Chapter 9
Sucker Rods

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Introduction

A sucker rod is the connecting link between the surface pumping unit and the subsurface pump, which is located at or near the bottom of the oil well. The vertical motion of the surface pumping unit is transferred to the subsurface pump by the sucker rods.

Two types of sucker rods are in use today—steel rods and fiberglass-reinforced plastic sucker rods. It is estimated that slightly less than 90% of the rods sold in 1985 were steel rods, while slightly more than 10% were fiberglass rods.

Steel rods are manufactured in lengths of 25 or 30 ft. Fiberglass rods are supplied in 37½- or 30-ft lengths. Both types of rods are connected by a 4-in.-long coupling. The pin ends of the sucker rod are threaded into the internal threads of the coupling, as illustrated in Fig. 9.1. Individual rods are connected to form rod strings that can vary in length from a few hundred feet for shallow wells to more than 10,000 ft for deeper wells.

Sucker rods were originally made from long wooden poles with steel ends bolted to the wooden rod. An improvement was to use steel instead of wood and to forge the upset end on the steel rod. Forging the end generates a heat transfer zone by the upset, which is susceptible to corrosion attack. Full-length heat treating of the steel rod eliminated this problem. While the general geometry of the steel rod has remained relatively unchanged, improvements in surface finish, surface condition, end straightness, metallurgy, and quality control have been responsible for increased performance.

API Spec. 11B details information—such as workmanship and finish, material grades, dimensions, and gauging practice—on sucker rods (pony and polished rods and couplings and subcouplings).

*Author of the original chapter on this topic in the 1962 edition was Walter H. Ritterbusch Jr.

The general dimensions for a sucker rod published by API[1] are listed in Table 9.1 and Fig. 9.2.

The general dimensions for sucker rod couplings are listed in Tables 9.2 and 9.3 and Fig. 9.3. At the present time, there is one grade of couplings, API Grade T. This coupling has a hardness designation of 16 minimum and 23 maximum on the Rockwell C scale. The hardness is controlled to provide resistance to embrittlement by H_2S and to provide a minimum strength level.

API has specified three grades of rods; their chemical and mechanical properties are listed in Table 9.4. The industry typically supplies sucker rods to the various categories, as listed in Tables 9.5 and 9.6. Other chemistries and types of rods are also available for special application.

Steel Sucker Rods

Manufacture of Sucker Rods

One-Piece Steel Sucker Rods. One-piece steel sucker rods are manufactured from hot-rolled steel finished with a special quality surface. The surface finish of the rod is very important, because rods fail prematurely as a result of discontinuities on the surface. These discontinuities can cause stress concentration that results in fatigue cracks.

The first operation in manufacturing a sucker rod is straightening the rod. In the second operation, the end of the rod is heated to about 2,250°F, and the lower bead, wrench square, pin shoulder, and pin are upset forged. The next operation is full-length heat treating. Heat treating develops the desired physical properties in the rod and provides a uniform surface structure to minimize corrosion. The type of heat treatment depends on the chemistry of the rod and the desired physical properties. Normalizing, normalizing and tempering, quenching and tempering, and surface hardening are heat treatments in use today.

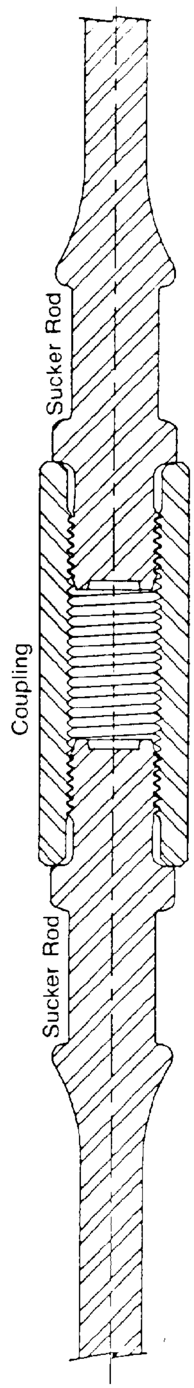


Fig. 9.1—Steel sucker rod and coupling connection.

After heat treatment, the rods are shot cleaned to remove scale. Any scale left on the rod provides the opportunity for a corrosion cell to begin. The pin ends of the rod are then machined and roll threaded. Roll threading puts the root of the pin thread in compression and hence increases the fatigue life.

The final operations are inspection, painting, and packaging. Most manufacturers protect steel sucker rods with an oil-soluble paint combined with a corrosion inhibitor.

Three-Piece Steel Sucker Rods. The three-piece sucker rod differs from a solid one-piece sucker rod in that the upset configuration is machined from a separate piece rather than integrally upset with the rod body as in a one-piece rod. The rod body of a three-piece rod is generally manufactured from cold drawn steel. The rod is threaded and screwed into the machined metal end connectors. The threads are usually joined by an adhesive. Their primary use has been in shallow wells.

Application

The selection of the size and grade of sucker rods depends on the rod stress and well conditions. The rod stress, in turn, depends on several variables—the amount of production required; the size of the tubing, which can influence the diameter of the pump, couplings, and rods; and the pumping unit, which will determine the surface stroke length. Generally, to determine rod stresses for a given well, the following information must be either known or approximated: fluid level, the net lift (in feet), pump depth (in feet), surface stroke length (in inches), pump plunger diameter (in inches), specific gravity of the fluid, nominal tubing diameter (in inches) and whether the tubing is anchored, pumping speed (in strokes per minute), sucker rod size(s) and design, and pumping-unit geometry.

With this information, the following can be calculated: plunger stroke (in inches), pump displacement (in barrels per day), peak polished rod load (in pounds force), minimum polished rod load (in pounds force), peak crank torque (in pounds force-inches), polished rod horsepower, and counterweight required (in pounds force).

