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Root Cause Failure Analysis is Essential for Failure Frequency Reduction in Wells With Artificial Lift.

Excerpted from ***Sucker Rod Failure Analysis*** *by: Clayton T. Hendricks and Russell D. Stevens*

Most failures associated with artificial lift systems can be attributed to one of three downhole components - pump, sucker rod, or tubing. A pump, sucker rod, or tubing failure is defined as any catastrophic event requiring servicing personnel to pull or change-out one or more of these components. By this definition, the failure frequency rate is the total number of component failures occurring per well, per year. Marginally producing wells with high failure frequency rates are often classified as "problem" wells and effective failure management practices can mean the difference between operating and plugging these wells. Failure management includes preventing, identifying, implementing and recording the "real" root cause of each failure and is central to overall cost-effective asset management. For the purpose of this photo essay, we will deal only with sucker rod failures.

Cost-effective failure management begins with prevention, and the time to stop the next failure is now-prior to an incident! Simply fishing and hanging the well on after a sucker rod failure will not prevent failure recurrence. In fact, most failures continue with increasing frequency until the entire rod string must be pulled and replaced. Achievable failure frequency reductions require accurate failure root cause analysis and the implementation of corrective action measures to prevent failure recurrence. A database capable of querying the well "servicing" history is needed to tack and identify failure trends. Once a failure trend is identified, remedial measures should be implemented during well servicing operations to prevent premature rod string failures. The database failure history should include information on the failure type, location, depth, root cause, and the corrective action measures implemented.

Sucker rods can be caused to fail prematurely. Understanding the effects of seemingly minor damage to rod strings, and knowing how that damage can produce catastrophic failures, is very important for production personnel. Sucker rod failure analysis is challenging and you need to be able to look past the obvious and seek clues from the not so obvious. All production personnel should have adequate knowledge and training in failure root cause analysis. Understanding how to identify failures and their contributing factors allows us an understanding of what is required to correct the root cause of the failure. Every step that can be taken to eliminate premature sucker rod failures must be taken. On-going training programs concerning sucker rods should include formal and informal forums that advocate following the recommendations of manufacturers for artificial lift design, care & handling, storage & transportation, running & rerunning, and makeup & breakout procedures. A variety of training schools are currently available and, with advanced notice, most can be tailored to meet the specific needs of production personnel.

Failure Mechanisms

All sucker rod, pony rod, and coupling fractures are either tensile or fatigue failures. Tensile failures occur when the applied load exceeds the tensile strength of the rod. The load will concentrate at some point in the rod string, create a necked-down appearance around the circumference of the rod, and a fracture occurs where the cross-section is reduced. This rare failure mechanism only occurs when pulling too much load on the rod string- such as attempting to unseat a stuck pump. To avoid tensile failures, the maximum weight indicator pull for a rod string in "like new" condition should never exceed 90% of the yield strength for the known size and grade of the smallest diameter sucker rod. For unknown sucker rod conditions, sizes, or grades a sufficient de-rating factor should be applied to the maximum weight pulled. All other sucker rod, pony rod and coupling failures are fatigue failures.

Fatigue failures are progressive and begin as small stress cracks that grow under the action of cyclic stresses. The stresses associated with this failure have a maximum value that is less than the tensile strength of the sucker rod steel. Since the applied load is distributed nearly equally over the full cross-sectional area of the rod string, any damage that reduces the cross-sectional area will increase the load or stress at that point and is a stress raiser. A small stress fatigue crack forms at the base of the stress raiser and propagates perpendicular to the line of stress, or axis of the rod body. As the stress fatigue crack gradually advances, the mating fracture surfaces opposite the advancing crack front try to separate under load and these surfaces become smooth and polished from chafing. As the fatigue crack progresses, it reduces the effective cross-sectional area of the sucker rod until not enough metal remains to support the load, and the sucker rod simply fractures in two. The fracture surfaces of a typical fatigue failure have a fatigue portion, tensile portion, and final shear tear.

Fatigue failures are initiated by a multitude of stress raisers. Stress raisers are visible or microscopic discontinuities that cause an increase in local stress on the rod string during load. Typical visible stress raisers on sucker rods, pony rods and couplings are bends, corrosion, cracks, mechanical damage, threads, and wear or any combination of the preceding. This increased stress effect is the most critical when the discontinuity on the rod string is transverse (normal) to the principle tensile stress. In determining the stress raiser of a fatigue failure, the fatigue portion opposite the final shear tear (extrusion/protrusion) must be carefully cleaned and thoroughly examined. Fatigue failures have visible or macroscopic identifying characteristics on the fracture surface, which help to identify the location of the stress raiser. Ratchet marks and beach marks are arguably two of the most important features in fatigue failure identification. Ratchet marks are lines that result from the intersection and connection of multiple stress fatigue cracks while beach marks indicate a change in the rate of crack growth. Ratchet marks are parallel to the overall direction of crack growth and lead to the initiation point of the failure. Beach marks are elliptical or semi-elliptical rings radiating outward from the fracture origin and indicate successive positions of the advancing stress fatigue crack growth.

Figure 1

Figure 1 is an example of tensile and fatigue failures. The two examples on the right are tensile failures. A tensile failure is characterized by a reduction in the diameter of the cross-sectional area at the point of fracture. Typical tensile failures have cup-cone fracture halves. The second example from the right is typical in appearance for tensile failures. During the final stages of an overload, fractures from tensile failures rupture, or shear, on 45ϒ angles to the stresses applied. A good example of the shear is the characteristic cup-cone fracture surfaces of a typical tensile failure. The rod body on the right is an excellent example of needing to look past the obvious for the not so obvious. A fatigue failure is primarily responsible for the failure even though fracture occurred while trying to unseat a stuck pump. Visual examination of the fracture surface reveals a small semi-elliptical, stress fatigue crack. This sucker rod had pre-existing, transverse fatigue cracks, from in-service stresses. One of the stress fatigue cracks opened during the straight, steady load applied in attempting to unseat the pump, and fracture occurred. The tensile failure is secondary and results in the unusual appearance of the fracture surface – with the small fatigue portion, large tensile portion and unusually large 45ϒdouble shear tears.

