SUCKER ROD PUMPING

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I. DEFINITION

Sucker rods together with a prime mover, pumping unit, and bottomhole pump is a simple mechanical system to lift fluid from a depth. Other competing artificial lift systems include hydraulic, submersible, impeller, gas lift and plunger.

II. TYPES

Sucker rods as part of an artificial lift system include rods produced from steel, fiberglass, wireline and aluminum. Steel rod strings are used in about 87% of artificially produced oil wells.

III. HISTORY

Sucker Rod pumping as it is used in today's oil field, evolved from the waterwell wooden sucker. Early history includes rope used for lifting water in irrigation systems.

IV. PURPOSE

Increasing rod string performance lift through manufacturing quality control, proper string design, correct handling and control of environment.

V. MANUFACTURING

A. Basic material:

1. Most steel raw material for sucker rods and couplings is scrap. Scrap is melted down, cleaned, adjusted for chemistry in a furnace. The furnace load is poured into a ladle where final quality control checks are made. The melt is continuous casted into a square or round billet depending on the mill design.

2. When ready to roll raw bars, the billets are reheated and reduced to a given bar diameter through a series of roughing, reducing and finishing stands. After cooling, the bars are sheared to length, bundled, and shipped to the sucker rod manufacturer.

B. Sucker rod fabrication:

1. Bundled raw bar stock is inspected for bent or damaged bars and checked for chemistry and physicals.

2. The first operation is straightening the raw bar. A sucker rod must be straight to prevent abnormal stress loadings in service.

3. After straightening, the raw bar is passed through electromagnetic induction NDT inspection equipment to reject bars with detrimental surface defects.

4. The next step is forging which is a hot metal gathering process to forge the upset. The upset provides the pin blank for threading, the shoulder for coupling seating, the wrench square for makeup, the bead taper for elevator handling, and identification stamping.

5. Heat treatment of the full length rods to a critical temperature relieves all residual and induced stress. Cooling is either by air or liquid quench. Alloy steel bars are further heat treated by tempering to set physical strength.

6. Mill and heat treat scale is removed by blasting with hardened steel shot.

7. Pin ends and shoulders are machined. The pin threads are cold rolled on the pin blank. Inspection, lubrication, coupling and protectors are fitted.

8. All rods are coated to prevent atmospheric corrosion during storage and transportation.

9. All rods are packaged to prevent handling and transportation damage from surface mechanical damage and bends.

C. Couplings:

1. Couplings are made from either mechanical pressure tubing or cold drawn bar stock.

2. After inspection and material conformation, the raw material is cut off and stamped for identification.

3. Next - the OD, end faces, thread land and recesses are machined.

4. The threads are tapped by cold forming, burnishing, or cutting.

5. After inspection, a zinc phosphate coating is bonded to the coupling surfaces as anti-galling treatment and as a base for lubrication.

6. Couplings to have a hard faced OD are blasted after machining and before threading. A .015" flame sprayed nickel-chrome material is fused to the OD. Finish grinding completes the process. The coupling is then threaded.

VI. <u>SIZES AND GRADES</u>

A. Sucker Rods:

1. Rod sizes are 1/2", 5/8", 3/4", 7/8", 1" and 1-1/8" in diameter. 1-1/4" can be made on special order. Lengths are 25' and 30'.

2. Grades include one carbon manganese and several alloy steels.

   a. API grade C is a plain carbon steel for loads to 22,000 PSI.
   b. API grade K is a nickel moly steel for loads to 25,000 PSI.
   c. API grade D includes all high tensile rods with a minimum tensile strength of 115,000 PSI in both alloy and carbon material for working loads to 50,000 PSI.

B. Pony rods are available in the same diameters and grades as rods in lengths of 1', 2', 4', 6', 8' and 10'.

C. Couplings:

1. Couplings are made in standard rod pin sizes with OD's of slim-hole, regular, and oversize.

2. Both alloy and carbon steel are used.

3. Two styles are made - thru hardened and surface hardened.

4. Couplings are either box and box, box and pin, or pin and pin design.

5. Combination couplings are made with any pin size and design depending on requirement.

D. Polished Rods:

1. OD sizes are available in 1", 1-1/8", 1-1/4" and 1-1/2". Standard lengths are 8', 11', 16', 22' and 30' with other lengths available on request.