Predictive Calculations

The method to perform these calculations is detailed in API RP11L.[2] This method was developed by simulating the sucker rod pumping system with an analog computer to resolve the many complex variables associated with a rod pumping system. API RP11L is a more reliable performance-predictive method than the previously available simplified equations. Remember that the API method, along with other methods, yields predictive performance results for typical wells.

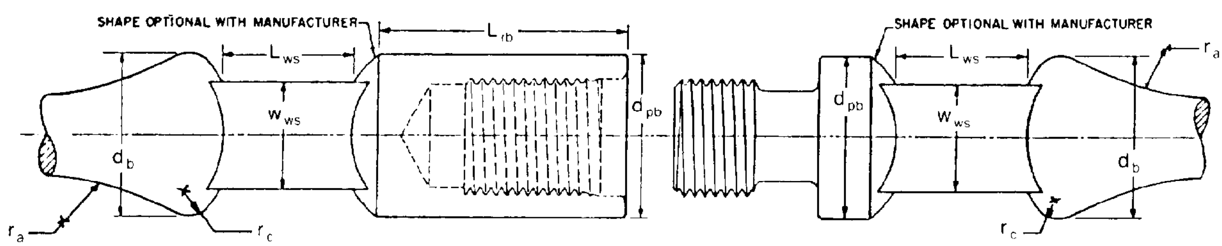


Fig. 9.2—General dimensions for sucker rod box and pin ends (see Table 9.1).

TABLE 9.1—GENERAL DIMENSIONS AND TOLERANCES FOR SUCKER RODS AND PONY RODS (see Fig. 9.2)

Rod Size (in.)	Pin Nominal Diameter (in.)	Pin Shoulder and Box OD, d_{pb} (in.)	Wrench Square Width $\pm 1/32$ in., w_{ws} (in.)	Wrench Square Length,* L_{ws} (in.)	Minimum Rod Box Total Length, L_{rb} (in.)	Sucker Rod Length,** ± 2.0 in. (ft)	Pony Rod Length,**,† ± 2.0 in. (ft)	Bead Diameter,‡ d_b (in.)	r_a, $\pm 1/8$ in. (in.)	r_c, $+1/16$ in. $-1/64$ in. (in.)
½	¾	$1.000^{+0.005}_{-0.010}$	⅝	¾	—	25, 30	1⅓, 2, 3, 4, 6, 8, 10, 12	$7/8^{+0.005}_{-1/2}$	1½	⅛
⅝	15/16	$1.250^{+0.005}_{-0.010}$	⅞	1¼	2⅛	25, 30	1⅓, 2, 3, 4, 6, 8, 10, 12	$1\,1/8^{+0.005}_{-1/2}$	1⅞	⅛
¾	1 1/16	$1.500^{+0.005}_{-0.010}$	1	1¼	2⅜	25, 30	1⅓, 2, 3, 4, 6, 8, 10, 12	$1\,3/8^{+0.005}_{-1/8}$	2¼	⅛
⅞	1 3/16	$1.625^{+0.005}_{-0.010}$	1	1¼	2⅜	25, 30	1⅓, 2, 3, 4, 6, 8, 10, 12	$1\,1/2^{+0.005}_{-1/8}$	2⅝	3/16
1	1⅜	$2.000^{+0.005}_{-0.010}$	1 5/16	1½	3	25, 30	1⅓, 2, 3, 4, 6, 8, 10, 12	$1\,3/4^{+0.005}_{-1/4}$	3	3/16
1⅛	1 9/16	$2.250^{\pm 0.015}$	1½	1⅝	3¼	25, 30	1⅓, 2, 3, 4, 6, 8, 10, 12	$2^{+0.005}_{-1/8}$	3⅜	3/16

*Minimum length exclusive of fillet.
**The length of sucker and pony rods shall be measured from contact face of pin shoulder to contact face on the field end of the coupling.
†The length of box-and-pin rods shall be measured from contact face of pin shoulder to contact face of box.
‡Dimensions d_b, r_a, and r_c became mandatory dimensions on June 20, 1986. Before this, d_b was not to exceed d_{pb}.

Well conditions—such as slanted or crooked holes, which result in excessive well friction, and viscous fluid, which results in abnormal loads, excessive sand production, large amounts of gas production through the pump, and wells that flow off—will result in actual performance that differs from predictive performance. API RP11L was developed to predict the performance of API-designated steel-only sucker rod strings with conventional-geometry surface pumping units and medium-slip motors. Enhancements available from various manufacturers include high-slip motors, advanced pumping unit geometry, and non-API sucker rod string design.

A FORTRAN source code listing for the API design calculations can be obtained from the Dallas API office.

In addition to the API program for predicting performance, proprietary mathematical solutions using partial-differential equations are solved by numerical methods with the aid of computers. These mathematical model solutions using the wave equation are flexible and can also be used for solving fiberglass rod calculations by changing the modulus of elasticity of the input file. These programs are available for installation and use on personal computers.

API also publishes API *Bull.* 11L3[3] for those who (1) do not have access to a computer with either the API program or a proprietary wave equation predictive program and (2) wish to avoid the tedious manual calculation of API RP11L. This design book lists a grid of conditions that have been calculated on a computer with the API RP11L method, and the results are tabulated. Pump depth varies from 2,000 to 12,000 ft in 500-ft increments. Various production rates are tabulated with different rod strings. An application can then be selected from the various pump diameters, stroke lengths, strokes per minute, peak and minimum polished rod loads, stresses, peak torques, and peak polished rod horsepower that are listed. In general, the smallest pump diameter—consistent with a reasonable cycle rate—that will achieve the desired production is the proper choice. This should result in the lightest fluid load and rod string, which, in turn, will require smaller surface equipment.

