DOWN-HOLE SUCKER ROD PUMP BARREL AND PLUNGER MATERIALSFOR ABRASION AND CORROSION

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ABSTRACT AND SCOPE

Manufacturers of down-hole sucker rod pumps have developed materials, coatings and treatments for barrels and plungers. Some of these have become standards in the industry while others have been tested and either did not meet expectations or were not economically viable. This paper will review historical, current and new materials, coatings and treatments for down-hole sucker rod pump barrels and plungers.

INTRODUCTION AND BACKGROUND

Down-hole conditions vary significantly in their effect on down-hole sucker rod pump materials. Abrasion, corrosion, erosion and high pressure affect the life of down-hole sucker rod pumps such that the time between repair or replacement of pumps varies from several months to decades. In some producing areas, variations in run life occur within a particular producing formation. The multitude of variables in down-hole pumping conditions, choices of sucker rod pump materials and operating characteristics make the selection of barrel and plunger materials an important choice for the operator.

Different materials have been developed for all of the parts in a sucker rod pump. The most expensive parts of the pump, the barrel and plunger have received special research and development attention over the years due to the critical role they play in producing fluid, and because they receive the most wear. This is due to their function in the pump of providing the moving seal surface and thus receiving the maximum exposure to the detrimental effects of abrasion, corrosion, erosion and high pressure. As an example: a moderate producing well of down-hole fluids and gas, operating with a 120roke, at 10 strokes per minute (SPM) will complete over 14,000cycles and move over a wearing surface distance of about 54 miles, all in one day.

Plain, uncoated or untreated plunger and barrel materials will only stand up to this kind of abuse if the well fluids provide good lubrication, are non-corrosive and do not contain abrasive particulates. These well conditions are rare. Most wells have some kind of detrimental production characteristics that dictate the use of hard surfaces for the barrel and plunger.

DISCUSSION

Barrel Base Materials

Plain Steel: The most commonly used steel for sucker rod pump barrels is UNS G10230 / G10260 steel. This is a low carbon, electric resistance welded, drawn over mandrel, cold drawn steel with a carbon content of 0.23% to 0.26%. It is not heat treatable (does not need to be), has a hardness equivalent to about HRC 10, and a yield strength of about 70.000 psi. Plain steel material is used in its uncoated, inside honed condition for many applications and is rated for mild corrosion, mild abrasion and high strength.

Plain steel is also used as the base material for chrome plated and nickel carbide plated steel barrels. These coatings are applied for abrasion and/or corrosion resistance. Chrome plating on plain steel is commonly used for up to severe abrasion and mild corrosive conditions. Nickel carbide plating on plain steel is used for up to severe abrasion and moderate corrosive service. Other details of these and other coatings and treatments will be covered later in this paper.

501 ***Steel:*** This is an interesting steel in that it contains only about 5% chrome (4% to 6%) yet shows a significant improvement over plain steel in corrosive conditions. Its official designation is UNS S50100. It is also referred to correctly as **,** it does not qualify as a stainless steel and should be referred to as corrosion resistant steel.rbon, 5% chrome, 0.5% molybdenum, and 1% Silicon. It has a hardness equivalent to about HRC 10, and a yield strength of about 75,000 psi.

Corrosion resistant (501) steel is not normally used in its bare state but is widely used as the base material for chrome plated, nickel carbide plated or with a carbonitrided inside surface. **All** three of these coatings are used for up to severe

abrasive service. Their order with respect to the most corrosion resistant is; nickel carbide, carbonitrided and chrome plated.

4/30 Steel: This alloy steel is used by at least one manufacturer for sucker rod pump barrels. It has about 0.30% carbon, 1% chrome, 0.2% molybdenum, and 0.25% Silicon and is a UNS G41300 steel. It is a heat treatable steel but is not used in that condition for sucker rod pump barrels. It has a hardness equivalent to about HRC 10, and a yield strength of about 60,000 psi. It is offered in its bare state, chrome plated, nickel carbide plated, and nitrided. In its bare state, it is used successfully for mild abrasion and mild corrosion. The chrome plated and nickel carbide versions have the same applications as the plated plain steel listed above. The nitrided version should be suitable for up to moderate abrasion and mild corrosion.

