SELECTION OF METALLIC MATERIALS FOR SUCKER ROD PUMPS FOR HYDROGEN SULFIDE ENVIRONMENT*

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INTRODUCTION

API Standard 11 AX, Subsurface Pumps and Fittings, sets forth specifications covering sucker rod pumps and establishes dimension requirements to assure interchangeability of component parts. No material specifications or guidelines for the proper application of the various API pumps are given.

This report was prepared by NACE Task Group T-1F-12 and is intended to serve as a supplement to API 11 AX. It presents general recommendations of metallic materials for the construction of sucker rod pumps for service in a hydrogen sulfide environment. Only pumps with one-piece barrels and metal plungers are considered.

The recommended materials are presented in tabular form and in a preferred order of listing for nine different environments with varying degrees of abrasion and hydrogen sulfide corrosion. The materials recommended are in common use and should perform satisfactorily when used in the specified environment. In certain circumstances other materials could also be satisfactory. The materials recommended in Tables 1, 2, and 3 and the order in which they are listed are based on the experience and judgment of the Task Group members. These recommendations are not intended to preclude the development and testing of new materials for improvement of sucker rod pump performance.

Tables 4-10 list some of the materials commonly used in sucker rod pumps along with pertinent chemical and physical properties. The numbering system for the steels is from the AISI classification, the brasses are identified by numbers from the Copper and Brass Research Association, and the copper-nickel alloys carry the International Nickel Company designations. The use of specific alloy numbers should be encouraged.

It is recognized that there are steels utilized in subsurface pumps with hardnesses greater than Rc 22** (valves, hard cases on barrel tubes, etc.). Experience has shown, however, that these materials give satisfactory service in the proper environment.

A good chemical program is considered necessary for optimum performance of sucker rod pumping equipment in a corrosive hydrogen sulfide environment. Some corrosion inhibitors control rod breaks and tubing and flowline leaks but do not significantly affect pump life. Other corrosion inhibitors significantly increase pump life by promotion of oil wetting thus reducing friction as well as reducing rod on tubing wear, rod breaks, and tubing and flowline leaks. However, in some pump designs the inhibitor cannot reach some stagnant areas and protective films may be removed by the rubbing action. There are chemicals used downhole that extend pump life by prevention of fouling, and still others that extend pump life by prevention of scale. Control of direct attack on pump materials, however, is best accomplished by materials selection in combination with chemical treatment.

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** See NACE Publication 1F166, "Sulfide Cracking Resistant Metallic Materials for Valves for Production and Pipeline Service".

DESCRIPTION OF TABLES

The recommendation for selection of metallic materials for sucker-rod pumps in a hydrogen sulfide environment are given in Tables 1, 2, and 3. Table 1 shows the materials recommended for mild corrosion; Table 2, moderate corrosion; and Table 3, severe corrosion. Each table is also divided into three degrees of abrasion, i.e., no sand, moderate sand, and high sand, for a total of nine different environments. No attempt is made to further define the severity of either abrasion or hydrogen sulfide corrosion. The development of more explicit definitions is not considered practical. As the environmental classifications are general, experience in a particular field or area must be considered with this report serving to determine the classification to be used for materials selection.

The first items shown under each environment are the recommended barrels and compatible plungers. In many instances the same plungers are recommended for use with more than one barrel but the preferred order is sometimes altered. After the barrel-plunger combination is chosen, selections of materials for valves, cages, pull tube or valve rod, and fittings are made. Where more than one material is shown, they are listed in a preferred order based on optimum operating costs rather than the length of pump run to be expected or the initial cost.

In many instances the performance of the first and last materials recommended for a specific environment will not be significantly different. In these cases and unless experience dictates otherwise, logically the least expensive of the recommended materials should initially be selected. Any material recommended for a more severe environment should also be suitable for a less severe environment; however, the additional pump life obtained may not justify the added cost. (See discussion on Economics.)

BARREL SELECTION

The nomenclature for steel barrels used in Tables 1,2, and 3 is of a general nature. More detailed information on pump barrels is shown in Table 4. With regard to the steel barrels, there are no significant differences between the five materials shown under "Carbon Steel, Unhardened". Similarly, the three barrels shown under "Carbon Steel, Hardened", can be considered comparable.