The remaining examples are fatigue failures on: casehardened sucker rods; normalized and tempered sucker rods; and quenched and tempered sucker rods. The example on the far left is a torsional fatigue failure from a progressing cavity pump. Ratchet marks found in the large fatigue portion, and originating from the surface of the rod body, completely encircle the fracture surface with the small tensile tear portion shown slightly off middle-center. The second rod body on the left is a casehardened fatigue failure. The case encircling the rod body diameter carries the load for this high tensile strength sucker rod and if you penetrate the case, you effectively destroy the load-carrying capability of this type of manufactured sucker rod. The fatigue crack advances around the case and progresses across the rod body. A fatigue failure on a casehardened sucker rod generally exhibits a small fatigue portion and a large tensile tear. The third rod body from the left is typical in appearance for most fatigue failures. Typical fatigue failures have a fatigue portion, tensile portion with a final shear tear. The width of the fatigue portion is an indication of the loading involved with the fracture. Mechanical damage can prevent or hinder failure analysis by destroying the visual clues and identifying characteristics normally found on a fatigue fracture surface. Care must be exercised when handling the fracture halves. It is very important to resist the temptation to fit the mating fracture surfaces together since this almost always destroys (smears) microscopic features. To avoid mechanical damage, fracture surfaces should never actually touch during fracture-surface matching.

Design and Operation Failures

Sucker rod failure prevention begins with design. It is possible for poorly designed rod strings to contribute to other component failures in the artificial lift system, such as rod cut tubing resulting from compressive rod loads. Designing the artificial lift system is a compromise between the amount of work to be done and the expense of doing this work over a cost-effective period of time. Numerous combinations of depths, tubing sizes, fluid volumes, pump sizes and configurations, unit sizes and geometries, stoke lengths, pumping speeds and rod tapers are available to the system designer. Sucker rod size and grade selection is dependent upon many factors including predicted maximum stresses, stress ranges, and operating environments.

Figure 2

Commercially available computer design programs allow the system designer to optimize production equipment at the least expense for the well conditions existing at the time of the design. After the initial design and installation of the rod string, periodic dynamometer surveys should be utilized to confirm that equipment load parameters are within those considered acceptable. A good initial design may become a poor design if well conditions change. Changes in the fluid volume, fluid level, stroke length, stokes per minute or pump size severely impact the total artificial lift system. Changes in fluid corrosiveness can affect the fatigue endurance lift of sucker rods and may lead to premature failures. When one of the preceding conditions change, the design of the artificial lift system must be re-evaluated.

Figure 3

Figures 2 and 3 are examples of design and operationally induced mechanical failures. Wear, flexing fatigue, unidirectional bending fatigue, and stress-fatigue failures indicate compressive rod loads, deviated wells, fluid pound, gas interference, highly stressed sucker rods, improperly anchored tubing, pumps tagging bottom, sticking pump plungers, unanchored tubing, or some combination of the preceding.

Wear causes rod failures by reducing the cross-section of the metal, exposing new surface metal to corrosion, and causes joint failures from impact and shoulder damage. The Class T coupling on the left, the Class SM coupling second from left, and the rod body on the left are all examples of wear. Wear on the sucker rod string is defined as the progressive removal of surface metal by contact with the tubing. Wear that is equal in length, width, and depth usually suggests a deviated or crooked well bore. Angled wear patterns indicate rod strings that are aggressively contacting the tubing at an angle, usually as a result of fluid pound or unanchored (improperly anchored) tubing. The middle rod body represents corrosion-abrasion wear. Wear also removes corrosion inhibiting films and exposes new surface metals to corrosive well fluids-which accelerate the rate of corrosion. The Class T coupling on the far right has a work-hardened ridge from tubing-slap wear. Tubing-slap wear is the result of the rod string “stacking out” – probably as a result of fluid pound, gas interference or pump tagging. The work-hardened material doesn’t wear as fast as the softer material on either side of the work-hardened area, and it leaves a ridge of material as the rest of the coupling wears.

The second rod body from the left is a flexing fatigue failure. Flexing fatigue failures occur from the motion of the rod string having a constant lateral or side movement during the pumping cycle. Stress fatigue cracks due to flexing will concentrate along the area of the rod where the greatest bending stresses occurred. The transverse, stress fatigue cracks will be on one half of the circumference of the rod body, closely spaced near the rod upsets and gradually spreading apart moving toward the middle of the rod body. Most flexing fatigue failures occur above the connection in the transition zone of the rod body-between the rigid coupling and upset area and the more flexible rod body. Flexing fatigue failures will not show permanent bends since this problem occurs while the rod string is in motion. The example on the far right is a unidirectional bending fatigue failure. This type of failure generally has two tips protruding above the fracture surface. These distinct failure characteristics indicate a double shear-lip tear. Double shear-lip tears are the direct result of unidirectional bending stresses, with fractures and the fatigue damage occurring under compressive rod loads. Compressive rod loads may be the result of large bore pumps with small diameter sucker rods or multiple tapers in shallow wells.

