BORONIZED ROD PUMP BARRELS – AN EFFORT TO REDUCE PUMP FAILURES DUE TO EXCESSIVE WEAR & ABRASION ON BARRELS

Mike Murray
Exceed Oilfield Equipment, Inc.

ABSTRACT

Rod pump failures often exceed the failures rates of other downhole products, such as sucker rods and tubing. The largest section of the rod pump, and most costly to replace, is the pump barrel. Barrels of all different shapes and sizes, material grades and coating options are available on the market. The available coatings have been questioned for their durability while also being limited in their applications. Chrome barrels and NiCarb surface coatings are widely available but often cannot be used in Acid Jobs (Chrome) or in heavy abrasive environments (NiCarb). Operators seek a barrel that can operate in Acid jobs while also providing the wear and abrasion resistance needed downhole. Exceed has pursued the task of utilizing the proven success of boron diffusion in production tubing and applying that technology to the rod pump barrels. The strict tolerances on the ID of rod pump barrels have made this an extremely challenging task leading to many companies attempting this process, only to fail. Exceed will be presenting on the 2-years' worth of Permian field trials downhole with US (United States) Operators on boronized rod pump barrels.

INTRODUCTION

The sucker rod pump is a vital component in the extraction of oil and gas from wells. The presence of sand, rocks, silicates, and other debris in the well can cause damage to the pump components, including the crucial and expensive Pump Barrel. With common lengths ranging from 12-40 feet, these barrels are made from various steel and brass materials often coated for wear and/or corrosion protection. Despite these measures, even minor scoring, abrasion cuts, and wear can render the barrel inoperable once the surface coating is compromised. Precision is essential during the barrel manufacturing and aftermarket coating processes as the fit of the internal plunger to the barrel is determined using an air micrometer, with a clearance smaller than a human hair.

The selection of rod pump barrels is often based on well characteristics. Other times it is simply a matter of standardization. The existing barrels on the market all have their ideal applications in which they perform exceptionally well in. Chrome Barrels perform well in heavy wear and abrasion environments while also offering suitable corrosion resistance but are susceptible to flaking and cracking while also suffering in acid. Nickel Carbide coated Brass barrels are great for certain types of corrosion but vary in wear and abrasion due to silicate carbide distribution within the layer.

Operating companies have a direct influence on which products they use to assemble their preferred pump design. These pump designs are provided to local pump shops to increase turnaround times with available assembly parts in stock for rebuilds and pre-built pumps on-hand for total replacements. When a pump assembly is pulled from the well, regardless of reason, it is customary practice to send the assembly to a local pump shop for teardown and inspection of all components. During this stage, barrels are visually inspected for corrosion and drift tested in the ID to ensure proper plunger fit. It is common at this stage for current barrels to fail the mic-test due to wear and abrasion encountered during application.

Market research collected by operators and pump shops revealed that many of the failures on the most popular barrel types, BrassNicarb, had over 50% failure mechanism from wear & abrasion. A deeper look into failures in application vs failure during teardown procedures will be conducted to highlight the value of a barrel that can pass multiple teardown inspections with the ability to rerun downhole.

The objective of this paper is to introduce a new tool to production engineers that addresses wear and abrasion, help engineers rethink failure rate vs scrap rate, and show the success of boronized rod pump barrels being deployed in the Permian to date. The financial incentive to produce more barrels of oil per rod pump barrel should also be strongly considered.

BACKGROUND ON BORONIZING

Boronizing is a surface hardening process that enhances the hardness, wear resistance, and corrosion resistance of metals, by incorporating a small amount of boron into their surface. The process was first developed in Germany in the 1930s and has since been extensively used in various industries, including automotive, aerospace, construction, and agriculture.

The boronizing process is highly effective in increasing the durability of parts that are prone to wear and tear, such as gears, bearings, and pump components. Steel parts that undergo boronizing are also used in high-temperature furnace linings, cutting tools, and dies. However, the current furnace restrictions limit the length of boronized parts to 6-feet or shorter.