2. Material is from carbon steel (common or piston), alloy, stainless, bronze, and monel.

3. Base material is made by cold drawing the bar to size, then grinding and polishing for a smooth, even packing bearing surface. Pins are machined on both ends and some are available with one end upset.

4. Hard facing is applied to provide the rod with surface corrosion and abrasion resistance.

5. Liners are made in a variety of materials for much the same purpose, bronze being the most common.

6. Certain size-load combinations are suggested:

   a. 1-1/2" for 1-1/8" and 1" rods
   b. 1-1/4" for 7/8" and 3/4" rods
   c. 1-1/8" for 5/8" and 1/2" rods

7. Problems:

   a. Pin failures - most susceptible caused by improper makeup.
   b. Body failures - usually at junction of clamp and carrier bar caused by bending moments, handling bends, and over tightened clamps.

VII. SHIPPING

A. Always pick up bundles of rods with T-hooks and spreader bars designed for this purpose.

B. Single rods should be picked up and moved with support at both ends and the middle.

C. Rods should be transported on a flat surface with each package supported by the spacers and single rods with at least four supports or spacers. Spacers should be any material except steel.

D. Tie down chains and boomers should never touch a rod surface. Always pad chains and support over wood.

VIII. STORAGE

A. Storage of new rods should always be in bundle quantities.

B. Bundles should be supported level and straight off the ground in a flat area free of weeds, junk, etc. A heavy sill should support each of the five spacer rows in the API bundle. Additional bundles in a stack should have spacer rows aligned.

IX. ROD STRING DESIGN - Proper design will provide the maximum predicted performance life of the rod string for given well conditions.

A. Maximum Allowable Load: This is the maximum allowable stress load for a given size and type of sucker rod. This stress limit applies to the top rod in the string being designed.

   1. Endurance limits are set from laboratory testing to find the maximum stress limit for steel under conditions of cycling loading. The number of cycles to failure are plotted and a limit is found where the range of stress from zero load to some value will permit unlimited cycles.

   2. Bar testing finds the limit for an as rolled, hot rolled sucker rod steel in full sections. This stress limit is called T/4.

   3. Goodman Diagram from API RP11BR gives the maximum allowable load for sucker rods working under a range of stress less than T/4.

B. Service factors are applied to the maximum recommended allowable load to reduce this stress for service conditions to give the longest performance life under the conditions given. Control of environment with inhibitors, care in physical handling, size and grade of material, are all factors involved. Actual field experience is the best guide to the service factor that should be applied.

C. Calculation factors affecting rod loads from API RP11L:

1. Peak Loads - maximum load imposed on the top rod.

2. Minimum Loads - minimum load imposed.

3. Range of Stress - range of load the top rod cycles through.

4. Pumping Speeds - non-syncroness speeds by formula.

5. Plunger Size - determines imposed load on rod string.

6. Stroke Length - from unit size.

D. A place to start:

1. Well Depth - seating nipple or hole depth.

2. Fluid Production - how much total fluid.

3. Tubing Size - anchored?

4. Unit Size - estimate from depth and fluid required.

5. Stroke Length - from unit selected.

6. String Taper - estimate from experience.

E. Design:

1. Design string to a maximum of 70% of the Goodman Diagram.

2. Whenever a change in the pumping system is made, always recheck the design.

3. Design to prevent shock loadings to the system such as fluid pound, gas pound, tagging bottom, rod whip from speed, or compression.

4. Rule of Thumb - design the system with the longest, slowest stroke with the smallest pump and largest rod.

. <u>CORROSION CONSIDERATIONS</u>

A. Definition:

Corrosion is the destruction of metal by its environment. Sucker rod metal is exposed to a variety of corrodents -- moisture, oxygen, salt water, acid gasses such as H_2S and CO_2, chlorides, galvanic, and other chemicals. The problem is compounded by surface scales, either deposited or corrosion products, such as oxides, carbonates, sulfates, or sulfides.

Mechanism:

Destruction of sucker rod steel develops as pitting. The mechanism is electro-chemical in that iron is reduced to a scale by cell action. The pit site is the annode, adjacent areas are the cathode, the external connection between the two is the rod body, and the electrolite is the fluid covering the two poles. All four conditions must be present for corrosion to continue.