The second rod body sample on the right (Figure 3) is a stress fatigue failure. Stress fatigue failures occur on highly stressed sucker rods as a result or worn out sucker rods, overloads, or extremely high rod loads for short periods of time. Stress fatigue failures may have closely spaces, fine, transverse secondary fatigue cracks that completely encircle the circumference of the rod body. The stress fatigue cracks may be on the wrench square and over the entire length of the rod body. With very old sucker rods, stress fatigue cracks and failure may occur within normal everyday operating loads.

Figure 4 is an example of coupling-to-tubing slap. Coupling-to-tubing slap is the result of extremely aggressive angle contact to the tubing by the rod string. This aggressive contact is the direct result of severe fluid pound, unanchored (or improperly anchored) tubing, sticking (or stuck) pump plungers, or any combination of the preceding.

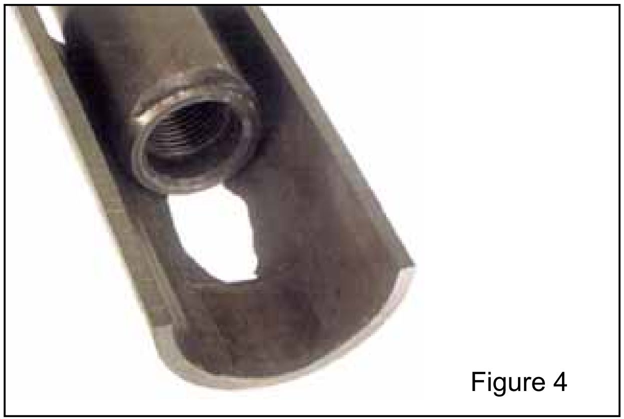

Figure 4

Figure 5

Figure 5 is an example of rod guide related damage. The example on the left is a reconditioned, high tensile strength sucker rod. Turbulent fluid flow, associated with short, blunt-end injection molded rod guides, allowed crevice corrosion in the critical wash area around the end of the guide. Prior to inspecting the mold-on rod guides were removed from the rod body for reconditioning. Class 1 reconditioned sucker rods cannot have discontinuities greater than 20 mils (0.020”) per API Specification 11BR. The crevice corrosion was under the 20 mils allowed for a Class 1 reconditioned sucker rod. However, the notch sensitivity (discontinuity intolerance) of a high tensile strength sucker rod is high. In other words, small pits can be detrimental to the high tensile stresses associated with the high strength sucker rod and reconditioned high strength sucker rods should be de-rated for load. The example in the middle is an erosion/corrosion failure resulting from short, blunt-end; field applied rod guides in small tubing with high fluid velocities. Erosion/corrosion pits will be “fluid cut” with very smooth bottoms. Pit shape characteristics may include sharp edges and steep sides if accompanied by CO_2 or broad smooth pits with beveled edges if accompanied by H_2S. The example on the right is abrasion wear from a field-applied guide moving up and down on the rod body during the pumping cycle. Generally speaking, mold-on rod guides provide better laminar flow, a minimum of three to four times more bonding and holding power and are more cost-effective than are field applied rod guides.

Mechanical Failures

Mechanical failures account for a large percentage of the total number of all rod string failures. Mechanical failures include every type except manufacturing defects and stress/corrosion fatigue. Mechanical damage to the rod string contributes to a stress raiser which will cause sucker rod failures. The time to failure will be influenced by many variables, of which maximum stress, operating environment, orientation of the damage, sucker rod chemistry, sucker rod heat treatment type, stress range and type of damage will be of the most important. Mechanical damage can be caused by inept artificial lift design, improper care and handling procedures, careless makeup and breakout procedures, out-of-date operating practices, or any combination of these elements.

Bent Rod Failures

Bending fatigue failures account for a significant number of all mechanical failures. It is a fact that all bent sucker rods eventually fail. New sucker rods are manufactured to a body straightness of no less than 1/16 inch in any twelve inches of rod body length. Sucker rods within this tolerance of straightness will roll easily on a level rack with five supports. Any degree of bend greater than this will cause an increase in local stress at the point of the bend during applied load. When the bent rod body is pulled straight during load, the fatigue strength of the material is quickly reached. The cycle of continually exceeding the ultimate material strength is repeated during the pumping cycle and causes stress fatigue cracks on the concave side of the bend. These stress fatigue cracks progress across the bar, during load, until not enough metal remains in the bar to support the load, and fracture occurs.

Straightening the raw bar stock is the first step in the process of manufacturing sucker rods. Cold straightening the bar deforms the grain structure below its recrystallization temperature, putting a strain in the bar that is accompanied by a work hardening effect. During the manufacturing process, the function of heat treatment is to stress-relieve the residual and induced stresses caused by bar rolling, bar straightening processes and from forging the rod upsets. Heat treatment changes the metallurgical structure of the forged ends to match that of the rod body and also controls the mechanical properties of the sucker rod. Any rod body bend created after hear treatment causes work hardening, which creates an area of hardness different than the surrounding surfaces. This condition is referred to as a “hard spot” and is a stress raiser to load. Mechanical processing, such as passing the finished sucker rod through a system of rollers, will attempt to remove the bend so it appears to be straight. However, reconditioning processes are not capable of stress relieving bent sucker rods. A bent sucker rod is permanently damaged and should not be used because all bent sucker rods will eventually fail.

Figure 6 (with inset of Figure 7) is an example of binding fatigue failures. Bending fatigue failures can be identified by the angled fracture surface, which will be at some angle other than 90ϒ to the axis of the rod body. The example on the left illustrates a fracture caused by a long radius bend, or gradual bow in the rod body (left example in Figure 7). The fracture surface shows fatigue damage, and has a slight angle when compared to the axis of the rod body. The middle example is a short radius bend (right example in Figure 7). The fracture surface is at a greater angle to the axis of the rod body with a small fatigue portion and a large tensile tear portion. The example on the right is the result of a corkscrewed sucker rod. Notice how convoluted the fracture surface is in appearance. As a general rule, the greater the bend in the rod body, the more convoluted the fracture surfaces appear. In operation, the time for the rod to fracture is greatly shortened. Poor care and handling procedures usually cause bent rods.