Another general rule of thumb is to use the longest stroke length and slowest cycle rate to achieve the production. The longer stroke length minimizes the effect of rod stretch, and the slower cycle rate generally minimizes the dynamic effects. A comparison of several trial calcu-

TABLE 9.2—FULL-SIZE COUPLINGS AND SUBCOUPLINGS (See Fig. 9.2)

Nominal Coupling Size* (in.)	OD, d_{oc} (in.)	Minimum Length L_{min} (in.)	Wrench Flat Length,** L_{wf} (in.)	Distance Between Wrench Flats, ℓ_{wf}, 0 to 1/32 in. (in.)	Used With Minimum-OD Tubing Size (in.)
⅝	1½	4	1¼	1⅜	2 1/16
¾	1⅝	4	1¼	1½	2⅜
⅞	1 13/16	4	1¼	1⅝	2⅞
1	2 3/16	4	1½	1⅞	3½
1⅛	2⅜	4½	1⅝	2⅛	3½

*Also size of rod with which coupling is to be used.
**Minimum length exclusive of fillets.

TABLE 9.3—SLIMHOLE COUPLINGS AND SUBCOUPLINGS (See Fig. 9.2)

Nominal Coupling Size* (in.)	OD d_{oc}, +0.005 in. −0.010 in. (in.)	Minimum Length, L_{min} (in.)	Used With Minimum Tubing Size, OD (in.)
½	1	2¾	1.660
⅝	1¼	4	1.990
¾	1½	4	2 1/16
⅞	1⅝	4	2⅜
1	2	4	2⅞

*Also size of rod with which coupling is to be used.

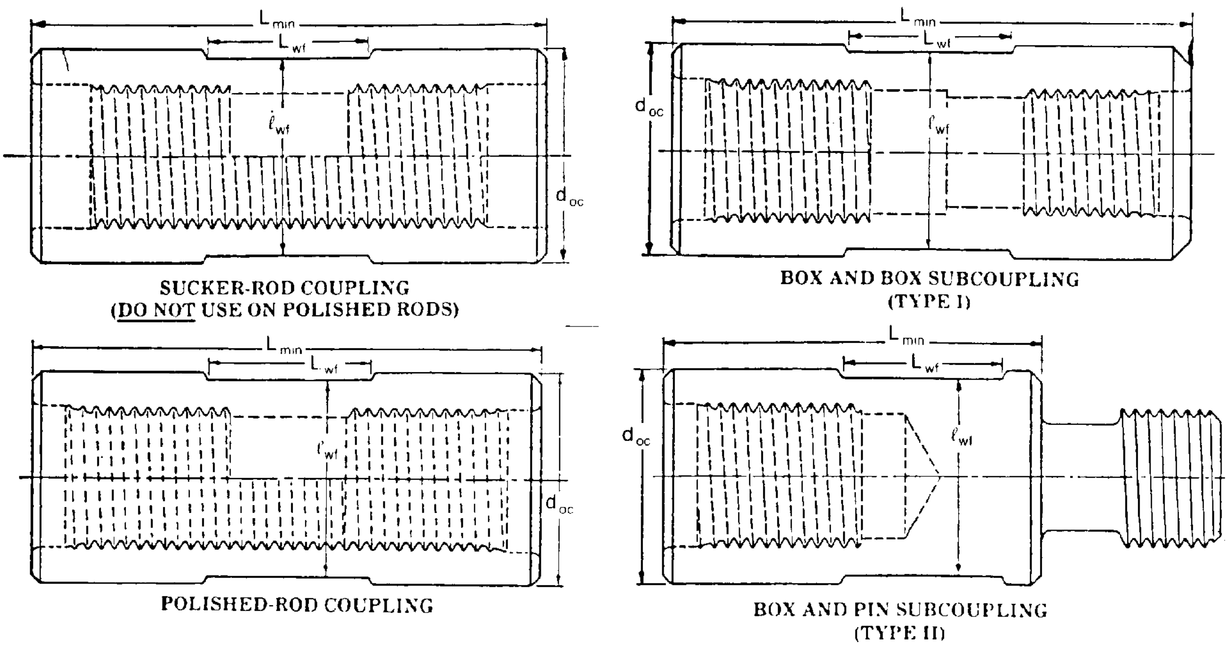


Fig. 9.3—Sucker rod couplings, polished rod couplings, and subcouplings (see Tables 9.2 and 9.3).

lations or a review of the tabulated answers in API *Bull.* 11L3[3] will give a basis for final selection of pumping parameters. The analog computer study, which resulted in the API design calculations, did not denote any significant effects, such as increased loads, in pumping at so-called synchronous pumping speeds. The damping effects of the well system apparently nullify any theoretical loading increase.

The maximum practical pumping speed is limited by the fall of the sucker rods. It is advisable to maintain a minimum load of several hundred pounds so that the polished rod clamp does not separate from the carrier bar on the downstroke. Extraneous loads can work against free fall of the rod string. Crooked holes and viscous fluid both retard the fall of rods, thus making the minimum load less than anticipated. Fig. 9.4 can be used to approximate the maximum practical pumping speed for a given stroke length with a conventional pumping unit. The actual maximum pumping speed will depend on the well conditions and the geometry of the pumping unit. A pumping unit with a faster downstroke than upstroke will have a lower maximum permissible speed than a conventional unit.

TABLE 9.4—CHEMICAL AND MECHANICAL PROPERTIES

Grade	Chemical Composition	Tensile Strength, psi Minimum	Tensile Strength, psi Maximum
K	AISI 46XX	85,000	115,000
C	AISI 1536*	90,000	115,000
D	Carbon or alloy**	115,000	140,000

*Generally manufactured from, but not restricted to, American Iron and Steel Inst. 1536.
**Any composition that can be effectively heat-treated to the minimum ultimate tensile strength.