1020 Steel: Another steel that is widely used in the industry is 1020 steel, UNS G 10200. It is the low carbon, electric resistance welded, drawn over mandrel, cold drawn, base steel that is commonly used to manufacture carbonitrided or carbonized sucker rod pump barrels. It has a carbon content of 0.18% to 0.23%, a hardness equivalent to about HRC 10. After carbonitriding or carbonizing it has a yield strength of about 75,000 psi . In its finished state of carbonitrided or carbonized it is suitable for up to severe abrasion and up to moderate corrosion.

Brass: The brass that is used successfully for sucker rod pump barrels is an arsenical, inhibited admiralty brass. It is resistant to virtually all down-hole corrosion and has a high enough strength to be used in deep wells in the heavy wall configuration. Its hardness is equivalent to about HRC 10 with a yield strength of about 50,000 psi. Brass is used in its uncoated, bare condition with soft-packed plungers, or with solid plungers when it is plated internally with either chrome or nickel carbide. The plain brass barrel or the nickel carbide coated version are good choices for severe corrosion, although brass nickel carbide coated is the only one qualified for severe corrosion and severe abrasion. Plain brass is only good for mild abrasion. Chrome plated brass barrels are rated for up to severe abrasion and up to moderate corrosion.

Stainless Steel: Some 304 stainless steel barrels, UNS S30400, are used in the industry with soft-packed plungers. This austenitic stainless steel is as corrosion resistant as brass but not quite as strong. Its hardness is equivalent to about HRB 80-85 and its yield strength is about 40,000 psi. It works well in mild abrasion and up to severe corrosion.

Monel: Very few, if any Monel barrels, nickel copper alloy, are used due to their high cost, the scarcity of raw material, and the successful use of the other materials listed above. Monel is more corrosion resistant than any other barrel material due to its high nickel content. It is thought to be a weak material, because of its reputation to gall threads on occasion, but it is actually as strong as the steel materials. Its hardness is equivalent to about HRC 10 with its yield strength about 70,000 psi. It is available for use with soft-packed plungers in its uncoated condition and solid plungers when it is chrome plated. It is good for mild abrasion and severe corrosion in its uncoated state, and severe abrasion and moderate corrosion when coated with chrome plating.

Chrome Molybdenum ***Steel:*** This steel is new to the downhole sucker rod pump market in its configuration with a new inside treatment for sucker rod pump barrels. The new process is similar to Carbonitriding in that it is a treatment of the inside surface to a hardness greater than HRC 75. Its core and exterior hardness is less than HRC 23, which is in accordance with NACE specifications for corrosion resistance, with a strength of about 75,000 psi. This barrel is qualified for up to severe abrasion and projected to handle up to moderate corrosion.

Coatings and Treatments for Sucker Rod Pump Barrels

Chrome Plating: Hard chrome plating has been used as a hard-wearing, interior surface coating for sucker rod pump barrels for many years. It is commonly used with a plated and honed thickness of about 0.003otal thickness of wearing surface when measured on the inside diameter. It is applied to the inside of the barrel tube with an electrode type plating process that electrically plates the element chrome onto the inside surface. The hardness of the plating is HRC 67 minimum. It is a long-wearing surface coating for abrasive applications and is used widely in the industry.

Hard chrome plating is by its plated nature subject to flaking off of the barrel's base material during normal operation. This is due to two physical operational characteristics of sucker rod pumping wells. One is simply that when the coating is worn through, and the base metal is thus exposed, the coating can flake off due to fluid and particulate erosion of the adjoining edge of the still attached chrome plating. The other reason is more subtle and historic. Hard chrome plating has always been characterized by tiny cracks in the plating that run from the surface to the base material. These cracks are

The effective down-hole life of hard chrome plating depends on several other factors. One of these is the base material. Due to the galvanic potential difference between two metals galvanic corrosion will occur, first below the microscopic cracks and later in the other areas. Those metals with more difference between their galvanic potentials will corrode faster: these are the ones further apart on the chart. The metal that aythe chart, the more reactive metal.

