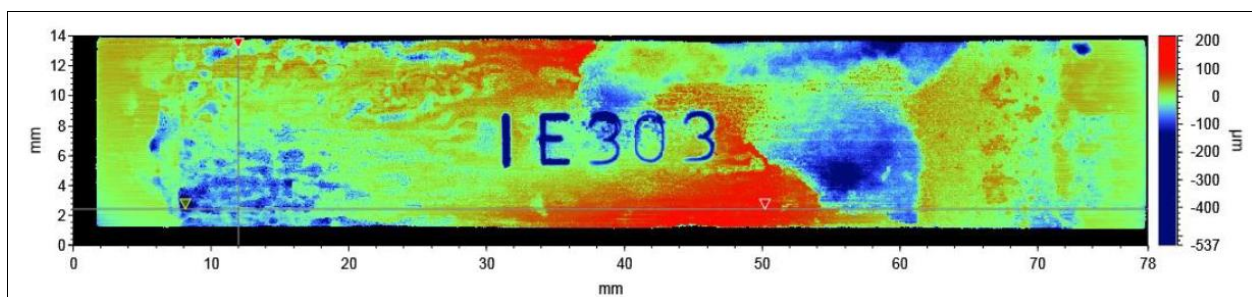


Figure 24
Colorado Trial 2 Sample White-light Interferometry Capture of IE303

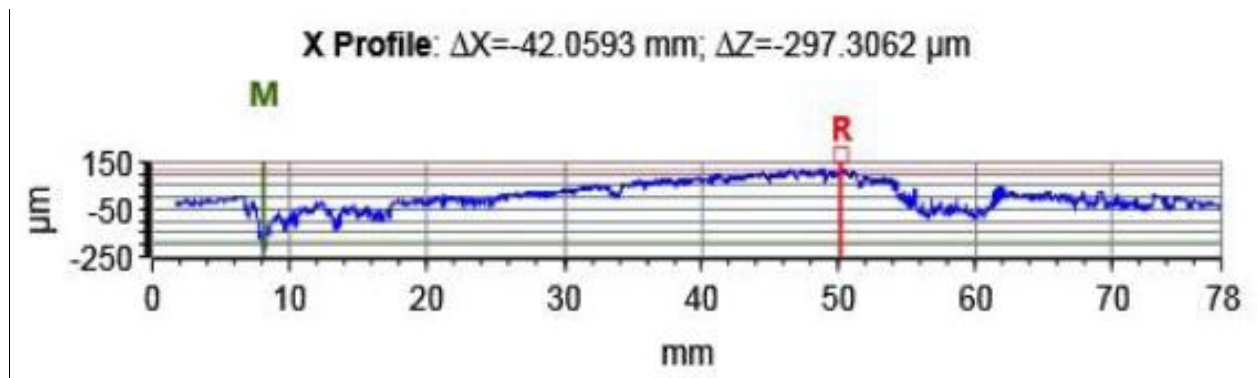


Figure 25
Colorado Trial 2 White-light Interferometry Pitting Analysis of IE303, 297 μm \approx 120mpy

4. CONCLUSION

One conclusion from the Texas trials is that modeling may not be reliable in all scenarios, and that the model should be validated by field testing. Downhole consumable probes and coupons enable validation of the modeling and are a more realistic representation of conditions downhole. The Colorado trials expanded the use of the downhole instrumentation by assembling a creative test configuration, allowing more data to be analyzed.

Water cut, failure statistics, H₂S, and other tubing displacement historical data can help narrow down testing procedures drastically, and assist with characteristics for corrosion monitoring and treatment

applications downhole. However, in reality, well characteristics may not be available in scenarios such as this one, and an in situ probe can provide quality baseline data.

Utilizing the DCMS, the DCHA and surface corrosion instrumentation has demonstrated their effectiveness in understanding downhole corrosion issues and inhibitor treatments. It can also assist in characterizing a series of wells with similar operating conditions. The costs can be justified by an adjusted treatment schedule, limiting shutdowns, and extending wells life. The configurations are not limited to those shown in the case studies which are rather examples of the flexibility of the instruments which can be used with other corrosion/erosion monitoring devices.