In the future, the application of boronizing is expected to expand as industries seek ways to improve the durability and performance of their products. Potential future applications include the manufacture of wear-resistant parts for machinery, high-performance engines, and transmissions, and the development of new energy-efficient technologies.

Overall, boronizing is a versatile and valuable surface hardening process that has significantly improved the durability and wear resistance of industrial products. With the continued advancement of technology and materials science, boronizing is expected to continue playing a significant role in the development of new and innovative products.

Boronizing in Oil & Gas

The boronizing process has been widely adopted in the oil and gas industry, particularly in the Bakken and Permian plays, for the production tubing. However, due to furnace limitations, there are limited vendor options for boronizing products longer than 6 feet.

Advancements in modular furnaces have allowed for incremental growth to accommodate longer products. Production tubing, typically 32 feet in length, is commonly boronized on the ID of J55 or 1Cr L80 tubing. The boronizing process is more effective on basic steel substrates, while boronizing traditional brass substrates is currently not feasible at a consistent level.

In addition to production tubing, boronized tools such as plungers, pump components, impellers, and sucker rod couplings are commonly used in the US market due to their ability to withstand heavy wear and abrasion.

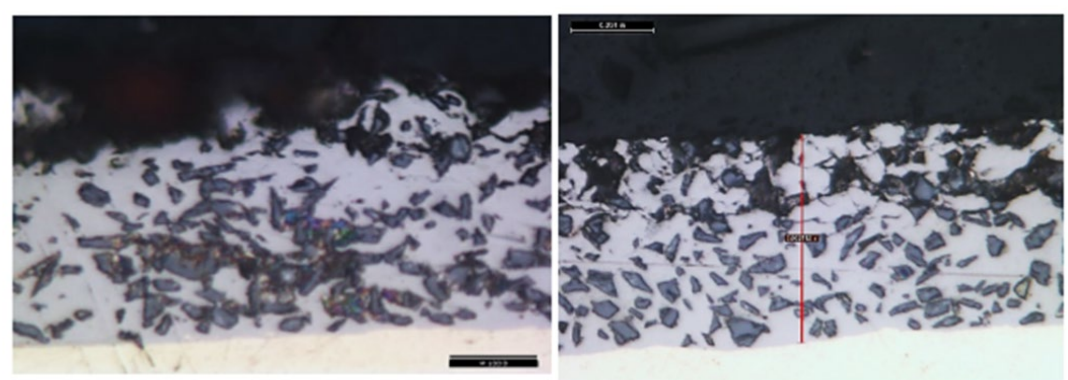
BRASS NICARB

Brass Barrels with Electroless Nickel Carbide Coating (Brass NiCarb) are the most common barrel types available in the market today. They have proven corrosion resistance from a brass substrate covered by a nickel-based electroless coating. Suspended within the coating is also a layer of silicate carbides that offer wear and abrasion protection. These barrels will have a place in the market soon.

A few issues with these Brass NiCarb barrels have come to attention in the recent years of evaluating the market. While many pump shops may manufacture their own barrels, none of the pump shops in the market have their own Electroless Nickel plating service in-house. This is an outsourced service that is applied to every barrel of every vendor. This has created a bottleneck in the market that is unavoidable. The mechanical bond of the coating layer to the substrate is susceptible to separation if continuity of silicate carbides is not maintained throughout the electroless nickel coating layer.