In Tables 1 and 2 no differentiation is made between the grades of steel and case-hardening processes for "Steel, Carbon or Alloy, Hardened". However, the literature states that nitrided steels are more corrosion-resistant and have a higher fatigue limit than most of the plain carbon, carburized steels. For a hydrogen sulfide environment, the increased corrosion resistance may not be significant. However, this factor should be considered since in some cases, the nitrided alloy steel barrels can possibly be considered as a separate group of materials suitable for more severe service than are the hardened carbon steels. Case-hardening processes recommended for steel pump barrels for a hydrogen sulfide environment are discussed in Appendix A.

PUMP SELECTION

Several factors other than the corrosive and abrasive nature of the produced fluids must also be considered when selecting materials for a sucker-rod pump. The type of pump, barrel length and diameter, seating depth, and required material strength are all interrelated; e.g., for a given pump size and seating depth, the strength requirement for a barrel in a top seating pump is greater than that for a barrel in a bottom holddown pump.

At this time there is no API Standard or Recommended Practice which specifies the most practical pump assembly for various operating conditions. However, some broad, generally accepted guidelines for the selection of the most suitable type of pump are discussed in Appendix B.

After the selection of materials has been made, these guidelines and the information shown in Tables 4 through 10 should be studied to ensure that the materials selected will meet the requirements of strength, hardness, etc. dictated by the type of pump to be used and the anticipated operating conditions.

The information shown in Tables 4-10 was supplied by manufacturers of sucker-rod pumps. Most of the materials shown are listed by a specific alloy number. In some cases common names are also shown in parentheses. Common names, i.e., brasses, are often used to describe alloys of significantly different compositions and properties so that a pump purchased under such specifications can conceivably be quite different from what the purchaser intended. Designation of specific alloys should also help prevent repetitive failures of the same part caused by substitution of trade name materials which are essentially the same as or no more suitable than the part which originally failed.

ECONOMICS

Oil production costs can be increased appreciably by repeated failures of sucker-rod pumps. The primary factors in these expenses are pulling costs, cost of replacement parts, labor charges for repairs, and loss of production. To minimize these expenses the pump selected must be of a type most suited to the physical conditions of the well, and its component parts made of materials capable of resisting the corrosive and abrasive nature of the produced fluids at the most economical cost.

An inexpensive carbon steel pump installed in a severely corrosive environment is not sound economics. While the initial cost is low, the expenses for pulling, repairing, etc. will be excessive. It is also unrealistic to specify a premium pump where it is not needed since the more exotic materials can more than double the initial cost of a pump.

The initial step in reducing expenses related to sucker-rod pump failures should be the adoption of a well-planned system of records-keeping in order to determine the optimum pump type, metallurgy, etc. Cross files by both well number and pump number should be maintained. These records should include such factors as pump type, size and metallurgy; pumping conditions; length of run; volume of fluid lifted during the run; cost and description of repairs and initial cost of the pump. The full cooperation of the pump repair shops will be required to make such a program effective. The program should also include some criterion for junking of the complete pump, e.g., when the estimated cost of repairs exceeds a certain percentage of the cost of a new pump.

A study of pump repair records should soon give some indication of the principal causes of the repeated failures so that corrective measures can be taken. Once the major problems have been resolved, the program can be continued by experimentation with various materials and comparing the cost of failure to that of up-grading. It is seldom necessary to upgrade the metallurgy of the entire pump assembly as so many factors other than corrosion and abrasion can cause pump failures; e.g., a well producing fluids which are neither corrosive nor abrasive can experience frequent cage and valve failures because of the manner in which the well is pumped. In this instance, if the operating conditions cannot be altered, the cost of repeated failures versus up-grading of the cage and valve assemblies should be considered.

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TABLE 1—MATERIALS FOR MILD H_2S CORROSION

No Sand Production		Moderate Sand Production		High Sand Production	
Barrel	**Plunger**	**Barrel**	**Plunger**	**Barrel**	**Plunger**
(1) Steel, Carbon, Unhardened	(1) Steel, Chrome Plated (2) Sprayed Metal, Plain Fittings (3) Alloy Iron, Plain Fittings	(1) Steel, Carbon or Alloy, Hardened	(1) Steel, Chrome Plated (2) Sprayed Metal, Plain Fittings (3) White Iron, Plain Fittings (4) Alloy Iron, Plain Fittings	(1) Steel, Carbon or Alloy, Hardened	(1) Steel, Chrome Plated (2) Sprayed Metal, Plain Fittings (3) White Iron, Plain Fittings
		(2) Steel, Chrome Plated;* Minimum Thickness - .003"	(1) Sprayed Metal, Plain Fittings (2) White Iron, Plain Fittings (3) Alloy Iron, Plain Fittings (4) Steel, Chrome Plated**	(2) Steel, Chrome* Plated, Minimum Thickness-.003"	(1) Sprayed Metal, Plain Fittings (2) White Iron, Plain Fittings (3) Steel, Chrome Plated**
				(3) Chrome Steel, 501, Nitrided	Same Plungers and Ratings as with Barrel No. 1