Figure 6


Figure 7

Surface Damage Failures

Everything possible should be done to prevent mechanical surface damage to sucker rods, pony rods and couplings. Surface damage increases stress during applied loads, potentially causing rod string failures. The type of damage, and its orientation, contributes to this increased stress effect. The orientation of the damage contributes to higher stresses with transverse damage having increased stresses over those associated with longitudinal damage. A sharp nick will create a higher stress concentration and would be more detrimental to load than a shallow, broad-based depression. Sucker rods with indications of surface damage must not be used and must be replaced. Care should be used to avoid all metal-to-metal contact that might result in dents, nicks, or scratches. To prevent potential sucker rod damage, place strips of wood between metal storage racks and between each layer of sucker rods so metal-to-metal contact can be avoided. Use sucker rods for what they were designed for- to lift a load. Never use sucker rods as a walkway or workbench. Keep metal tools not intended for use on sucker rods and all other metal objects away from the rods. Make sure the tool you use is intended for the purpose and ensure that it is in proper working order.

Figure 8

Figure 8 is an example of various surface damage failures. The example on the left shows a slight depression from a wrench, tool, or other metal object. The second example from the left is damage from a pipe wrench used in applying field-installed rod guides. The second example from the right has a small longitudinal scratch, through metal-to-metal contact, by allowing sucker rods to run down other rods in a rod bundle during installation. The example on the right exhibits transverse surface damage.

Figure 9

Figure 9 is an example of surface damage caused by sucker rod elevators. The bottom example is damage from worn or misaligned elevator seats. After an extended period of service, the elevator seats become so worn that they develop an oval shape rather than a round shape. As the oval shape grows, the tangency ring of the rod upset to the elevator seat face is lowered in the front half of the seat. As the seat continues to wear the seating position of the rod upset is moved forward of the elevator trunnion centerline. This causes an offset in the hook load and tilts the elevator body forward. When the elevator lifts the rod string load, the hook load will bend the sucker rod centerline to coincide with the elevator trunnion centerline. As the rod string weight increases, the hook load will bend every sucker rod engaged by this elevator. Bent sucker rod failures that occur below the surface upset bead may be from bad elevator seats. The top example is damage caused by the elevator latches. This type of damage normally occurs as a result of picking up or laying down in doubles. Never pick up or lay down anything more than one single sucker rod. Anything else causes the elevator latches to act as a fulcrum and allow bending stresses to concentrate in the transition zone of the rod body and the forged upset.

Connection Failures

The API sucker rod connection is designed as a shouldered, friction loaded connection. Since the fatigue endurance of the sucker rod connection is low when subjected to cyclic loads it is necessary to limit the cyclic loads with pin preload. If the pin preload is greater than the applied load the load in the connection remains constant and no fatigue occur from cyclic loads. The friction load that develops between the pin shoulder face and the coupling shoulder face, helps lock the connection together to prevent it from coming unscrewed downhole. However, if the preload is less than the applied load, the pin shoulder face and the coupling shoulder face will separate during the cyclic motion of the pumping unit. Once these faces separate the connection is cyclically loaded and will result in a loss of displacement, or loss of tightness, failure. Loss of displacement failures may result from improper lubrication, inadequate makeup, over-torque, tubing-slap wear, or any combination of these elements.

Figure 10

Figure 10 is an example of pin failures due to a loss of displacement. The sample on the right is typical in appearance for a loss of displacement pin failure. Insufficient makeup, or the loss of tightness, caused the pin shoulder face and the coupling shoulder face to separate. When these faces separate, a bending moment is added to the tensile load in the pin. The threaded section of the pin is held rigid while the rest of the pin flexes. The motion of the rod string causes stress fatigue cracking to start in the first fully formed thread root above the undercut. Small fatigue cracks begin along the thread root and consolidate into a major stress fatigue crack. The fracture surface of a typical loss of displacement pin failure has a small fatigue portion covering approximately one-third of the fracture surface with the tensile tear portion and final shear tear covering the remaining fracture surface. The examples on the left and in the middle will occur as a result of stress loading when stress-raising factors such as corrosion or mechanical damage is present on the surface of the pin undercut.


Figure 11

Figure 11 is another example of two types of pin failures. The sample on the left is typical in appearance for a loss of displacement pin failure. However, this pin fracture was caused by the hydraulic rod tongs during makeup as is evidenced by the stair-stepped tensile tear. It is not uncommon for pin fractures to occur at makeup, if the pin has a pre-existing stress fatigue crack due to the high torque required during joint makeup, with large diameter Class D and all sizes of high tensile strength sucker rods. The sample on the right is an example of excessive torque on a soft pin. The fracture surface has a large fatigue portion, with multiple ratchet marks in the pin-thread root, and a small tensile portion.


Figure 12

Figure 12 is an example of a loss of displacement coupling failure. The fracture initiated in the coupling thread-root opposite the first fully formed pin starting thread. One-third/two-third fracture halves, in length, with ratchet marks originating in the thread root indicate a loss of displacement coupling failure. The fracture surface of a typical loss of displacement coupling failure has a small fatigue portion and a large tensile tear portion. Loss of displacement coupling failures are primarily associated with Class D sucker rods and high tensile strength sucker rods.