There are four base materials that are commonly hard chrome plated: low carbon steel, 4130 steel, 501 steel, and brass. Brass is closer to chrome with respect to galvanic potential than the other listed steel materials. Therefore, it has longer life in corrosive conditions than the other three materials. This is due to the slower development of corrosion between the hard chrome plating and brass base material. The next most corrosion resistant is 501 steel, due to its composition of 5% chrome. Extreme galvanic corrosion of chrome plated steel can cause holes in the steel base material, since steel will

Chrome plating should not be used in wells that are acidized. The acid that is used as a producing formation enhancement treatment is normally hydrochloric acid mixed with other chemicals. Unfortunately, chrome dissolves rapidly in hydrochloric acid, with the rate of dissolution dependent on the concentration of the acid. A strong acid solution will affect the chrome plating faster. The measure of a fluid's acidic or base characteristic is the Ph scale. On this scale, a Ph of 7 is neutral, greater than 7 is a base fluid and less than 7 is an acid type fluid. The greater the Ph above 7 indicates a stronger base fluid and the less the Ph than 7 indicates a stronger acidic fluid. Whenever the Ph of the production fluid is less than Ph 7 there is the possibility of chrome plating damage, with a lower Ph affecting the chrome plating more quickly.

Nickel Carbide Plating: Compared to hard chrome plating nickel carbide plating is a relatively new process. It is a composite coating that was developed so that the nickel plating would provide a corrosion barrier and the carbide particles would give the coating excellent wear resistance. It is commonly applied at the depth of 0.0015a total effective coating thickness of 0.003asured inside diameter. The exception to this is the Harbison-Fischer nickel carbide coating on steel and 501 steel. It is applied to a depth of 0.003r a total effective coating thickness of 0.006measured diameter.

Nickel carbide plating is applied with an electrode-less process to the inside and outside of the barrel. It is a chemical deposition plating that adheres well to plain steel, 501 steel, 4130 steel and brass. It is used extensively on sucker rod pump barrels for the most abrasive and corrosive well applications. Nickel carbide on brass is the most corrosion resistant combination with nickel carbide on 501 steel the next most corrosion resistant.

Galvanic corrosion deserves respect when considering the application of nickel carbide coated down-hole sucker rod pump barrels. Nickel is near chrome in the galvanic series and therefore has the same sort of corrosion potential difference as exists between steel and chrome. Although the nickel carbide plating is seamless, without cracks or voids, it can be mechanically damaged and create a condition for aggressive galvanic corrosion with steel base materials. Since steel is higher on the galvanic series than nickel it will galvanically tecttions, a hole can be corroded through the steel base material in a short time. Brass is not subject to this problem, since it is close to nickel on the galvanic series. For the steel base materials, the most corrosion resistant nickel carbide combination is the 501 steel base material.

Carbonitrided or Carbonized Treatment: With this process, steel is processed through a high temperature, carbon rich atmosphere furnace. The inside surface of the barrel gains carbon and thus becomes a high carbon steel on the inside surface for a relatively deep depth. Later the barrel is passed though another heating process and water quenched. Since the core and outside of the barrel tube is still a non-heat-treatable steel, it does not increase in hardness. The inside surface for about 0.005in hardness to about HRC 58 to HRC 62, depending on the manufacturer. This is about 0.010when measured on the diameter.

The carbonitrided barrel differs from the carbonized barrel in that nitrogen is introduced with the carbon rich atmosphere into the high temperature furnace during the carbonitriding process. Nitrogen enhances the absorption of carbon into the steel and deposits nitrides that increase the hardness.

Both processes yield a tough, abrasion resistant inside wearing surface. The hard layer is actually a part of the wall thickness, so it cannot flake off. It can only wear off. Since it is hardened steel on the inside surface it is subject to hydrogen sulfide cracking for the depth of the hard layer, about 0.010has shown that the small cracks that develop stop when they reach the softer core of the barrel below the hardened layer.

Two materials are processed in this manner, 1020 steel and 501 steel. Both are recommended for up to severe abrasion and moderate corrosion, with the 501 steel base material being the more corrosion resistant.

Induction Case Hardened Only the inside surface of the barrel is hardened. A medium carbon, heat-treatable steel is heated with an induction coil on the inside and water quenched. Only the inside surface attains a high enough temperature to harden significantly during water quenching. The inside surface is about HRC 58 for 0.005 The application characteristics of the barrel are the same as for the carbonized barrel tube with the same, minor hydrogen sulfide inside cracking characteristics.

Nitriding: This is an older process that was popular many years ago when Nitralloy Steels were available. These steels were developed especially for the nitriding process and achieved high hardness with good corrosion resistance. The current nitrided barrel on the market is a nitrided 4130 steel which achieves an interior hardness of only about HRC 52 for a depth of about 0.005 It is applied in up to moderate abrasion and mild corrosion.