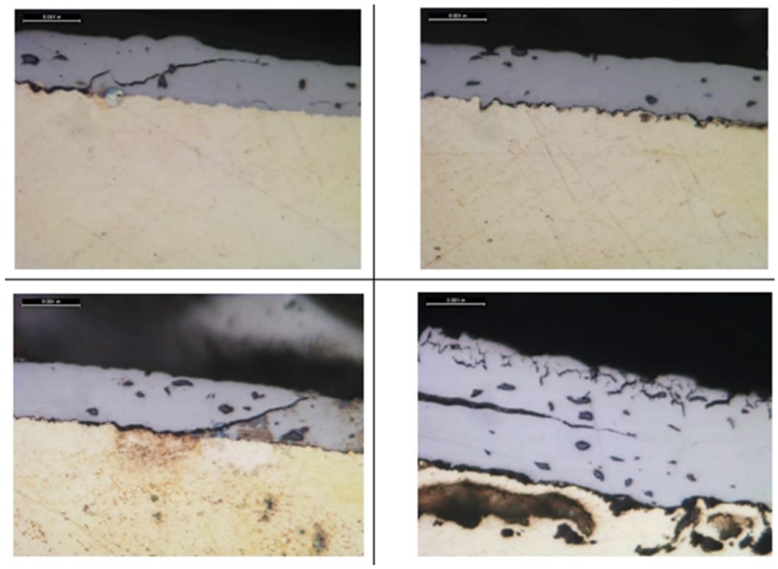
NICKEL CARBIDE CLUSTERING

Recent metallurgy review of NiCarb coatings by US Corrosion Services [2] have shown inconsistency in the silicate carbide distribution throughout the entire barrel. Image1 and Image2 show three different barrels coated by the same vendor, all with varying levels of silicate carbide distribution. A uniform distribution is ideal to maintain the integrity of the coating layer while allowing the silicate carbides to properly protect against wear and abrasion. Image1 shows damage in the outer most surface of the coating due to clustering.



[Image1]

Clustering of silicate carbides in electroless nickel coatings can negatively impact the durability and adhesion properties of the coating. The clustering of silicate carbides can create stress concentrations within the coating, leading to premature cracking and failure. This can reduce the ability of the coating to resist wear and abrasion and may also lead to delamination of the coating from the steel substrate, as seen in Image2. Over time, this can result in the formation of voids and other defects within the coating, which can further weaken the adhesion of the coating to the substrate.



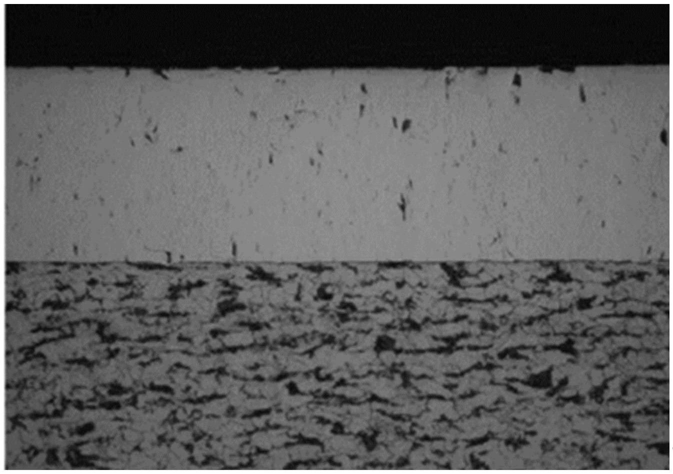
[Image 2]

To mitigate the effect of clustering of silicate carbides, it is important to carefully control the composition and processing conditions of the electroless nickel coating. This can help to reduce the formation of silicate carbides and improve the durability and adhesion properties of the coating. Additionally, post-treatment processes, such as heat treatment or vacuum impregnation, can be used to improve the performance of the coating.