The various rod string designs for given plunger diameters are listed in Table 9.7. Use of these percentages results in the stress in the top rod of each rod size being approximately equal.

Allowable Loading

The selection of a sucker rod's size and grade depends on the allowable stress and the well conditions. After the minimum and maximum stresses for the application are determined, the permissible stress is determined from the API modified Goodman diagram (see Fig. 9.5). For a given minimum stress, the maximum allowable stress can be determined from a graph of the API modified Goodman diagram for the particular rod in question or from the equivalent mathematical equation.

Example Problem 1. Assume that the minimum stress of an application is 15,000 psi [103 N/mm^2]. Determine the maximum allowable stress for a Grade C rod that has a minimum tensile stress of 90,000 psi [620 N/mm^2] and a service factor, F_s, of 1:

$$\sigma_a = (0.25\sigma_T + 0.5625\sigma_{\min})F_s$$

$$= [0.25(90,000) + 0.5625(15,000)]1.0$$

$$= 30,938 \text{ psi.}$$

The application stress should be below 30,938 psi to be within the guidelines recommended by API. The diagram is not a failure diagram but is an operating diagram. The API Goodman diagram has been modified by a safety factor of 2 for the left side of the diagram and a safety factor of 1.75 for the higher portion of the diagram.

TABLE 9.5—TYPICAL SUCKER ROD CHEMISTRIES

	Steel Type	C	Mn	P	S	Si	Ni	Cr	Mo	Other
API Grade K (Nickel/molybdenum)	4621	0.18 to 0.23	0.79 to 0.90	0.04	0.05	0.20 to 0.35	1.65 to 2.00		0.20 to 0.30	
API Grade C (Carbon steel)	1536	0.30 to 0.37	1.20 to 1.50	0.04	0.05	0.15 to 0.30				
API Grade D (Chrome/molybdenum)	4142	0.39 to 0.46	0.65 to 1.10	0.04	0.04	0.20 to 0.30		0.75 to 1.20	0.20 to 0.30	
API Grade D (Special alloy)	Special	0.17 to 0.22	0.80 to 1.00	0.035	0.04	0.15 to 0.30	0.90 to 1.20	0.80 to 1.05	0.20 to 0.30	0.02 to 0.03 V 0.40 to 0.60 Cu

*Maximum values.

Service Factor

The effects of corrosion and corrosion pits serve as stress raisers on the body of the rod. The effect can vary widely, and if well history does not indicate the service factor to be used, the following downward adjustments are recommended: reduce H_2S from 0.85 to 0.60, CO_2 from 0.90 to 0.70, and salt water from 0.90 to 0.80.

Some trial and error may be necessary for final selection. An effective corrosion-inhibition program should be implemented, if possible.

The limiting factor in rod string design is considered to be the rod body. The slim-hole coupling can be a limiting factor because of the reduced coupling cross-sectional area combined with the stress concentration factor of the thread. Slim-hole-coupling derating factors have been developed for use with the API modified Goodman diagram and are listed in Table 9.8. This F_d factor can be used in the same manner as the service factor—i.e., if Grade D ⅞-in. rods are used with ⅞-in. slim-hole couplings in 2⅜-in. tubing, multiply the allowable rod-body stress from the API modified Goodman diagram by the slim-hole coupling derating factor, F_d, of 0.690.

Rod Grades

The selection of which grade of rod to use should be made according to these guidelines. The lowest-cost rod is a Grade C rod, and its applicability should be checked first. The API Grade D rod (chrome moly) should be analyzed next. Other grades of rods contain various alloying elements. These alloying elements are not added in the quantity necessary to make a rod truly corrosion resistant, as the 18% chromium/8% nickel corrosion-resistant trim does on a valve. Experience has shown, however, that these relatively small alloy additions can have a positive

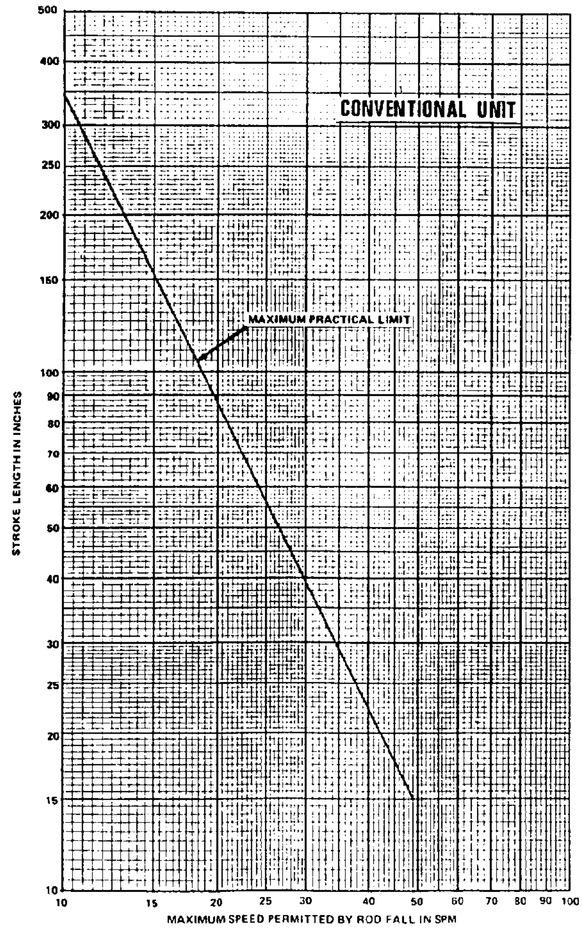


Fig. 9.4—Maximum practical pumping speed (conventional unit).