Mid-length coupling fractures, with ratchet marks leading from the outside, indicate another type of failure. The fatigue crack starts from the outside coupling surface, progressing inward toward the threads, then around the coupling wall to a tensile fracture. Mid-length fractures indicate coupling failures from mechanical damage to the coupling surface, exceeding the stress fatigue endurance limit of the material, or a manufacturing defect. Most mid-length coupling fractures are the result of mechanical damage or over load. Mid-length coupling fractures due to overload have a small fatigue portion and large tensile tear portion. This failure is common with high strength sucker rods and Class SM couplings. Use Class T couplings to avoid mid-length coupling failures with high tensile strength sucker rods.


Figure 13

Figure 13 is an example of thread galling in the sucker rod connection. Thread galling is mechanical damage to the sucker rod and/or coupling threads. Thread galling is the result of damaged or contaminated threads causing the interference between the threads to be great enough to rip and tear the thread surfaces. The threads weld together during makeup and strip apart at breakout and the connection is damaged and destroyed beyond use. Hard stabbing damage to the leading thread, contaminated threads and cross threading on larger diameter rods are the primary causes of thread galling. Cleaning the threads prior to makeup, properly lubricating the threads and following careful makeup procedures will prevent thread galling.

Figure 14 is an example of wrench square failures. Wrench square failures are extremely rare and seldom occur unless from mechanical damage, corrosion, manufacturing defects or torsional stress causing fatigue damage. The example on the left is a wrench square failure from severe mechanical damage. A loose or sloppy backup on the hydraulic rod tongs has rounded the wrench square corner. The stress fatigue crack began in the corner of the wrench square and progressed to final rupture or fracture.

The example on the right is a wrench square failure from a manufacturing defect. The failure initiated in the die stamp mark and is an example of an excessive die stamp depth failure. Die stamp markings can become notches that serve as stress raisers if the depth of the die stamping, during the forging process, is not controlled and kept within API Specification 11B, allowable tolerances.

Figure 14

Figure 15

Figure 15 is an example of the damage that occurs as a result of severely over-tightening the sucker rod connection. The example shown is an over-tightened coupling that has flared out or bulged near the contact face. Slim-hole couplings are more susceptible to this type of over-tightened damage than are full sized couplings. Over-tightened full size couplings on Class D and high strength sucker rods generally exhibit slight bulges and have the concentric deformation ridge of material on the coupling shoulder face from the impression of the pin shoulder face. Over-tightening with hydraulic rod tongs will twist off soft pins resulting in a tensile failure appearance. The pin undercut will neck down and fracture occurs rapidly. With Class D sucker rods, an indication of over-tightening is the concentric deformation ridge of material on the pin shoulder face from the impression of the coupling shoulder face. Over-tightening on normalized and tempered high tensile strength sucker rods will begin to pull the threads out of the coupling.

Figure 16

Figure 16 is an example of impact cracks on couplings. The practice of “warming up,” or hammering, on couplings in order to loosen them should not be allowed. This example shows how impact damage to a Class T coupling causes stress fatigue cracks around the impact points and accelerated localized corrosion. Hammering on Class SM couplings causes stress fatigue cracks in the hard spray surface and results in a coupling failure due to stress/corrosion fatigue.

Figure 17

Figure 17 is an example of polished rod failures. The majority of all polished rod failures occur either in the body, just below the polished rod clamp, or in the pin. Polished rod body failures below the polished rod clamp result from the addition of bending stresses. These bending stresses may be imposed by pumping units out of alignment, carrier bars that do not set level, worn carrier bars, misaligned load cells, or incorrect polished rod clamp installation. The polished rod failure on the left is an example of polished rod clamp on the sprayed portion of a Spraymetal polished rod. Spraymetal polished rods have an unsprayed portion for polished rod clamp placement. Never put a polished rod clamp on the sprayed portion of a Spraymetal polished rod. The polished rod failure on the right has small, longitudinal scratches caused from mishandling.

Polished rod pin failures generally occur due to the installation of sucker rod couplings. Polished rod pins have a 9ϒthread taper between the straight-threaded section and the shoulder. Sucker rod couplings have a 30ϒ starting thread and a deep recess that doesn't engage all the polished rod pin threads. Polished rod couplings have a 9ϒ starting thread and a profile designed to properly fit the polished rod pin. The shallow recess to the first thread easily distinguishes polished rod couplings from sucker rod couplings and allows every polished rod pin thread to be engaged.

Corrosion Failures

Corrosion is one of the greatest problems encountered with produced fluids and accounts for about one-half of all sucker rod failures. Corrosion is the destructive result of an electrochemical reaction between the steel used in making sucker rods and the operating environment to which it is subjected. Simply put, corrosion is nature's way of reverting a man-made material of a higher energy state (steel), back to its basic condition (native ore) as it is found in nature. The elemental iron in steel combines with moisture or acids, to form other compounds such as iron oxide, sulfide, carbonate, etc. Some form and concentration of water is present in all wells considered corrosive and most contain considerable quantities of dissolved impurities and gases. For instance, carbon dioxide (CO_2) and hydrogen sulfide (H_2S) acid gases, common in most wells, are highly soluble and readily dissolve in water, which tends to lower its pH. The corrosivity of the water is a function of the amount of these two gases that are held in solution. All waters with low pH values are considered corrosive to steel, with lower values representing greater acidity, or corrosiveness.

All downhole environments are corrosive to some degree. Some corrosive fluids may be considered non-corrosive if the corrosion penetration rate, recorded as mils of thickness lost per year (mpy), is low enough that it will not cause problems. However, most producing wells are plagued by corrosion problems and no currently manufactured sucker rod can successfully withstand the effects of this corrosion alone. While corrosion cannot be completely eliminated it is possible to control its reaction. All grades of sucker rods must be adequately protected through the use of effective chemical inhibition programs (reference current editions of API Specification 11BR and NACE Standard RPO195). Some sucker rod grades, due to different combinations of alloying elements, microstructures and hardness levels, are capable of longer service life in inhibited corrosive wells than other grades of either low or high tensile strength.