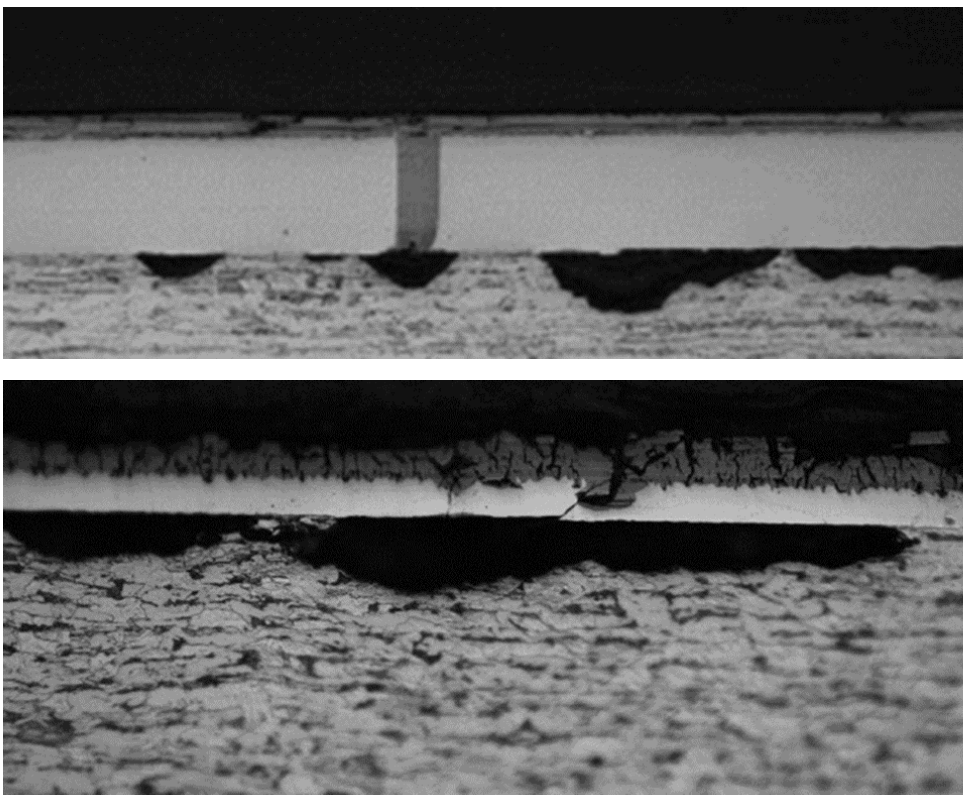
<u>CHROME PLATING</u>

Chrome plating of steels is not a new process. It is well documented that, while chrome plating does offer superior corrosion and wear resistance than Brass NiCarb materials, the porous profile of chrome plating and its susceptibility to cracking and flaking make it less than ideal. Any void or fault that occurs in a chrome plating will result in a concentrated corrosion attack. Chrome is also unable to be downhole during an acid treatment of a well that is quite common.

The below images show the porosity of chrome surface coatings [1]. Image 3 is a chrome coating layer that has not been exposed to corrosion. Image4 shows how corrosion can attack the substrate of the steel while the chrome surface stays mostly intact. The porosity of the chrome layer acts as an internal fracture that can develop into a full crack within the coating layer. Once a pathway is created, corrosion will find a way to attack the substrate.

 [1]

[Image3]



[Image4]