TABLE 9.6—TYPICAL SUCKER ROD MECHANICAL PROPERTIES

	Yield Strength (1,000 psi)	Tensile Strength (1,000 psi)	Elongation 8 in. (%)	Reduction of Area (%)	Brinell Hardness
API Grade K (nickel/molybdenum)	68 to 80	85 to 100	18 to 25	60 to 70	175 to 207
API Grade C (carbon steel)	60 to 75	90 to 105	18 to 25	55 to 66	187 to 217
API Grade D (chrome/molybdenum)	95 to 110	115 to 135	10 to 13	50 to 60	235 to 270
API Grade D (special alloy)	90,000	115,000	12 to 16	50 to 60	227 to 247

TABLE 9.7—ROD AND PUMP DATA

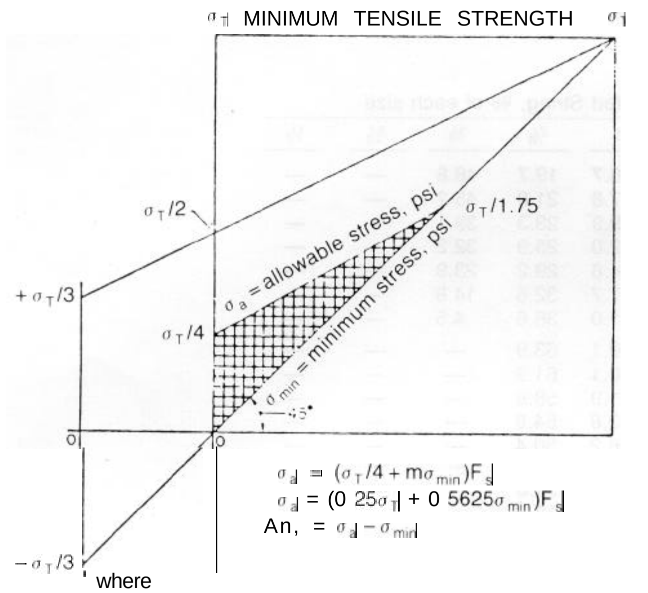
Rod*	Plunger Diameter, d_p (in.)	Rod Weight, W_r (lbm/ft)	Rod String, % of each size					
			1⅛	1	⅞	¾	⅝	½
44	All	0.726	—	—	—	—	—	100.0
54	1.06	0.892	—	—	—	—	40.5	59.5
54	1.25	0.914	—	—	—	—	45.9	54.1
54	1.50	0.948	—	—	—	—	54.5	45.5
54	1.75	0.990	—	—	—	—	64.6	35.4
54	2.00	1.037	—	—	—	—	76.2	23.8
55	All	1.135	—	—	—	—	100.0	—
64	1.06	1.116	—	—	—	28.1	33.1	38.8
64	1.25	1.168	—	—	—	31.8	37.5	30.7
64	1.50	1.250	—	—	—	37.7	44.5	17.8
64	1.75	1.347	—	—	—	44.7	52.7	2.6
65	1.06	1.291	—	—	—	31.3	68.7	—
65	1.25	1.306	—	—	—	34.4	65.6	—
65	1.50	1.330	—	—	—	39.2	60.8	—
65	1.75	1.359	—	—	—	45.0	55.0	—
65	2.00	1.392	—	—	—	51.6	48.4	—
65	2.25	1.429	—	—	—	59.0	41.0	—
65	2.50	1.471	—	—	—	67.4	32.6	—
65	2.75	1.517	—	—	—	76.6	23.4	—
66	All	1.634	—	—	—	100.0	—	—
75	1.06	1.511	—	—	22.6	26.1	51.3	—
75	1.25	1.548	—	—	24.8	28.6	46.6	—
75	1.50	1.606	—	—	28.3	32.6	39.1	—
75	1.75	1.674	—	—	32.4	37.4	30.2	—
75	2.00	1.754	—	—	37.2	42.8	20.0	—
75	2.25	1.843	—	—	42.5	49.2	8.3	—
76	1.06	1.787	—	—	25.9	74.1	—	—
76	1.25	1.798	—	—	27.8	72.2	—	—
76	1.50	1.816	—	—	30.9	69.1	—	—
76	1.75	1.836	—	—	34.3	65.7	—	—
76	2.00	1.861	—	—	38.5	61.5	—	—
76	2.25	1.888	—	—	43.1	56.9	—	—
76	2.50	1.919	—	—	48.3	51.7	—	—
76	2.75	1.953	—	—	54.1	45.9	—	—
76	3.75	2.121	—	—	82.5	17.5	—	—
77	All	2.224	—	—	100.0	—	—	—
85	1.06	1.709	—	15.9	17.7	20.1	46.3	—
85	1.25	1.780	—	17.9	19.9	22.5	39.7	—
85	1.50	1.893	—	21.0	23.4	26.5	29.1	—
85	1.75	2.027	—	24.8	27.5	31.0	16.7	—
85	2.00	2.181	—	29.0	32.3	36.3	2.4	—
86	1.06	2.008	—	19.3	21.9	58.8	—	—
86	1.25	2.035	—	20.7	23.5	55.8	—	—
86	1.50	2.079	—	23.0	26.0	51.0	—	—
86	1.75	2.130	—	25.6	29.0	45.4	—	—
86	2.00	2.190	—	28.7	32.5	38.8	—	—
86	2.25	2.257	—	32.1	36.5	31.4	—	—
86	2.50	2.334	—	35.8	41.6	22.6	—	—
86	2.75	2.415	—	40.3	45.6	14.1	—	—
87	1.06	2.375	—	22.3	77.7	—	—	—
87	1.25	2.384	—	23.5	76.5	—	—	—
87	1.50	2.397	—	25.5	74.5	—	—	—
87	1.75	2.414	—	27.9	72.1	—	—	—
87	2.00	2.432	—	30.6	69.4	—	—	—
87	2.25	2.453	—	33.7	66.3	—	—	—
87	2.50	2.477	—	37.2	62.8	—	—	—
87	2.75	2.503	—	41.0	59.0	—	—	—
87	3.75	2.632	—	60.0	40.0	—	—	—
87	4.75	2.800	—	84.7	15.3	—	—	—
88	All	2.904	—	100.0	—	—	—	—