No Sand Production	Moderate Sand Production	High Sand Production
VALVES	**VALVES**	**VALVES**
(1) 440 Stainless Steel	(1) 440 Stainless Steel	(1) Cobalt Alloy, Cast (2) 440 Stainless Steel
CAGES	**CAGES**	**CAGES*** **
(1) Steel, Carbon or Alloy	(1) Steel, Carbon or Alloy	(1) Steel, Carbon or Alloy
PULL TUBE, VALVE ROD, FITTINGS	**PULL TUBE, VALVE ROD, FITTINGS**	**PULL TUBE, VALVE ROD, FITTINGS**
(1) Steel, Carbon or Alloy	(1) Steel, Carbon or Alloy	(1) Steel, Carbon or Alloy

*A potential exists between the chrome plate and the base metal which can cause flaking of the chrome in some instances.
**Chrome-on-chrome has not been generally favored in the past; however, it is run successfully under oil-wet conditions.
*** Specialty Cages Also Available

TABLE 2—MATERIALS FOR MODERATE H_2S CORROSION

No Sand Production		Moderate Sand Production		High Sand Production	
Barrel	**Plunger**	**Barrel**	**Plunger**	**Barrel**	**Plunger**
(1) Steel, Carbon, Unhardened	(1) Sprayed Metal, Plain Fittings (2) Steel, Chrome Plated (3) .oy Iron, Plain :tings	(1) Steel, Carbon or Alloy, Hardened	(1) Sprayed Metal, Plain Fittings (2) Steel, Chrome Plated (3) White Iron, Plain Fittings (4) Alloy Iron, Plain Fittings	(1) Steel, Carbon or Alloy, Hardened	(1) Sprayed Metal, Plain Fittings (2) Steel, Chrome Plated (3) White Iron, Plain Fittings
		(2) Steel, Heavy Chrome Plated, Minimum Thickness - .006"*	(1) Sprayed Metal, Plain Fittings (2) White Iron, Plain Fittings (3) Alloy Iron, Plain Fittings (4) Steel, Chrome Plated**	(2) Steel, Heavy Chrome Plated, Minimum Thickness-.006"*	(1) Sprayed Metal, Plain Fittings (2) White Iron, Plain Fittings (3) Steel, Chrome Plated**

No Sand Production	Moderate Sand Production	High Sand Production
VALVES	**VALVES**	**VALVES**
(1) Cobalt Alloy, Cast	(1) Cobalt Alloy, Cast	(1) Sintered Carbides (2) Cobalt Alloy, Cast
CAGES	**CAGES**	**CAGES*** **
(1) Copper Alloy 464 (Naval Brass) (2) Steel, Carbon or Alloy	(1) Copper Alloy 464 (Naval Brass) (2) Steel, Carbon or Alloy	(1) Steel, Carbon or Alloy (2) Copper Alloy 464 (Naval Brass)
PULL TUBE, VALVE ROD, FITTINGS	**PULL TUBE, VALVE ROD, FITTINGS**	**PULL TUBE, VALVE ROD, FITTINGS**
(1) Steel, Carbon or Alloy (2) Copper Alloy 464 (Naval Brass)	(1) Steel, Carbon or Alloy (2) Copper Alloy 464 (Naval Brass)	(1) Steel, Carbon or Alloy (2) Copper Alloy 464 (Naval Brass)

*A potential exists between the chrome plate and the base metal which can cause flaking of the chrome in some instances. ***Specialty Cages Also Available.
**Chrome-on-chrome has not been generally favored in the past; however, it is run successfully under oil-wet conditions.

