ROD WEAR AND CORROSION PREVENTION PRINCIPLES

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ABSTRACT: Rod wear and corrosion have a complex relationship often misunderstood or oversimplified. This paper provides a technical framework and empirical evidence of principles clarify this complex relationship. More importantly, this paper will review stress levels and metal failure mechanisms that dispel many commonly held beliefs. A better understanding of these principles will lead to opportunities to reduce an operator's total operating footprint.

ROD WEAR: Rod wear is generally defined as the loss of metal from the rod string or the tubing string where contact is between surfaces during the stroke of a pumping unit. This contact wear is more pronounced in deviated sections of the well in areas of compression buckling, fluid pounding, or tagging bottom. Quite often, chemical companies disavow responsibility and blame rod wear as a mechanism separate from corrosion. The typical interpretation is that rod wear is a design or operating problem resulting in metal to metal galling. Unfortunately, this oversimplification is reinforced by the visual appearance of channels that appear to "cut" in the same pattern as rods, or rod boxes, or rod guides.

Rod cutting is the result of thousands of cycles of wear in three distinct mechanisms. The first mechanism is the lack of corrosion protection, which results in corrosion oxides being formed almost continuously. The oxides are then repeatedly wiped away. The second mechanism is wear from grit, which acts as stress risers that cut the steel over and over in the same place (i.e. "sand paper effect"). The third mechanism is metal to metal wear or galling. This mechanism will be shown to occur only over a very short period and virtually never results in a failure. Unfortunately, many in the industry disregard the first two mechanisms and miss opportunities to improve their operations by staunchly believing in the last mechanism.

LOAD VERSUS STRESS. A better understanding of rod wear principles begins with differentiating loads from stresses. The wave equation, used for modeling the dynamic loading of rods, has been used to calculate side loading from deviations and rod movement. The calculations effectively assume a rod is a discreet point. The load, however, is most prominent at the point of contact between the rod box and the tubing. The calculations are expressed in pounds of force.

The industry has developed an empirical understanding of the loads and has created an entire industry devoted to the deployment of molded rod guides. The guides are intended to wear out before the tubing and the guides also spread the side loads over a greater area. The concept makes intuitive sense but is generally not backed up with hard science on the nature of the wear mechanism and material sciences.

Side loading forces are seldom translated into stresses (i.e. forces distributed over areas). Converting loads to stresses throughout the history of rod wear involves defining the area of wear. From an analysis of channels worn into tubing, rod wear is concentrated at the interface of the rod boxes and the tubing. The cross-sectional area of this interface varies dramatically over time. When a new rod box is run in new tubing, the cross-sectional area approaches the width of a line. After very little wear, the area is approximately a thin rectangle. After extensive wear, the area resembles the partial profile of a rod box. The stress at each level can provide important insights.

With new boxes and new tubing, 200 lbs. of side loading over a 4" box and a contact width of 0.0005" yields a theoretical stress of 100,000 psi. This stress exceeds the strength of most oil field tubulars and can result in metal to metal galling. These stress levels, however, last only a short period of time.

As the tubing or rod wears, the contact area grows. The same 200 lbs. of side loading over a 4" box and contact width of 0.125" yields an approximate stress of 400 psi. This level of stress is so far below the yield strength of oil field tubulars that metal to metal galling is not likely to occur.

As the tubing wears further, the channels approximate a portion of the circumference of the rod box. The same 200 lbs. of side loading over a 4" box and an equivalent contact width of 1" yields a stress of only 50 psi. At this stress level, metal to metal galling is inconceivable.

These simple calculations suggest there cannot be enough error in the load calculations to ever reach stress levels that approach the strength of the steel. The stress levels, as wear develops, are overwhelmingly dominated by the area considerations in each rod by tubing contact area and then reduced further by the number of rod boxes.

Despite the calculations that should dispel belief in metal to metal galling, the visual appearance of a channel being worn over the length of a downhole stroke is so compelling that the testing industry differentiates rod wear from random pitting.

Damage mechanisms, other than metal to metal galling, are indicated by a closer analysis of the rod wear channels. These channels rarely show the polished profile of metal to metal wear. Almost all the channels show evidence of corrosion pitting and/or striations from other wear mechanisms. Many of the striations have profiles of corrosion around or near the striations. Each of these mechanisms have different relationships to stress and material science.

<u>CORROSION RELATED ROD WEAR:</u> Oil field corrosion is an electrochemical attack of steel by water or other corrosive fluids. Once attacked, an oxide film remains on the steel. The physical properties of this oxide film are not comparable to the underlying metal fibers. They have virtually insignificant tensile and compressive strength and are not well bonded to the steel. Several empirical examples in everyday lives help illustrate the concept. The easiest illustration at atmospheric conditions is rust that can be rubbed off with a finger down to bare steel. While everyone can understand this example, there is a conceptual problem that people have with understanding the corrosion process on a continuous basis at a microscopic scale. The closest everyday analogy regarding the awareness of the continuous nature of corrosion is the internal combustion engine. No one knowingly puts water in the crankcase of their cars. Proper oil with proper inhibitors are run to place inhibiting and lubricating films between the pistons and the cylinders thousands of times per minute.