*Rod number shown in the first column refers to the largest and smallest rod size in eighths of an inch. For example, Rod 76 is a two-way taper of ⅞ and 6/8 rods. Rod 85 is a four-way taper of 8/8, ⅞, 6/8, and ⅝ rods. Rod 109 is a two-way taper of 1¼ and 1⅛ rods. Rod 77 is a straight string of ⅞ rods, etc.

TABLE 9.7—ROD AND PUMP DATA (continued)

Rod*	Plunger Diameter, d_p (in.)	Rod Weight, W_r (lbm/ft)	Rod String, % of each size					
			1⅛	1	⅞	¾	⅝	½
96	1.06	2.264	14.8	16.7	19.7	48.8	—	—
96	1.25	2.311	16.0	17.8	21.0	45.2	—	—
96	1.50	2.385	17.7	19.9	23.3	39.1	—	—
96	1.75	2.472	19.9	22.0	25.9	32.2	—	—
96	2.00	2.572	22.1	24.8	29.2	23.9	—	—
96	2.25	2.686	24.9	27.7	32.6	14.8	—	—
96	2.50	2.813	27.9	31.0	36.6	4.5	—	—
97	1.06	2.601	17.0	19.1	63.9	—	—	—
97	1.25	2.622	18.0	20.1	61.9	—	—	—
97	1.50	2.653	19.3	21.9	58.8	—	—	—
97	1.75	2.696	21.4	23.8	54.8	—	—	—
97	2.00	2.742	23.4	26.2	50.4	—	—	—
97	2.25	2.795	25.8	28.9	45.3	—	—	—
97	2.50	2.853	28.5	31.7	39.8	—	—	—
97	2.75	2.918	31.4	35.0	33.6	—	—	—
97	3.75	3.239	45.9	51.2	2.9	—	—	—
98	1.75	3.086	23.6	76.4	—	—	—	—
98	2.00	3.101	25.5	74.5	—	—	—	—
98	2.25	3.118	27.7	72.3	—	—	—	—
98	2.50	3.136	30.1	69.9	—	—	—	—
98	2.75	3.157	32.8	67.2	—	—	—	—
98	3.75	3.259	46.0	54.0	—	—	—	—
98	4.75	3.393	63.3	36.7	—	—	—	—
99	All	3.676	100.0	—	—	—	—	—
107	1.06	2.977	16.9	16.8	17.1	49.1	—	—
107	1.25	3.019	17.9	17.8	18.0	46.3	—	—
107	1.50	3.085	19.4	19.2	19.5	41.9	—	—
107	1.75	3.158	21.0	21.0	21.2	36.9	—	—
107	2.00	3.238	22.7	22.8	23.1	31.4	—	—
107	2.25	3.336	25.0	25.0	25.0	25.0	—	—
107	2.50	3.435	26.9	27.7	27.1	18.2	—	—
107	2.75	3.537	29.1	30.2	29.3	11.3	—	—
108	1.06	3.325	17.3	17.8	64.9	—	—	—
108	1.25	3.345	18.1	18.6	63.2	—	—	—
108	1.50	3.376	19.4	19.9	60.7	—	—	—
108	1.75	3.411	20.9	21.4	57.7	—	—	—
108	2.00	3.452	22.6	23.0	54.3	—	—	—
108	2.25	3.498	24.5	25.0	50.5	—	—	—
108	2.50	3.548	26.5	27.2	46.3	—	—	—
108	2.75	3.603	28.7	29.6	41.6	—	—	—
108	3.25	3.731	34.6	33.9	31.6	—	—	—
108	3.75	3.873	40.6	39.5	19.9	—	—	—
109	1.06	3.839	18.9	81.1	—	—	—	—
109	1.25	3.845	19.6	80.4	—	—	—	—
109	1.50	3.855	20.7	79.3	—	—	—	—
109	1.75	3.867	22.1	77.9	—	—	—	—
109	2.00	3.880	23.7	76.3	—	—	—	—
109	2.25	3.896	25.4	74.6	—	—	—	—
109	2.50	3.911	27.2	72.8	—	—	—	—
109	2.75	3.930	29.4	70.6	—	—	—	—
109	3.25	3.971	34.2	65.8	—	—	—	—
109	3.75	4.020	39.9	60.1	—	—	—	—
109	4.75	4.120	51.5	48.5	—	—	—	—

*Rod number shown in the first column refers to the largest and smallest rod size in eighths of an inch. For example, Rod 76 is a two-way taper of ⅞ and ⁶⁄₈ rods. Rod 85 is a four-way taper of ⁸⁄₈, ⅞, ⁶⁄₈, and ⅝ rods. Rod 109 is a two-way taper of 1¼ and 1⅛ rods. Rod 77 is a straight string of ⅞ rods, etc.



where

σ_a = maximum available stress, psi
$\Delta\sigma_a$ = maximum allowable range of stress, psi
m = slope of σ_a curve = 0.5625
σ_{min} = minimum stress, psi (calculated or measured)
F_s = service factor
σ_T = minimum tensile strength, psi

Fig. OS-Modified Goodman diagram for allowable stress and range of stress for sucker rods in noncorrosive service.

effect on reducing the pitting of a rod. For many applications, it is the pitting of the rod that causes an increased stress concentration, which can then lead to failure.