Why do new sucker rods seem to corrode faster than older rods in the same string? Two sucker rods with the same chemical analysis will form a galvanic corrosion cell if the physical condition of one is different from the other. Physical differences in a sucker rod may be caused from poor care and handling practices (i.e. surface damage resulting in bruises, nicks, bends) and/or corrosion deposits. Since new sucker rods go into the well without corrosion deposits, they often corrode preferentially in relation to rods that are coated with corrosion deposits. Corrosion on steel starts very aggressively but often slows down as soon as an obstructive surface film of corrosion deposit (scale) is formed upon the metal surface. For example, CO_2 generates iron carbonate scale as a by-product of its corrosion. This scale coats the sucker rod and retards the corrosion penetration rate, which tends to slow down corrosion. However, if this deposit is continuously cracked by a bending movement or removed by abrasion, aggressive local corrosion continues on the area with the scale removed, and results in deep corrosion pitting.

Can high tensile strength sucker rods be used in a corrosive environment? Generally soft rods tolerate corrosion better than hard rods and, as a rule of thumb; you should always use the softest rod that will handle the load. However, if load requirements dictate the use of high tensile strength rods than it is important to protect the rods with an effective surface film of corrosion inhibitor. In most cases, if you can adequately protect downhole equipment from corrosion, you should be able to adequately protect high tensile strength rods from corrosion by increasing the application frequency of the corrosion-inhibitor program. In other words, if you effectively batch treat once a week with 40 parts per million (ppm) of corrosion inhibitor for D class rods, you will need to batch treat twice weekly with 40 ppm of corrosion inhibitor for high tensile strength rods. Treatment volumes vary and are dependent upon many factors too numerous to list. Always consult with a corrosion control specialist prior to the installation of every rod string, especially when corrosion fatigue is suspected as the failure root cause.

Figure 18

Figure 18 is an example of corrosion fatigue from CO_2 corrosion. The size of the pit, as far as when it becomes detrimental to the rod, depends on two factors- material type and hardness. Class K sucker rods may develop deeper and larger pits than a Class D sucker rod before it becomes detrimental to the rods. Class D sucker rods may develop deeper and large pits than a high tensile strength rod before it becomes detrimental to the rods. Softer materials with lower rod stress tolerate larger pits than do harder materials with higher rod stress. Therefore, small pits can be detrimental to higher tensile strength sucker rods as opposed to a softer rod that does not have as much rod stress.

Acid Corrosion

Service companies use acids for well stimulation and cleanout work. All acid work should have an inhibitor mixed with the acid prior to injection into the well. Spent acids are still corrosive to steel and the well should be “flushed“ long enough to recover all acid. In rare instances, some produced waters contain organic acids that have formed downhole, such as acetic, hydrochloric and sulfuric acids. Corrosion from acid is a general thinning of metal, leaving the surface with the appearance of sharp, feathery or web-like residual metal nodules. Metallic scale will not be formed in the pits. The left sample in Figure 5 is an example of acid corrosion.

Figure 5

Chloride Corrosion

Chlorides contribute to the likelihood of an increase in corrosion related sucker rod failures. The corrosivity of water increases as the concentration of chlorides increase. Corrosion inhibitors have more difficulty reaching and protecting the steel surface of sucker rods in wells with high concentrations of chlorides. Corrosion, from waters with high concentrations of chlorides, has the tendency to be more aggressive to carbon steel sucker rods than to alloy steel sucker rods. Chloride corrosion tends to evenly pit the entire surface area of the sucker rod with shallow, flat-bottomed, irregular shaped pits. Pit shape characteristics include steep walls and sharp pit edges.

CO_2 Corrosion

CO_2 combines with water to form carbonic acid, which lowers the pH of the water. Carbonic acid is very aggressive to steel and results in large areas of rapid metal loss that can completely erode sucker rods and couplings. The corrosion severity increases with increasing CO_2 partial pressure and temperature. CO_2 corrosion pits are round based, deep with steep walls and sharp edges. The pitting is usually interconnected in long lines but will occasionally be singular and isolated. The pit bases will be filled with iron carbonate scale, a loosely adhering gray deposit generated from CO_2.

Figures 19 and 20 show typical examples of CO_2 corrosion. Figure 19 is an example of CO_2 corrosion on couplings and Figure 20 is an example of CO_2 corrosion on rod bodies.