TABLE 3—MATERIALS FOR SEVERE H_2S CORROSION

No Sand Production		Moderate Sand Production		High Sand Production	
Barrel	Plunger	Barrel	Plunger	Barrel	Plunger
(1) Nickel-Copper Alloy (Monel 400) (2) Copper Alloy 443 (Inhibited Admiralty)	(1) Sprayed Metal, Corrosion Resistant Fittings (2) loy Iron, Corro- on Resistant ttings (3) White Iron, Corrosion Resistant Fittings Same Plungers and Ratings as Above.	(1) Nickel-Copper Alloy (Monel 400) Chrome Plated; Minimum Thickness-.003" (2) Copper Alloy 443 (Inhibited Admiralty), Chrome Plated; Minimum Thickness-.003"	(1) Sprayed Metal, Corrosion Resistant Fittings (2) White Iron, Corrosion Resistant Fittings (3) Alloy Iron, Corrosion Resistant Fittings Same Plungers and Ratings as Above.	(1) Nickel-Copper Alloy (Monel 400) Chrome Plated; Minimum Thickness .003" (2) Copper Alloy 443 (Inhibited Admiralty) Chrome Plated; Minimum Thickness-.003"	(1) Sprayed Metal, Corrosion Resistant Fittings (2) White Iron, Corrosion Resistant Fittings Same Plungers and Ratings as above.
VALVES. (1) Cobalt Alloy, Cast		VALVES (1) Cobalt Alloy, Cast (2) Sintered Carbides		VALVES (1) Sintered Carbides	
CAGES (1) Nickel-Copper Alloy (Monel 400, R-405) (2) Copper Alloy 464 (Naval Brass)		CAGES (1) Nickel-Copper Alloy (Monel 400, R-405) (2) Copper Alloy 464 (Naval Brass)		CAGES* (1) Nickel-Copper Alloy (Monel 400, R-405) (2) Copper Alloy 464 (Naval Brass)	
PULL TUBE, VALVE ROD, FITTINGS (1) Nickel-Copper Alloy (Monel 400, R-405) (2) Copper-Alloy 464 (Naval Brass)		PULL TUBE, VALVE ROD, FITTINGS (1) Nickel-Copper Alloy (Monel 400, R-405) (2) Copper Alloy 464 (Naval Brass)		PULL TUBE, VALVE ROD, FITTINGS (1) Nickel-Copper Alloy (Monel 400, R-405) (2) Copper Alloy 464 (Naval Brass)	

*Specialty Cages Also Available.

TABLE 4—SOME TYPICAL PROPERTIES OF COMMONLY USED PUMP BARREL MATERIALS FOR HYDROGEN SULFIDE ENVIRONMENTS

Material	Case Hardening or Plating	Typical Yield* psi x 1000	Typical Hardness* Core	Typical Hardness* Surface	Typical Thickness of Case or Plate
Carbon Steel, Unhardened (C1018, C1020, C1025, C1035, C1045)	None	80	210 BHN	-	-
Carbon Steel, Hardened (1018, C1020)	Carburized, Liquid Carburized & Induction Hardened, Carbonitrided	80	210 BHN	60 Rc	.015"
Carbon Steel, Plated I.D.[1] (C1018, C1020, C1035)	Chrome Plated	80	210 BHN	70 Rc	.003"
Carbon Steel, Plated O.D. and I.D. (C1015/1020)	Nickel Plated	80	210 BHN	68 Rc	.003"
Alloy Steel, Hardened	Nitrided				
4130	"	75	245 BHN	60 Rc	.012"
Nitralloy N	"	120	320 BHN	69 Rc	.008"
501 (4-6 Chrome)	"	95	240 BHN	70 Rc	.014"
Alloy Steel, Plated I.D. 501 (4-6 Chrome)	Chrome Plated	75	200 BHN	70 Rc	.003"
Copper Alloy 443 (Admiralty)	None				
Thin Wall		75	195 BHN	-	-
Heavy Wall		65	165 BHN	-	-
Copper Alloy 443, Plated I.D.	Chrome Plated				
Thin Wall		75	195 BHN	70 Rc	.003"
Heavy Wall		65	165 BHN	70 Rc	.003"
Nickel-Copper Alloy (Monel 400)	None	80	200 BHN	-	-
Nickel-Copper Alloy, Plated I.D. (Monel 400)	Chrome Plated	80	200 BHN	70 Rc	.003

(1) Available with thicker plating.
* For information only. Not to be used for design purposes.