The API Class K rod is one alloy rod specifically recognized by the API. The rod selection chart also lists special-alloy rods that meet the API Class D requirements. Because of the addition of the alloys, the initial cost of these rods is more than a Grade D chrome moly rod. This cost must be judged against possible increased life and reduced pulling costs and well expenses.

Miscellaneous and special-service rods are also available that are generally used in special situations.

Failures

The control and minimization of sucker rod failures is one of the key elements in controlling lifting costs. Proper classification of failures and the determination of the cause is the first step in corrective action. A forma1 failure reporting system can help provide the discipline necessary to identify the problems and causes of failures and to provide the impetus for equipment and/or operation review to remedy the situation.

TABLE 9.8—SLIM-HOLE-COUPLING DERATING FACTOR, F_d

API Rod Size (in.)	API Grade K	API Grade C	API Grade D
5/8		0.97	0.77
3/4	—	—	0.86
7/8	0.93	0.88	0.69
1	—	—	0.89

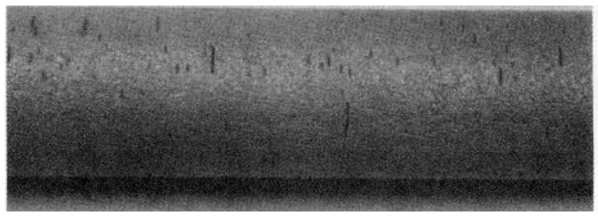


Fig. 9.6—H_2S rod part (note cracks caused by corrosion pits).

Steel sucker rod string failures can be segregated into four categories: body failures, upset failures, pin failures, and coupling failures. The most common failure is a body break. The most common cause of body breaks is corrosion caused by H_2S, CO_2, salt water, 0_2, or a combination of these corrosive materials.

H_2S (sour corrosion) occurs in almost half of U.S. wells and has its own distinctive corrosion pattern. A black iron sulfide scale is deposited on the rod, and a rotten-egg odor is associated with H_2S. The corrosion pits formed are generally small and sharp and have the effect of a notch on the surface. This corrosion pit or notch creates a stress concentration effect on the surface of the rod. The stress concentration effect, along with the effect of the hydrogen in the metal, can cause rapid failure of a rod. The failure looks as though the rod were brittle. In many cases, the actual corrosion pit that initiated the failure can be seen only with the aid of magnification. Close examination of the rod may also locate adjacent corrosion pits that are the focal point for additional fatigue cracks. Fig. 9.6 illustrates this condition.

CO;! corrosion (sweet corrosion) is caused by carbonic acid, which is formed when CO_2 combines with water. Carbonic acid combines with the iron to form iron carbonate, which is a hard, dark scale. The corrosion forms pits that appear rather smooth in nature and are usually larger than the H_2S-type pits. In addition, the pits can be connected, and the metal loss is usually much larger before breakage than the metal loss of the H_2S breaks. The stress concentration effect of CO_2 corrosion pits is generally not as severe as the H_2S pits. CO_2 corrosion is illustrated in Fig. 9.7.

The vast majority of wells contain salt water to some degree. Water is necessary for both H_2S and CO_2 corrosion. However, salt water by itself is also corrosive and causes a generalized pitting attack, but it is not as severe as other types of corrosion.

Oxygen sometimes enters the pumping system through the tubing casing annulus. In the presence of water, the corrosion, while general in nature, can occur in a comparatively short time.

An effective corrosion inhibition program abates these corrosive attacks. Such a program is required for the entire production system, including the rods. The rods are

Fig. 9.7-CO_2 corrosion

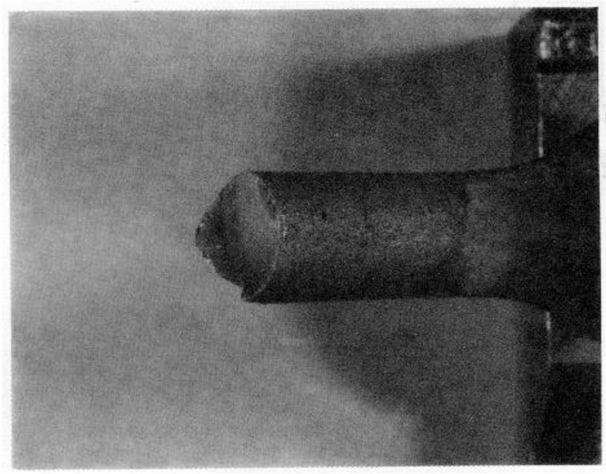


Fig. 9.8--Rod failure (cause of failure is in dark area 180° from ductile projection).

probably the most sensitive to pits because they operate in fatigue and therefore are susceptible to the effects of stress concentration.

One of the problems encountered in maintaining this effective inhibition film is wear. When the rods rub the tubing, the protective film can be destroyed. The inhibitor acts to reduce the frictional force and has deterred problems encountered with light wear. Wear on rods can be identified by a flat spot on one side of the rod.

When a rod fails, the last area to part generally fails in a ductile mode and leaves a small tip on one face. The cause for the failure usually can be found 180° opposite this tip. This condition is found in Fig. 9.8. Corrosion pits can be difficult to identify, but handling marks or marks caused by hatchets when the bundle is broken can be more easily identified.

Many body breaks occur within 2 ft or so of the upset. This can be attributed to a bend of the body in relation to the upset, which imposes a bending moment on the rod. All rods have straightness tolerances, and the maximum of the tolerance, as specified by API, will produce an added stress of about 20%. For example, if the axial stress (determined by dividing the load by the area) is 20,000 psi and the rod end has the maximum bend allowed by API, the true stress will be' the summation of the axial stress and the 20% extra stress caused by the bend, or 24,000 psi.