<u>BARREL SCRAP RATES HIDDEN BY PM PROGRAMS</u>

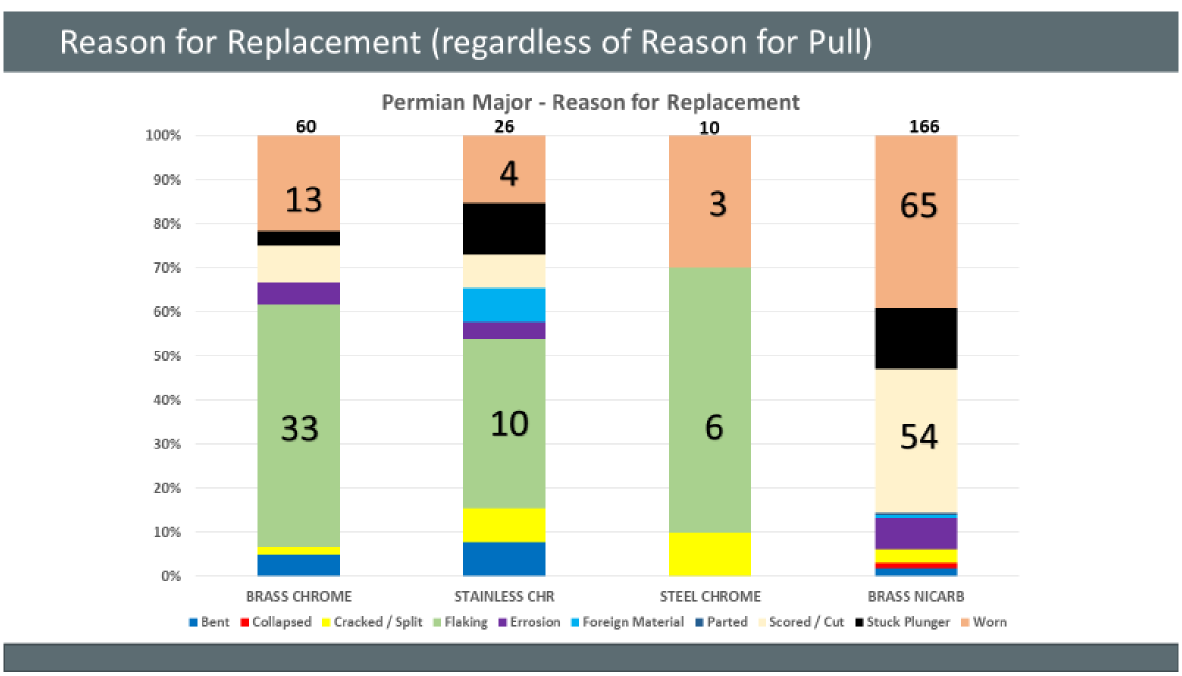
When conducting market research on where boronized barrels fit in the market, operators would focus on MTBF of pumps. We discovered that when pumps were pulled from a well, regardless of workover on site (HIT, Rod Part, Pump, stimulation, etc.) rod pumps were being sent in for tear down as a Preventative Maintenance (PM) program. The next step was to guide operators to collect their total barrels consumed from local service pump shops. When we started asking more questions about barrel usage vs on-site workovers caused by barrel failures, we realized there is a significant disconnect between how failures are recorded in terms of Pump Failures, Pump Pulls, and Barrel Replacements.

Figure 1 is a sample data set provided by a Permian Major “Operator A”. This dataset shows by what means their pump barrels are failing, regardless of the reason for pull. At this time, Operator A did not have any reason to believe they had pump problems because their pump failure rate was less than 30% of their causes for workover. Our goal was to see if this matched their barrel consumption.

This operator uses the Brass NiCarb barrels for most of their wells, but when wear and abrasion created premature failures, they resulted in the harder Chrome plated barrels. When using Chrome barrels, they see a shorter run time due to failures from flaking, but otherwise longer than they could expected from Brass NiCarb failing due to wear or abrasion.

Chrome plated barrels make up 36% of Operator A’s demand. These barrels commonly fail due to flaking and wear at 61% of the recorded failure modes. Brass NiCarb barrels make up 64% of Operator A’s demand. These barrels show the highest failure due to Wear and Scored/Cut at 71% of the recorded failure modes.

A closer look at their internal data, Operator A determined that each time a pump is sent in for teardown inspections, their barrels have a 64% failure rate and only a 36% rerun rate. The goal for this operator is to find a barrel that can perform as well or better than the current NiCarb and Chrome Barrels in applications, but also pass the pump tear downs. The ability to rerun barrels after initial or repeat use is highly attractive to these production engineers.