TABLE 5—SOME TYPICAL PROPERTIES OF COMMONLY USED PLUNGER MATERIALS FOR HYDROGEN SULFIDE ENVIRONMENTS

A. ONE PIECE PLUNGERS

Finish	Core Material	Typical Yield* psi x 1000	Typical Hardness* Core	Typical Hardness* Surface	Typical Thickness of Coating
Sprayed Metal[1,2]	(C1015, C1021, C1025, C1040)	55	170 BHN	59 Rc	.012"
Chrome Plated[3]	(C1025, C1040)	80	210 BHN	70 Rc	.007"
	(Copper Alloy 443)	65	165 BHN	70 Rc	.007"

(1) Alloys of nickel, chromium, boron, iron and silicon (Colmonoy No. 6 or equivalent).
(2) Available with standard pins, e.g. Carbon or low alloy steel, or with corrosion resistant pins, e.g. Monel or nickel plated.
(3) Available with thicker plating.
* For information only. Not to be used for design purposes.

B. COMPOSITE PLUNGERS

Tubes: Material	Tubes: Typical Yield** psi x 1000
Carbon Steel (C1018, C1021, C1025, C1035)	80
Alloy Steel 501 (4-6 Chrome)	75
Copper Alloy 443 (Admiralty)	65
Nickel-Copper Alloy (Monel 400)	80

Sections*: Material	Sections*: Typical Hardness**
Sprayed Metal on C1042	59 Rc
Alloy Cast Iron	40 Rc
Hard Cast Iron	53 Rc
Eutectic Nickel Iron	60 Rc
White Iron	63 Rc

Fittings Material: Plain	Fittings Material: Corrosion Resistant
C1117***	Copper Alloy 464 (Naval Brass)
8620	Nickel-Copper Alloy (Monel 400, R405)

* See Table 8 for analysis.
** For information only. Do not use for design purposes.
*** Mild environments only.

TABLE 6—SOME COMMONLY USED MATERIALS FOR CAGES IN A HYDROGEN SULFIDE ENVIRONMENT

CAGE

Material	Typical Hardness
C1117*	135 BHN
C1141*	220 BHN
10L18*	210 BHN
A8620	225 BHN
48L20	225 BHN
Copper Alloy 464 (Naval Brass)	135 BHN
Nickel-Copper Alloy (Monel 400, R405)	225 BHN

GUIDES (When Modified)

Material	Typical Surface Hardness
CF1141, Surface Hardened*	50 R_c
A8620, Carburized	58 R_c
48L20, Surface Hardened	44 R_c
4140, Induction Hardened	45 R_c
Type 416 SS, Induction Hardened	45 R_c
Cobalt Alloy (such as Stellite)	58 R_c

*Mild environment only.

TABLE 7—SOME COMMONLY USED MATERIALS FOR PULL TUBES, VALVE RODS, AND FITTINGS IN A HYDROGEN SULFIDE ENVIRONMENT

Pull Tubes: Material	Pull Tubes: Typical Yield* psi x 1000	Valve Rods: Material	Valve Rods: Typical Yield* psi x 1000	Fittings
Carbon Steel (C1020, C1025, C1035)	80	10L18**	65	C1117**
		2317	95	C1015
		4615	85	C10L18**
Alloy Steel - 501 (4-6 Chrome)	90	A4620	106	B1137**
Copper Alloy 443 (Admiralty)	65	Copper Alloy 443 (Admiralty)	60	A8620
Nickel-Copper Alloy (Monel 400)	80	Nickel-Copper Alloy (Monel 400, R405)	90	4150
				4615
				48L20
				Copper Alloy 464 (Naval Brass)
				Nickel-Copper Alloy (Monel 400, R405)

*For information only - not to be used for design purposes.
**Mild environments only.

TABLE 8—TYPICAL ANALYSES OF MATERIALS USED FOR PLUNGER SECTIONS

	"ALLOY IRONS"		"WHITE IRONS"	
	Hard Cast Iron	Alloy Cast Iron	White Iron	Eutectic Nickel Iron
C	3.30	3.30	3.00	3.70
Mn	0.70	0.80	1.00	0.60
P	-	0.30	0.02	0.30
S	-	0.12	0.02	0.12
Si	2.40	2.80	1.00	2.20
Ni	-	-	4.25	6.00
Cr	-	-	-	8.50
Mo	0.80	1.00	-	-
B	-	-	1.00	-
Cu	0.55	-	-	-