B. Problem:

Sucker rod steel exposed, unprotected to an environment containing the four conditions, will corrode at a certain rate. As pitting at the annode progresses, the stress loading at that cross section increases as the area decreases. Since the pumping load is imposed on the entire cross section, the area of reduction on the two tension sides of the pit develops a shear stress at the pit base which forms a progressing fatigue crack. With each cyclic loading of the rod, the crack progresses across the rod perpendicular to the rod axis. At some point the yield point of the remaining metal is reached and the crack develops very rapidly. The tensile strength of the balance of the section is reached, and the rod fails from the tensile mode.

C. Extent of problem:

About sixty percent of all sucker rod failures are directly caused by corrosion. Another twenty percent is indirectly caused by corrosion.

D. Remedy of problem:

The general approach has been to break the electrochemical reaction by separating the electrolite from the cathode or present a passive material to corrosive well environments.

1. Coatings:

a. Non-metallic coatings - Baked on plastics of various compositions are used. Holidays and abrasion reduce the effectiveness of plastics. A void or mechanical break in the coating causes concentrated cell activity at the spot. Plastics have no wear resistance, and the rod will corrode as soon as the plastic coating is worn through.

b. Metallic coatings - Nickel and chrome coatings have had limited success because of the holiday problem from uneven application and mechanical damage that exposes the base material accelerating corrosion.

2. Material:

   a. Metallurgical - Wrought iron, alloy steels, monel, aluminum, stainless, and bronze have been used for sucker rods. Cost over that of common steels have stopped the main development of these metals. Working strength levels over steels is usually lower. Steel wire lines have not been effective because of the flexing problem.

   b. Non-Metallurgical - Wood, fiberglass perform under selected service conditions. Corrosion has no effect, but mechanical problems are the cause of failure.

3. Chemical:

   The most effective method to control corrosion is an adequate downhole chemical inhibitor control program, properly designed and adequately maintained. Corrosion inhibitors function by absorbing to the sucker rod steel surface presenting a barrier to well fluids.

   a. Build film on steel at first introduction to corrodant.
   b. Inject sufficient inhibitor concentration in well fluid to maintain film.
   c. At all well operations, exclude oxygen from the system.
   d. Continuous injection and batch treatment are the most common method used to protect downhole materials.
   e. Periodic monitoring is essential to review the corrosion control effectiveness.

E. Types of Corrosion:

1. Oxygen

   a. Very destructive to steel as it readily combines with iron to form a scale.

   b. Combines with other corrodents to accelerate corrosion attack.
   c. Forms shallow, broad based pits.
   d. Controlled by scavengers and by preventing the introduction into the well bore.

      1. Injection systems - water or chemical.
      2. When servicing the well.

2. Hydrogen sulfide - sour corrosion

   a. Found in about 60% of wells.
   b. The sulfide ion combines with iron to form iron sulfide scale. Black and granular scale.
   c. Iron sulfide can become cathodic to the base material furthering corrosion.
   d. The hydrogen ion has an embrittlement tendency.
   e. Pitting is round, smooth based and surrounded by cathodic areas. Often covered by sulfide scale.

f. Prevention is by chemical inhibitors.

3. Carbon dioxide - sweet corrosion

   a. Pitting is round based, sharp edged inter-connected to far lines of pitting on surface.
   b. Forms a very tight surface scale.
   c. Controlled by chemical inhibitors.

4. Chlorides

   a. Forms hydrocloric acid in water.
   b. Dissolves surface iron over total surface. Rough surface texture.
   c. Controlled by chemical inhibitors.

5. Water and salt water

   a. Even distilled water can act as an electrolite and corrode steel.
   b. Combines with iron causing small pitting evenly over entire surface.
   c. Forms iron oxide or rust scale.
   d. Prevented by chemical inhibitors.

6. Bacteria

   a. Forms round, tapered pits with scale covering where colony grows. Usually isolated.
   b. Control with biocide or prevent from contaminating well bores with clean downhole equipment.

7. Galvanic

   a. Pitting as result of dissimilar metals in close contact in well fluids. Current flows destroy the less noble of the two metals.
   b. Use compatible metals or close together on galvanic scale.

8. Electrolysis

   a. Pitting caused by an external electric current induced into the rod string.
   b. Pitting is usually cone shaped with metallic residue in base.
   c. Remedy is to find and break the current flow.