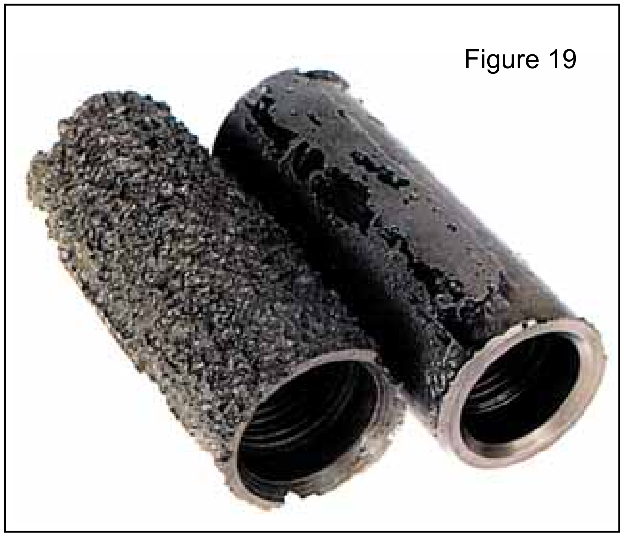
Figure 19

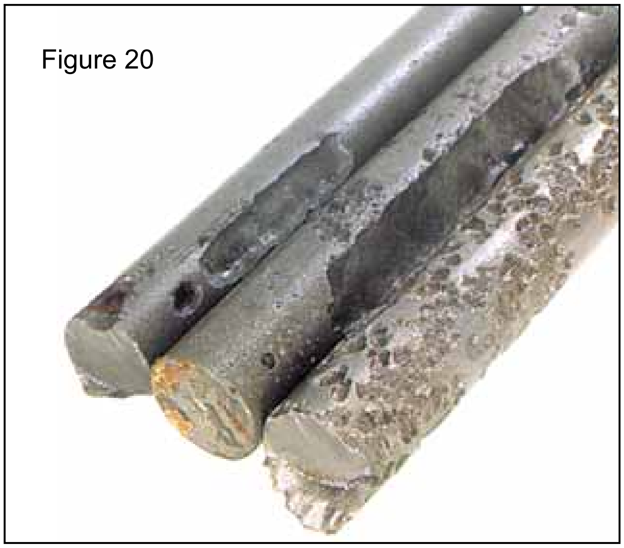
Figure 20

H_2S Corrosion


Figure 21

H_2S pitting is round based, deep with steep walls and beveled edges. It is usually small, random, and scattered over the entire surface of the rod. A second corrodent generated by H_2S is iron sulfide scale. The surfaces of both the sucker rod and the pit will be covered with the tightly adhering black scale. Iron sulfide scale is highly insoluble and cathodic to steel which tends to accelerate corrosion penetration rates. A third corroding mechanism is hydrogen embrittlement, which causes the fracture surface to have a brittle or granular appearance. A crack initiation point may or may not be visible and a fatigue portion may not be present on the fracture surface. The shear tear of a hydrogen embrittlement failure is immediate during fracture due to the absorption of hydrogen and the loss of ductility in the steel. Although a relatively weak acid, any measurable trace amount of H_2S is considered justification for chemical inhibition programs when any measurable trace amount of water is also present.


Figure 22

Figure 21 and 22 are examples of H_2S corrosion. The three rod body samples on the left are examples of localized corrosion (pitting) and the two rod body samples on the right are examples of general thinning corrosion from under-scale deposit corrosion. The sample in Figure 22 is an example of a pin failure due to hydrogen embrittlement.

Microbiologically Influenced Corrosion (MIC)

Some amount of microscopic life form is present in essentially every producing well. Of primary concern to sucker rods are the single celled organisms capable of living in all sorts of conditions and multiplying with incredible speed-commonly referred to as bacteria or "bugs”. Suspect fluids should be monitored continuously for bacteria by sampling, identifying and counting the bacteria. The extinction dilution technique is commonly used to culture bacteria for an estimation of the number of bacteria present in the well. Bactericide should be used on all suspect fluids to control bacteria populations. Bacteria are classified according to their oxygen requirements: aerobic (requires oxygen), anaerobic (no oxygen), and facultative (either). Some bacteria generate H_2S, produce organic acids or enzymes, oxidize soluble iron in produced waters, or any combination of the preceding. MIC has the same basic pit shape characteristics of H_2S, often with multiple stress cracks in the pit base, tunneling around the pit edge and/or unusual anomalies (i.e. shiny splotches) on the rod surface. Bacteria are very aggressive and all sucker rod grades corrode rapidly in downhole environments containing bacteria. Sulfate reducers (SRB's), those that produce H_2S, probably cause more problems to downhole artificial lift equipment than do any other bacteria type. Multiple cracking in the pit bases results from the hydrogen sulfide by-product of the bacterial lifestyle, which corrode and embrittle the surface of the steel under the colony. Figure 23 show several examples of microbiologically influenced corrosion (bacteria) on sucker rod bodies.


Figure 23

Oxygen Enhanced Corrosion

Oxygen enhanced corrosion will be most prevalent on couplings, with a few instances found on rod upsets. Oxygen enhanced corrosion is rarely seen on the rod body. In fact, aggressive oxygen enhanced corrosion can erode couplings without harming the sucker rods on either side. The rate of oxygen enhanced corrosion is directly proportional to the dissolved oxygen concentration, chloride content of the produced water and/or presence of other acid gases. Dissolved oxygen can cause severe corrosion at extremely low concentration and evaporate large amounts of metal. Pitting is usually shallow, flat-bottomed, and broad-based with the tendency of one pit to combine with another. Pit shape characteristics may include sharp edges and steep sides if accompanied by CO_2 or broad, smooth craters with beveled edges if accompanied by H_2S. Corrosion rates increase with increased concentrations of dissolved oxygen.

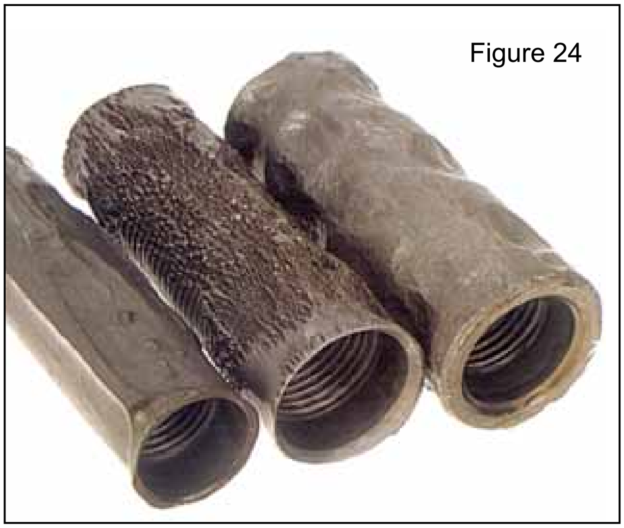
Figure 24

Figures 24 and 25 are examples of oxygen enhanced corrosion. The coupling sample on the left is an example of the effects of oxygen enhanced CO_2 corrosion (left), H_2S corrosion (middle), and chloride corrosion (right) while the rod samples in Figure 25 show the effects of oxygen enhanced CO_2 corrosion near the upset (left) and CO_2 corrosion on the rod body (right).