TABLE 9—TYPICAL ANALYSES OF CAST COBALT ALLOYS USED FOR VALVES

	BALL	SEAT
Cobalt	45.2%	57.9%
Chromium	32.0%	24.5%
Tungsten	18.0%	12.0%
Carbon	2.3%	2.1%
Others	2.5%	3.5%
R_c	58-63	51-55

TABLE 10—TYPICAL ANALYSES OF SINTERED CARBIDES USED FOR VALVES

	Tungsten Carbide
Tungsten	65.0%
Cobalt	8.5%
Carbon	7.6%
Titanium	11.0%
R_c	91

	Titanium Carbide*
Tungsten	4.5%
Nickel	25.0%
Titanium	52.0%
R_c	91

* Used primarily for balls.

CASEHARDENING PROCESSES FOR STEEL PUMP BARRELS FOR H_2S ENVIRONMENT

Pump barrels intended for service in an abrasive, hydrogen sulfide environment must have a very hard, wear-resistant surface and a tough body resistant to sulfide stress corrosion cracking. This combination can be achieved in steel barrels by either plating or case hardening.

The ID surfaces of steel pump barrels are commonly hardened by five case-hardening processes used either singularly or in combination, i.e., flame hardening, induction hardening, carburizing, carbonitriding, and nitriding. Although low carbon steels can be properly cased by induction hardening, the carburizing, carbonitriding, and nitriding processes are preferred for service in a hydrogen sulfide environment. Barrels through-hardened by flame hardening or induction hardening are not recommended for a hydrogen sulfide environment because of their susceptibility to sulfide stress corrosion cracking. Steel barrels which have been cold-worked are not recommended because of residual stresses.

The surface hardness obtained by carburizing and carbonitriding depends upon heat treatment after the composition of the case has been altered. Nitriding alters the composition of the case in such a way that the compounds formed are inherently hard.

A brief description of each of the three preferred case-hardening processes follows.[1, 2, 3]

CARBURIZING

Carburizing is a process by which the carbon content of the surface of a low carbon steel (0.15 to 0.25% carbon) is increased. There are two carburizing processes used to caseharden pump barrels. The characteristics of the case produced by both methods are somewhat similar. Hardness values as high as R_C62 can be obtained with both methods.

1. In gas carburizing, carbon is absorbed into the barrel surface by heating in an atmosphere of methane. Carbon is dissolved and subsequently precipitated as iron carbide.
2. Liquid carburizing utilizes a fused bath of sodium cyanide and alkaline earth salt. The salt reacts with the cyanide to form a cyanide of the alkaline earth metal which then reacts with iron to form iron carbide. A small amount of nitrogen is liberated and absorbed. Nitrogen increases the hardenability of steel and increases the solubility of carbon. Barrels treated by this process are hardened on both the OD and ID.

The final characteristics of a carburized barrel will depend on the heat treatment used after the carburizing and there are two treatments in general use. One method is a direct quench from the carburizing temperature into a suitable quenching medium. A second treatment is to cool slowly from the carburizing temperature, reheat to above the critical of the case and quench.

CARBONITRIDING

Carbonitriding is a modification of the gas carburizing process. A low carbon steel is normally used. Anhydrous ammonia is added to the furnace atmosphere so that both carbon and nitrogen are absorbed by the steel surface. Carbonitriding is conducted at lower temperatures than gas carburizing so as to increase the absorption of nitrogen. Nitrogen increases the hardenability of steel and the solubility of carbon. At higher temperatures the process approaches gas carburizing with a minimum transfer of nitrogen. The final properties are dependent primarily on the rate of cooling following the carbonitriding process. The increased hardenability made possible by the alloying effect of nitrogen permits the oil-quenching of carbonitrided plain carbon steels that would otherwise require drastic water-quenching to develop effective hardening. Hardness values as high as R_C62 can be obtained by carbonitriding.

NITRIDING

Nitriding is a process by which the surface hardness of certain alloy steels may be increased by heating in contact with ammonia, without the necessity of quenching. The process involves the formation of hard, wear-resistant nitrogen compounds on the surface of the steel by absorption of nascent nitrogen. Prior to nitriding, it is essential that the required core properties be developed by heat treatment of the steel. In such treatment, the tempering temperature must be at least 100°F above the intended nitriding temperature.