Even though downhole pumps are essentially single cylinder engines, analogies that illustrate corrosion or lack of corrosion in downhole environments are not widely recognized. The historical record is not well documented by today's digital standards. However, older professionals can attest to the lack of significant corrosion and wear when oil production was virtually water free in the early days of the domestic oil industry. However, most of the current oilfield personnel rarely produce much oil that does not have significant amounts of water.

There are, however, several significant downhole observations that are noteworthy. The first example comes from the early rod guide industry. Before molded rod guides were used, the earlier rod guides snapped onto existing rods. This type of rod guide, unfortunately, tended to ride up and down the body of the rod. This motion then "wore" the rods down to almost pencil size dimensions until they failed. Clearly, the plastic was not wearing out the steel. The guide was simply removing the corrosion inhibitor film, allowing the steel to corrode continuously.

Another artificial lift example that dispels the myth of metal to metal galling while simultaneously showing the enormous benefits of continuous corrosion protection is shown in Table I. The depth of the well, the overcapacity of the artificial lift, the amount unanchored tubing, and the lack of an effective corrosion mitigation program all favored rod wear being a dominant failure mechanism. However, when the well was pulled, and the tubing was inspected, there was minimal "wear" in the long, unanchored section below the tubing anchor. The well's production best explains the lack of wear. The well produces about 90% sweet oil that has a slight amount of paraffin. This type of production continuously films the steel and reduces the window of corrosion to insignificant periods of time. Similar configurations in the field with 50% water cuts, or greater, showed severe degradation in the tubing below the anchor. Clearly, the benefits of continuous corrosion protection in this example dispel the myth metal to metal galling.

ROD WEAR FROM SOLIDS**:** The next most dominant method of wearing tubing is the result of produced solids creating stress risers in the contact area. Striations in the rod cut area are oriented in the direction of rod motion and are effectively scratches in the surface of the tubing or the rod box. Again, examining this "sand paper" effect from the perspective of the stress versus load provides useful insights. Side loading of 200 lbs. that are carried on 100 particles with an effective contact area of .005" yields a stress of approximately 102,000 psi. These stress risers can easily reach the strength of the steel. **More importantly, there are no known corrosion films or bonds between oxide films and steel that can withstand the stresses from even a modest amount of grit.** Once protective films are damaged, each stroke is exposed to corrosive attack on repeated cycles until the film is restored.

SOURCES OF SOLIDS: There are a variety of sources of solids that are present in wells. There are some wells with friable sands that naturally produce solids to the point that gravel packing is necessary. There are formation fines liberated from the stimulation of formations. There are solids that are from the flowback of the proppants. Longer term, weathered iron sulfide and other scales are the source of most fines above the pump discharge. Water is the major culprit. Scales form as precipitates from the water or corrosion oxide scales, like iron sulfide, are deposited on the tubulars. The rods weather or grind up the scales that then must be produced with the oil. Some of this material remains in the well and settles on top of the pump. This weathering process is the most likely process of solids being present when no fill in found in the bottom of the hole. The last source of solids in a well are surface operations that inadvertently introduce solids into the well (i.e. hot oiling, chemical treating, etc.). These sources of grit represent mechanisms that can be lead to strategies for improvement.

The depth of rod wear in typical wells also contribute to the understanding of wear mechanisms and the priority of strategies to improve operations. Most wells experience the greatest rod wear in the section just above the pump. Because this section has the greatest side loading from compression buckling, fluid pounding, and tagging, many operators oversimplify and assume the wear is a mechanical problem. However, this section is also where the temperature and corrosion are the greatest, where scaling tendencies are the highest and where protective paraffin filming is lowest. The convergence of these issues may mask the underlying priorities.

UDERSTANDING TRUCK TREATING: Truck treating is one of the most misunderstood operating practices in the oilfield. A truck is used to pump corrosion inhibitor and other chemicals into the tubing by casing annulus. The truck then flushes the treatment to displace the chemicals to the bottom of the well. The well's downhole rod pump then disperses the chemical back up into the tubing. As the chemical is pumped, films as little as several molecules thick are deposited on the tubing and rods. Samples at the surface can be taken to determine presence of inhibitor in the system. The process is repeated every week or two.

Although this description seems simple, there are serious issues seldom discussed with the treating industry. The first issue is the concept of average metal loss per year or mpy. Chemical companies have developed this concept from flowing systems that involve the loss of their films over time under various conditions including the type of fluids, temperature, velocity regimes, etc. These lab-based experiments generally are uniform within the tubing being tested. However, this concept is not consistent with rod pumping operations where reciprocating variable wear over thousands of feet is added to the system. Given the vast empirical evidence of metal loss above the pump in "channels", the concept of average mpy of metal loss on all surfaces is not a reasonable measurement without a vast number of disclaimers.