Figure 25

Scale Corrosion

Scales such as barium sulfate, calcium carbonate, calcium sulfate, iron carbonate, iron oxide (rust), iron sulfide, and strontium sulfate should be prevented from forming on sucker rods. Although scale on a sucker rod slows down the corrosion penetration rate, it also reduces the effectiveness of chemical inhibitors. Severe localized corrosion in the form of pitting results any time the scale is cracked by a bending movement or removed by abrasion.

Stray Current Corrosion

Rarely seen in most producing wells, stray current corrosion refers to the induced, or stray, electrical currents that flow to or from the rod string. Stray current corrosion can be caused by grounding electrical equipment to the well casing or from nearby cathodic protection systems. Arcs originating from sucker rods leave a deep, irregular shaped pit with smooth sides, sharp edges and a small cone in the base of the pit. Arcs originating from the tubing leave deep pits with smooth sides and sharp edges that are random in dimension and irregular in shape. Stray current corrosion pits are usually singular and isolated in a row down one side of the sucker rod near the upsets.

Manufacturing Defects

Failures due to manufacturing defects are rare and seldom occur. Manufacturing defects are easily recognized and it is important that you understand what these defects look like if you are to file accurate claims for warranty reimbursement. No manufacturer is excluded from the possibility of defects in material or workmanship and the following failure examples include defects from all manufactures.

Figure 26

Figure 26 is an example of mill defects. Mill defects occur along one side of the rod body and these discontinuities normally have longitudinally tapered, sharp "V" shaped bottoms with indications of the longitudinal seam in the base. The example on the far left is an example of a sliver. The rod body third from the left is also an example of a sliver. When fishing the rod failure, the sliver folded against the fracture surface. The rod body second from right is an example of a scab. A sliver is a small loose or torn segment and a scab is a large loose or torn segment of material longitudinally rolled into the surface of the bar. One end of the sliver or scab is normally metallurgically bonded into the rod body while the remaining end is rolled into the surface and physically attached. Fatigue failures, which result from slivers or scabs, will have a piece of loose material protruding over the fatigue portion of the fracture surface. The rod body second from the left is an example of rolled-in-scale. Rolled-in-scale is a surface discontinuity caused when scale (metal-oxide), formed during a prior heat, has not been removed prior to bar rolling. The rod body sample on the far right is an example of a rolling lap. Rolling laps are longitudinal surface discontinuities that have the appearance of a seam from rolling, with sharp corners folded over and rolled into the bar surface without metallurgical bonding.

Figure 27

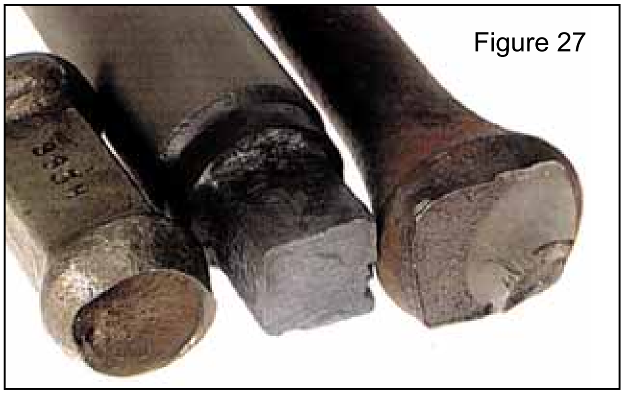

Figure 27 is an example of forging defects. The fracture begins internally below a forging crack in the upset area and is brittle or granular in appearance. A crack initiation site may or may not be visible and a fatigue portion may not be present on the fatigue fracture surface. The examples on the left and in the middle occur as a result of low forging temperatures. The example on the left is a failure from cold-shut and the example in the middle is a failure from a forging crack. The fracture on the right is a failure caused by a subsurface longitudinal seam located near the end of the raw bar. During the forging process the orientation of this discontinuity was changed transversely.

Figure 29 is an example of processing defects. The lower example is a casehardened sucker rod and the upper example is a coupling that has been processed through a grinding operation to reduce the diameter. In both examples, a difference in the material hardness has resulted in preferential corrosion attack.

Figure 29

Figure 30 is an example of a mill defect and a machining defect. The lower example is a failure due to a large, internal, nonmetallic inclusion in the pin. The fracture began internally and is brittle or granular in appearance. A crack initiation site may or may not be visible and a fatigue portion may not be present on the fatigue fracture surface. The upper example is from rolling the pin threads twice. Rolling twice has flattened the pin thread crest and will not be capable of achieving the correct friction load required for makeup.

Figure 30

Your initial investment in sucker rods is substantial. Moreover, the cost related to replacing damaged sucker rods generally out weights the original cost of the new rod string. Protecting your investment and getting the maximum service life out of your rod string just makes good sense. It is important to diagnose rod failures accurately and to implement corrective action measures to prevent future failure occurrences. This photo essay is intended for use as a reference guide in sucker rod failure analysis. It explains how rod failures occur and expounds methods for identifying the characteristics of the several failure mechanisms. Where sucker rod failures are concerned, there are no absolutes and no two fractures look exactly alike in appearance. But, by recognizing the visual clues and identifying characteristics of the different failure mechanisms, corrective action measures can be taken to prevent sucker rod failures, thus allowing the operator to produce marginally profitable wells more cost effectively.

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