[Figure1]

Another Permian Major Operator, "Operator B," showed interest in boronized barrels in 2022. The initial discussions of pump problems and barrel failures were not on their radar until we started asking them to take a closer look at Pump Failures vs Pump Pulls vs Barrel Replacements. This operator discovered that while their pump failures in application were low, their PM program at the territory pump shops were scrapping barrels more than 50% of the time. Each time a barrel was sent in for teardown, worn out barrels that could not pass mic tests were scrapped, a new barrel was added to that unique pump ID#, and sent back to the wellsite, or put back into customer pump inventory. This PM program covered the high failure rate of barrels.

As we sought to have more operators look at these three areas, we find that barrels are being replaced at a significantly higher rate than their recorded pump failures. This makes sense from a PM standpoint but is often overlooked, or simply not visible, by production engineers. One event showed a specific well that had had not failed in 4 years, but a closer look revealed that 8 Brass NiCarb barrels were replaced on this well in the same period. The number of barrels between failures is a failure rate operators should consider when evaluating the effectiveness of the style barrel being used. Many see this as a preventative measure that was aimed at preventing rod pump failures for being the cause for a workover rig to come on location. But the total barrel cost to achieve this run time must be considered. In this case, well over $16k was spent on barrels alone.

After talking with each of these operators, it was concluded that there is room for improvement in a more reliable pump barrel that can be rerun after multiple tear downs.

OBSTACLES FOR BORONIZING PUMP BARRELS

Boronized barrels is not a new idea. There have been many companies that have attempted this project for all the previously mentioned reasons, but there have been a few issues preventing this from reaching the market; Furnace Size, Straightness, Diffusion Consistency, Clearance.

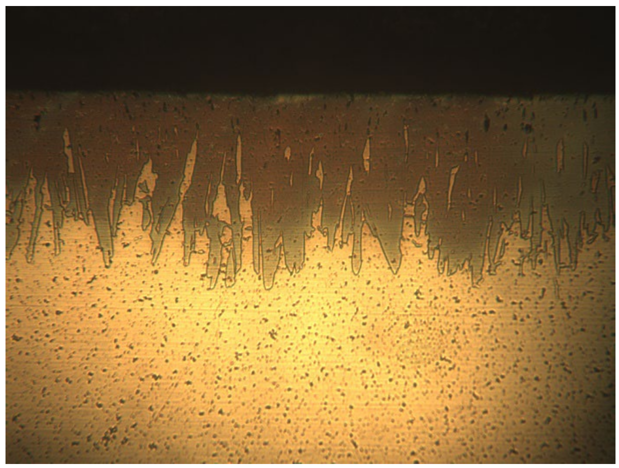
Since boronizing is traditionally conducted on small items less than 6-feet in length, a large enough furnace had never been designed to handle products as long as barrels. The producers of boronized production tubing overcame this issue through modular furnaces. The next obstacle was achieving the required straightness.

A RH B12 rod pump barrel measures ~10mm (about 0.39 in) in thickness. Since boronized barrels are heated for several hours near critical temperatures, the physical properties of the barrel and the cooling process can result in warping and straightness issues. The current heat treatment processes and furnaces used for production do make it difficult for the barrels to maintain a straightness that would pass drift tests and mic tests. Until now, this is still a limiting factor of producing reliable pump barrels.

The next issue is the diffusion consistency of boron atoms into the substrate. These barrels must be powder packed with a boron mixture that is suitable for the substrate to be diffused into. A "sawtooth" or rooted diffusion occurs as a metallurgical bond between the boron surface layer and the substrate. [image5] All steel reacts differently and requires a unique powder pack recipe, temperatures, and treatment times to achieve the desired diffusion depths. A quality control program is required in the selection of suitable substrate for boron diffusion treatment. A targeted diffusion layer thickness no less than 80microns should be established.

The last, and perhaps most difficult test to achieve the required diffusion layers will allow every barrel to pass a mic-test. The clearance of a plunger is smaller than the width of a human hair, across the entire length of the barrel. Many companies have tried and failed at this very point.

For the past 4 years, we have been using a specialized heating furnace, proprietary cooling and honing techniques that allowed us to resolve all previous obstacles for boronizing rod pump barrels.