Once a truck treats a well and excess inhibitor is pumped to the tanks, most of the tubing still has a reservoir of inhibitor to heal any damage that may occur to the film. This reservoir of additional chemical is what is scraped or worn or washed off the joints below the joint in question. Each successive joint down the hole has less tubing below it to act as a reservoir of fresh filming material. The real problem with truck treating is what happens to the bottom joints that have no tubing deeper in the well that act as a reservoir for fresh film. This problem is particularly acute when the well pumps off.

There is no published data that indicates films can survive rod side loading. There is no published data that indicates thin films can withstand shear stresses. This data does not exist because the film is only a few molecules thick and does not intended to have strength. This lack of film tenacity is the fundamental problem with the next issue within the chemical industry.

The measurement of inhibitor residuals is a serious problem with the chemical industry and can lead to a lack of trust. Residual tests measure the inhibitor that is leaving the system at the surface that is not attached to the steel. The residual measurement at the surface is an indicator of what is available for the top joint. In effect, the measurement is what is being removed from steel deeper in the well. The chemical treating industry wants to infer treatment based on the presence at the surface without a discussion of what the residuals are further down the well.

The reason no attempt is made to create a downhole measurement or correlation for downhole residuals versus depth is that there are likely no residuals at the bottom of the well very soon after the well is treated. In effect, truck treating treats some of the well 100% of the time until the well is retreated. **For many wells, particularly those that pump off, certain sections well may not be treated 99% of the time.** The opportunity for treating fluids to be present at the top of well while no chemical is present at the bottom of the well is one of the more difficult concepts for operators to understand take corrective measures.

<u>THE VISCIOUS CYCLE:</u> The lack of effective corrosion treatment is far worse than operators realize. Corrosion generates more corrosion by-products and accelerates the growth of scale. Both these factors result in more solids that generate more stress riser effects.

<u>STRATEGIES FOR IMPROVEMENT:</u> There are a variety of operating practices that can address the dominant mechanisms that lead to what is known as rod wear that can improve a company's operating footprint, including:

Cultural Change: Operators first need to change the cultural inertia as to how they operate wells. Changing cultural norms is a difficult process when there are long held beliefs that may also involve long term relationships. This process is perhaps the most critical to continually reducing operating footprints.

Continuous downhole treating: If an operator accepts metal to metal galling is not the primary mechanism behind "rod wear", continuous treating should be used to reduce the window of corrosion. Vehicles have oil continuously in their crankcases. Pumping units are continuously oiling the gear train. There does not appear to be a good reason to let the bottom of the hole be untreated for large periods of time. Downhole treating needs to be as close to continuous as practical.

Compatible fluids: Maintaining corrosion filming is generally the highest priority. Unfortunately, combination treatments are sometimes used that inadvertently work to undermine the corrosion program. Paraffin prevention inhibitors are one such chemical treatment. To help with the paraffin prevention mechanism, chemical companies sometimes add carrier fluids that are highly active solvents that can strip inhibitor films. When challenged to use less active carrier fluids, several chemical companies have reformulated their paraffin inhibitors. Undermining corrosion protection should not be the unintended consequence of a paraffin inhibitor program.

Reducing relative velocities: Fluid erosion/friction and rod/tubing friction can be reduced by slowing down the pumping units. Reducing forces by reducing acceleration can be an important tool to diminish the corrosion wear on tubing.

Reducing pump sizes/rod loads: This operating strategy has added benefits beyond reducing the corrosion wear mechanisms. Smaller pump diameters reduce pump off impact loads and side loading and can often improve the down hole stroke.

Reducing solids: The amount of grit needs to be reduced to diminish the effects of stress risers. Using cleaner fluids and using filtered fluids are strategies that should be considered. Anything pumped from the surface should be filtered.

A closer analysis of downhole failure mechanisms and the processes to protect this equipment demonstrate serious flaws in current operating practices that keep operators from reducing the footprint of their operations. Truck treating, accepted for years, is a costly habit that fails to protect the most vulnerable portion of the well just above the pump. Understanding that "rod wear" is really a complex corrosion wear mechanism is the first step towards improvement. Chemical companies should never be allowed to blame failure on rod wear without proving they have closed the window of corrosion. Converting to continuous treating and applying other principles to reduce the downhole degradation are critical concepts necessary to reduce failure frequencies.

Table I
Poor Artificial Lift Design Example
90% oil cut, paraffin crude

Well Depth	9000		Length of unanchored tubing	1200
Tubing Anchor depth	800		Quality of Corrosion treatment	Poor
Rod Design	76		Pump off control	Off
Pump Size	150		Pump Capacity (QRod)	150
SPM/SL	5.2/168		Production Total (fluid/day)	22

- Severe fluid pound
- High degree of mechanical design and operating problems that should lead to a wear problem
- Run time 3.7 years
- Electronic inspection of the tubing below the anchor: 27 yellow band, 6 blue band