Most of the steels that are commonly used for nitriding contain combinations of aluminum, chromium, molybdenum, vanadium, and in some instances, nickel. Steels of special composition which are used principally for the purpose of nitriding are referred to as nitralloys. Nitriding of these special steels can develop a surface hardness as high as R_c 70. In addition to high hardness and wear resistance, nitrided steels are more corrosion-resistant and have a higher fatigue limit than most of the plain carbon, carburized steels. Steels in the AISI 4000 series also respond well to nitriding but do not develop as hard a surface. Hardenable stainless steels may also be nitrided but their corrosion resistance is greatly reduced by nitriding.

APPENDIX B

SELECTION OF OPTIMUM TYPE PUMP

In selecting materials for a sucker-rod pump, the pump type, size, seating depth and required material strength must also be considered. The methods for determining the size pump required are well known.[4,5] Considerable difference of opinion exists as to the proper application of the various API pumps. However, there are some generally accepted recommendations that are outlined below as a guide.[4,5,6,7]

TUBING PUMP

A tubing pump is a simple, rugged pump suitable for severe service. It is adaptable for producing viscous fluids because of the large flow areas. A tubing pump has fewer working parts and is often lower in cost than a rod pump of corresponding size. However, these savings can be offset by repair costs since the tubing must be pulled to repair the barrel of a tubing pump. Tubing pumps are generally used where it is necessary to lift large volumes of fluid and a pump of high displacement is required. The greater volume can result in a heavier fluid load on the sucker rod string so that a portion of the capacity advantage may be lost in excessive rod and tubing stretch.

INSERT PUMPS

Stationary Barrel with Top Holddown

A top seating pump is a good choice for low fluid level wells as the standing valve can be submerged in the well fluids. It is also capable of handling low gravity crudes. This type pump is ideally suited for fluids carrying sand. The top seating holddown provides a seal just below the point where fluid is discharged to the tubing so that sand cannot settle around the barrel and cause the pump to stick in the tubing. Intermittent pumping may allow sedimentation between the plunger and barrel; this can be prevented by sealing off the pump body at the top with a sand-check guide and drop. The barrel in this type pump is subject to tensile stresses which can lead to premature failure in a sulfide environment. This pump is not suitable for deep pumping because of the pressure differential across the wall of the barrel, the inside of the barrel being exposed to pressure of the full column of fluid and the outside only to the pressure of submergence. The resulting breathing of the barrel during the pumping cycle tends to increase the clearance between the plunger and the barrel thereby increasing the slippage of fluid past the plunger. In extreme cases, the barrel can burst.

Stationary Barrel with Bottom Holddown

The stationary barrel pump with bottom holddown is better suited for deep well pumping because both sides of the barrel are exposed to the pressure of the column of fluid. However, it is not advisable to use a long pump since it is not anchored at the top and the action of the sucker-rod string will tend to weave it back and forth, which may cause premature failure. This pump is not suited for handling fluid containing sand as sand will tend to settle between the barrel and the tubing, sticking the pump. The outside of the barrel tube of this type pump is susceptible to corrosion as it is surrounded by stagnant fluid. Arrangements are available which permit sealing the top of the pump which prevents settling of the sand in the tubing-pump annulus and corrosion of the barrel. This represents the ideal arrangement for deep wells producing sand with the well fluids and is especially suited when a long pump is needed for a deep well.

Traveling Barrel Pump

The bottom seated traveling barrel pump is well suited for handling fluid with sand because the turbulence caused by the action of the barrel prevents the sand from settling. Also, the construction of this type pump is such that sand cannot settle into the pump barrel when the pump is shut down because the large traveling valve acts as a built-in sand check valve. However, in intermittent pumping it is possible for sand to settle below the barrel, between the barrel and the holddown, and prevent full travel of the barrel on the downstroke. This type pump can be used to pump deep wells since both sides of the barrel are exposed to the full fluid column pressure. However, long traveling barrel pumps are seldom used to pump deep wells because the compressive load on the standing valve tends to buckle the pull tube. This pump is not suited for pumping large volumes of heavy, viscous oil. Because of the long fluid passage, the smaller standing valve, and the comparatively smaller compression ratio, this pump is not suited for pumping wells that tend to gas lock.

Special Pumps

In addition to the standard API pumps, specialty sucker-rod pumps have been designed to handle unusual down-hole conditions. These include such pumps as casing pumps, double displacement pumps, three-tube pumps and pumps having two compression chambers. Detailed discussion of these pumps is beyond the scope of this report.

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