[Image5]

FIELD TRAILS – Phase 1

Phase one of our trial included 6 barrels being delivered to the US. The barrels we received were 1026 Base steel of three (3) RH 1.5” x 24’ barrels and three (3) RH 1.75” x 24 barrels.

Operator 1 in the Eagle Ford ran all three 1.5” barrels with uncoated OD on the below dates:

Well	Install Date	Days	SPM	NPD	Total Strokes	History
1	4/27/2021	665	6.4	0	6,349,824	Only historical failure 410 days on stainless steel pump – Stuck pump
2	2/2/2022	384	7	0	4,112,640	Stuck Pump History
3	4/1/2022	326	6.1	0	3,074,400	Initial Rod up

Operator 1 manages their own in-house pump shop services and was an ideal candidate for this trail due to their heavy sand environment. The local pump shop manager stated that heavy sands and other solids in the Eagle Ford have been an issue for this operator causing pump stuck pumps. High replacement rates of worn out NiCarb barrels made this operator prefer stainless steel pumps until new replacements are available. All three barrels are still in operation at the submission of this paper.

Operator 2 in the Permian ran three 1.75" barrels with a TK750R O.D. coating on the below dates:

Wel l	Install Date	Days	SPM	NPD	Total Strokes	History
1	8/4/2021	566	6.3	0	5,352,480	last failure pull tube break at 337. Upsized from 1.5"-1.75". Installed in CO2 flood
2	8/31/2021	539	6.1	12	4,840,984	Rod part after 78 days. Barrel mic'd all 1's during teardown. Rerun Corod failure after 154 days. Barrel mic'd all 1's, during teardown. Rerun. Pump teardown 2x and barrel still reran in CO2 flood.
3	1/12/2022	341 Fail	7.4	0	3,638,606	Historical failure: BNiCarb Barrel & Plunger cut after 507 days. Only recorded failure from OD Corrosion through OD coating.

The lead production engineer was concerned about the corrosion of the stagnant oil in contact with the OD of the barrel. To test this concern, all barrels were coated with a section of 1026 exposed near the threads, as seen in Image5. The coating company was worried about coating too close to the threads on the first trial of this application. Future coatings were applied in Phase 3 of the trails with no issues.

One failure has occurred on a Phase-1 trial barrel for Operator 2 after 341 days. This failure will be reviewed later in the paper.

[Image6]

FIELD TRIALS – PHASE 2

Operator 2 reordered all our second round of barrels as they arrived in the Permian to expand trials. All barrels in Phase 2 of the trial have been coated as seen in Image2. RiteWrap covering was made up to overlay the coupler and barrel coating for greater protection from corrosion.

Well	Install Date	Days	SPM	NPD	Total Strokes	History
4	6/21/2022	245	5.5	0	1,020,855	Last failure HIT (Hole in Tubing). No failure on this barrel
5	8/7/2022	198	8.4	0	1,205,513	Last failure Rod Part. No failure on this barrel
6	7/11/2022	225	7.83	0	2,687,108	Last failure HIT. No failure on this barrel
7	7/5/2022	231	6.76	0	2,538,667	Last failure HIT. No failure on this barrel
8	7/5/2022	231	6.67	0	2,418,708	Last failure Stuck Pump. No failure on this barrel
9	7/7/2022	229	7.78	0	2,865,532	Last failure Stuck Pump. No failure on this barrel
10	8/3/2022	202	6.78	0	1,350,430	Last failure PR failure. No failure on this barrel
11	8/14/2022	191	6.56	0	1,170,308	Last failure Rod Part. No failure on this barrel
12	7/4/2022	232	7.01	0	2349163	Last failure HIT. No failure on this barrel

FIELD FAILURES & RERUNS

The primary goal of this boronized barrel is to obtain the ability to rerun barrels after they have been downhole for an extended period. Operators want to see what these barrels look like when they come out of the hole. At the date this paper was written, only two barrels had been pulled from wells with Operator 2. The results of those wells are seen below:

Operator 2: Well #2

- Workover History: Rod Parts, Polished Rod Parts, Tubing Damage

- Boronized Barrel Install Date 8/31/2021
- 11/16/21 - Sucker Rod Failure at 78 Days – Pump sent to local pump shop for teardown and inspection.
- Barrel Mic'd All 1's and was Rerun. Performed camera run down and saw no signs of scoring.
- No sacrificial wear on plunger from contact with boronized barrel.
- TPA and Travel Cage Galled to plunger and plunger was replaced.
- The Cups were worn and abrasion cut.
- Hold Down was abrasion cut and replaced.
- Seat plug had thread damaged and replaced
- Valve Rod Collet Nut tagged and replaced.
- Switched to continuous rod for well.
- Pump was repaired and taken back to the well on 11/16/21.

[Image7]

[Image8]

Operator 2: Well #2

- 2/23/2022 - Continuous Rod Failure
- Boronized barrel mic'd all 1's again and was put aside for a new well install.
- "Chum" barrel replaced boronized barrel to be used on new well. Divesture candidate.

- Plunger still showed no signs of preferential wear.
- Collet nut and guide were damaged.
- No solids found in pump.

BARREL INSPECTION

Pull

1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	1	1	1	1	1	1	1	1	1	1	1	1

15	16	17	18	19	20	21	22	23	24
1	1	1	1	1	1	1	1	1	1

Operator 2: Well #3

- Workover History – Plunger and Barrel Worn & Cut
- Boronized Barrel Installed 1/12/2022.
- 12/20/2022 Pump Failure – Corrosion. [Image9]
- This was the only barrel installed in a water-flood. All other barrels in CO_2 floods.
- Corrosion through TK750R Coating. [Image9, Image10]
- Corrosion through 1026 exposed thread neck. [Image12]
- Cut the barrel and split to examine ID. “Boronized ID looked to be in very good shape with no wear or corrosion” [Image11]
- OD Corrosion was always the concern with these barrels and finding an economic coating that will hold up is the next goal.

[Image9]

[Image10]

[Image11]

[Image12]

IMPROVEMENTS

Improvements have been made to the coating process to allow complete coverage of all exposed 1026 steel. Pump shops can also use a corrosion protection wrapping system like RiteWrap to overlap over the coupling and barrel body. On the date of publication of this paper, only one barrel has failed in any of the Texas wells installed. This corrosion failure occurred 341 days (about 11 months) after the initial installation and 3.6million active strokes. Despite the corrosion failure, the condition of the boronized ID layer is promising as we continue this trail program forward.

If boronized barrels are of interest, a partnership with reliable coating experts is strongly encouraged to protect these assets from OD corrosion attack.

CONCLUSION

The use of boron-diffused rod pump barrels is beginning to offer compelling results to suggest these as an alternative to traditional brass-Nicarb and chrome-plated barrels. With improved wear resistance, increased durability, and enhanced efficiency, boron-diffused barrels represent a smart choice for downhole pumping operations. The need for traditional brass NiCarb and chrome plated barrels still have their place in the market if downhole corrosion is unable to managed properly.

Financially, the extended run life of boronized barrels, due to their ability to be rerun after workovers, can produce more barrels of oil per pump barrel. By replacing brass and chrome-plated barrels with boron-diffused barrels, production engineers can ensure the longevity and performance of their pumping operations, and achieve their goals of increasing production, reducing downtime, and lowering costs on commodities.

References:

[1] P.Pickell, Comparison of Corrosion/Wear Resistant Barrel Coatings and their Failure Behavior Under Acid Conditions: Lufkin Don-Nan, Southwest Petroleum Short Course 2022

[2] J. Jackson, Failure Report of Brass Substrates with Electroless Nickel Carbide Coatings: US Corrosion Services, 2022