HTC 75+® Treatment: This new product was announced last year by Harbison-Fischer. It has been tested for four years in severe abrasive conditions in several production areas. A chrome molybdenum steel is processed in a similar manner to a carbonitrided barrel to yield a surface hardness greater than HRC **75.** This hardness extends to about 0.005 depth per side on the inside only. This yields 0.010 of hardened wear surface when measured on the inside diameter. This treatment is a transformation of the steel microstructure in the hardened area, and as such is an inherent part of the wall thickness of the barrel and cannot flake off like coatings. The hardened structure is resistant to hydrogen sulfide cracking, handles severe abrasion and is expected to be successful in up to moderate corrosion.

Base Materials for Sprayed Metal Plungers

Low Carbon Steel: Although various materials are listed in API 11AX as being candidates for base material for plungers, low carbon steel, generally in the 1023 to 1026 series (.23% to .26% carbon) is used for all plungers, (UNS G10230 to UNS G10260.) This steel is more than strong enough for all applications and fairly resistant to corrosion, due to its low carbon content. Other possible base materials are; G41300 steel and G86200 steel.

Coatings for Sucker Rod Pump Plungers

Chrome Plated: As with chrome plated barrels, chrome plated plungers have been used in the industry for many years. In the absence of corrosive well fluids chrome plated plungers give long run times in up to severe abrasive conditions. The characteristics of the chrome plating are the same as covered earlier in this paper except for the thickness of the chrome. For plungers chrome is applied at twice the thickness of chrome plating on barrels. The thickness is .006 aring depth of .012

The same mechanism for terminal life of the chrome plating applies to plungers as it does to barrels covered above. Chrome plating is an electrically applied plating that can flake off due to mechanical forces or corrosive down-hole conditions.

Sprayed Metal: Sprayed metal coatings are applied at a high temperature onto a prepared base metal surface. The base metal surface is also at a high temperature so that when the sprayed metal coating comes into contact with the base metal it forms a metallurgical bond with the base metal. This bond is strong enough that it acts like it is part of the base metal, such that it cannot flake off, it can only wear off during operation.

The sprayed metal coating is comprised of a high percentage of nickel. This gives the coating excellent corrosion resistance, and combined with the other elements in the sprayed metal achieves a high hardness that is very useful for abrasive conditions. The coating is finish ground to a precision size and smooth finish.

Several hardness ranges for sprayed metal coatings are available:

HRC 48-52: This sprayed metal coating is the r mild to moderate abrasive conditions and up to moderate corrosive conditions. It is manufactured to the same standards as the other sprayed metal plungers and its lower hardness minimizes manufacturing grinding costs.

HRC 55 minimum: This is the API 11AX standard requirement for the hardest API specified sprayed metal plungers.

HRC 58-62: A higher hardness range is available from at least one manufacturer. It complies with the API 11AX requirement but is provided with the higher specification hardness as a standard product.

Composite Sprayed Metal Coating, Tuffr Plus®: Harbison-Fischer has tested a special composite sprayed metal coating for plungers for several years and has recently offered it to the down-hole sucker rod pump industry with the name of Tuffr Plus®. It is much harder than all other plungers listed above and thus has a longer wear life in severe abrasive

conditions. Tungsten Carbide particles are blended with their standard HRC 58-62 Tuffr® sprayed metal powder in a proprietary mixture that has been proven in the field and test lab to last much longer than common sprayed metal coatings. It is applied in the same manner so that it has the same tight, metallurgical adhesion properties to the base metal. A customized Taber abrasion test has been developed to test the wear properties of this composite sprayed metal coating, as the standard hardness tests cannot accurately represent the hardness of a composite coating. The high hardness (HRA 88) of the carbide particles provide the long wearing characteristics of this newly developed sprayed metal coating for plungers. The finished surface is ground with a diamond wheel so that a smooth, hard surface is presented to the mating part of the pump, the barrel surface. This is so that the plunger does not become an abrasive surface, just a hard, smooth, long wearing surface.

SUMMARY

Down-hole sucker rod pump barrel and plunger materials differ significantly in their manufactured compositions and successful applications. Care should be taken when choosing these materials so that sucker rod pump run times can be extended as much as possible and early replacements can be avoided.

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REFERENCES

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Galvanic Series From Most to Least Reactive
Magnesium
Zinc
Cadmium
Aluminum
Low Carbon Steel
4130 Steel
501 Steel
300 Series Stainless
Lead
Tin
Naval Brass
Chrome
Admiralty Brass