XI. MECHANICAL CARE AND HANDLING OF SUCKER RODS

A. Basic handling involves always moving a rod as straight as possible and not letting it contact another piece of metal.

   1. Prevent rods from becoming bent

      a. Move rods in bundles, when possible.
      b. Use three people to move single rods by hand.
      c. Use gin trucks with proper lifting hooks and spreader bars.

d. Tail into and away from single rods when running from horizontal rack.
e. Watch condition of elevators that rod does not bend when it is picked up.
f. Bent rods should never be run in the hole.
g. Hanging rods in derricks is preferable to laying rods down.
h. Failures from bent rods show transverse stress fatigue cracks on the concave side of the bend. The break face will not be perpendicular to the axis of the rod.

2. Prevent contact with another piece of metal

   a. Do not allow rods to touch in storage, transit, or when running or pulling in the hole.
   b. Provide sills under spacers that separate rods.
   c. Use wooden strips to separate rows of rods on racks.
   d. Never place tools, stuffing boxes, wrenches, etc., on rods. Place such on wood sills.
   e. Run rods in hole in such a manner that surface damage doesn't occur.
   f. Keep elevators in good repair so as not to damage the rod under the upset from nicks or bends.
   g. Failures show a fatigue crack that starts at the base of a damaged area. The nick, etc., will show moved metal.

B. Flexing or bending of the rod string during operation can cause damage. In general, the rod string should run as smooth as possible and hang in tension.

   1. High pumping speeds generally above eighteen strokes per minute or an $\frac{N}{N_o}$ of .3 will cause rod whip and excessive stress ranges.

   2. Plunger area to rod body area ratios of 7 or larger should be avoided as downstroke compression will buckle the rod string.

   3. Fluid or gas pounding will send shock waves up the rod string causing flexing. The pumping system should be designed to the amount of fluid available to the pump.

   4. Tapping the pump either top or bottom will cause the same problems as pounding.

   5. Crooked holes cannot be straightened, but tubing in them can be anchored in tension to prevent rod string from flexing around a bend. The same holds true for corkscrewed tubing.

   6. These conditions cause transverse stress cracks to form in a longitudinal line along one side of the rod on the concave side. The rod will be straight and not show a permanent bend. Changing the system is the only way to prevent failures from these conditions.

C. Makeup of joints properly done will eliminate about 40 to 50% of rod string maintenance costs. In general, a properly make up joint that maintains its prestress will not fail. Upon loss of preload or backoff, either the pin or box will fail from fatigue cracking or the joint will unscrew.

1. The circumferential displacement method as presented in the API RP11BR publication is recommended as the best available method for the makeup of sucker rod strings.

2. Pin threads should be cleaned of scale and dirt.

3. Damaged threads should be repaired, if possible, otherwise the rod replaced.

4. Threads should be lubricated with an inhibitor either straight or mixed with oil or grease. Lubrication should coat the threads only. Clean box and pin shoulder face of dirt and lubricant for effective friction hold.

5. Power wrenches provide consistent and sufficient torque for recommended displacement. Hand wrenches might be inconsistent and are insufficient for 7/8" and longer rods.

6. For proper makeup, stab the joint, start by hand, spin in to shoulder with a spinning wrench, then makeup with power.

    a. Stab pin or box carefully so as not to damage threads.
    b. Start by hand to make positive engagement of starting thread to prevent galling.
    c. Spin in by hand to feel any dirty or damaged threads.
    d. Run power wrenches at lowest RPM possible to prevent thread damage.

7. Pin failures usually occur at first thread root above undercut. These are caused by loose joints and bending forces on the pin. Failures at the radius above the shoulder also occur depending on susceptibility. Corrosion can also contribute.

8. Coupling failures opposite the last thread on the pin end with the crack progressing outward from the thread root are also caused by improper makeup. Cracks between the pins with the fatigue crack progressing inward from the outside are generally caused by surface mechanical damage. Coupling should never be hit for any reason.

XII. CONCLUSION

Steel sucker rod pumping is the most efficient and economical method of lifting oil field fluids to the surface. Given the depth and volume limitations, proper care and handling, design and operating conditions, sucker rod can give satisfactory performance life and return on investment.

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