The API modified Goodman diagram has a safety factor of about 2. The bending moment infringes on this safety factor. Because of the greater cross-sectional area of the upset, failures in this part of the rod are rare.

Sucker rod pin failures can be caused by overtorquing the joint. This type of failure can be identified by the reduction in area of the undercut portion of the pin. In addition, the shoulder of the pin will generally have an indentation caused by the force exerted by the coupling face.

The load on a sucker rod pin consists of two components: the load that results from tightening the joint, or preload, and the external load resulting from the pumping cycle. As long as the face of the coupling and the face of the pin remain in contact during the pumping cycle, the pin will see only a part of the upstroke load and a part of the downstroke load. The amount of each upstroke and downstroke load is determined by the metal cross-sectional area relationship of the pin and coupling. Because the pin experiences a varying load, it also is subject to fatigue. This fatigue failure will occur at the root of the first thread adjacent to the relief. If the joint loosens and the pin and the coupling faces separate, the failure will occur in the same place in the first engaged thread. It is extremely important that the joint be clean and the faces free from nicks so that the joint will have the best chance of retaining the preload.

API recommends the use of circumferential displacement values rather than torque to achieve the desired pin preload stress. When power tongs are used, they should be calibrated for initial use and checked each 1,000 ft.

The method of marking the joint for circumferential displacement is indicated in Fig. 9.9. The circumferential displacement values are listed in Table 9.9.

Thread galling is another joint problem that sometimes occurs. Galling is generally caused by cross threading or making up threads that were not cleaned properly.

Coupling failures typically break at the plane of the last engaged thread of the pin. This is the plane where the load is transferred totally to the coupling. If failures occur at any other location, an examination should be made to determine the origin of the failure. A likely cause is cracks created by hammer marks.

As the clearance between the coupling and tubing is minimal, the coupling can be subjected to wear. The metal spray coupling has a hard, corrosion-resistant coating with a very low friction coefficient. This coupling is popular in wells where failure as a result of corrosion or coupling wear is a problem. This coupling should not be used indiscriminately, however, because it may, in some circumstances, transfer the wear to the tubing. As with all couplings, hammer blows should not be used to loosen couplings. The metal spray coupling is especially susceptible to the formation of cracks from hammer blows because of the hard, brittle coating.

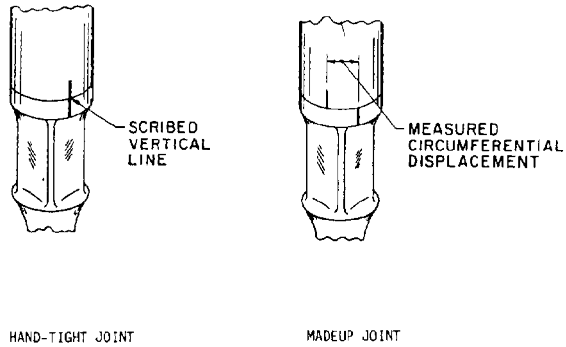


Fig. 9.9—Marking for circumferential displacement.

Care and Handling

Sucker rods are handled in the factory with equipment and facilities specially designed for protecting sucker rods from damage. The rods are shipped from the factory in packages also designed to protect the rod from damage. Care must be exercised in handling and storing the rods in the field so that the rods are run in the well in the same condition as they left the factory.

A successful sucker rod operation includes attention to detail while the rods are out of the well and a sound in-the-well program. It is particularly important to protect the surface of the rod from any handling damage, such as nicks or gouges.These discontinuities concentrate the stress in the same manner as a corrosion pit. Rods should always be properly supported so that no bends or kinks are induced. All rods with nicks, gouges, bends, or kinks should be discarded. Rods are shipped with end caps that protect not only the threads but also the pin shoulder. If any rods are without end caps, inspect the pin end, and if it is undamaged, clean and grease the end and replace the cap. Do not remove end caps until the rods are ready to be run. If it is necessary to walk across rods, provide a wooden walkway to protect the rod surface.

Unloading and Loading

Rod packages should always be lifted and laid down with handling equipment that supports the package without damaging the rods. When packages are stacked, the bottom supports should be placed directly on the top supports of the next lower package. Tie-down chains, straps, or cables should be placed over the crosswise supports and should not be in contact with the rods.

Individual rods should be picked up and supported near each end. Locate the pickup points to minimize sag in the rod. Do not drag the rod across surfaces. Rods should never be flipped from one position to the next.

When unpackaged rods are transported, the rods should be supported with wooden or nonabrasive material so that the rod body and ends do not rest on the bed. A minimum of at least four supports is required. The rod layers should be separated by spacers positioned directly above the bottom supports. The spacers should be long enough to extend beyond the stack on each side. If the spacers are not notched, the spacers should be chocked on each side to prevent the rods from rolling off. The tie-down chains, cables, or straps should be placed over the crosswise supports and should not be in contact with the rods.

TABLE 9.9—SUCKER ROD JOINT CIRCUMFERENTIAL DISPLACEMENT VALUES

Rod Size (in.)	Running New Grade D Displacement Values (in.)		Rerunning Grades C, D, and K Displacement Values (in.)	
	Minimum	Maximum	Minimum	Maximum
½	6/32	8/32	4/32	6/32
⅝	8/32	9/32	6/32	8/32
¾	9/32	11/32	7/32	17/64
⅞	11/32	12/32	9/32	23/64
1	14/32	16/32	12/32	14/32
1⅛	18/32	21/32	16/32	19/32

Rod Storage

Rods should be stored off the ground to minimize corrosion and grouped separately by grade and size to minimize misidentification. Inspect the rods at scheduled intervals. Replace any missing end caps and brush rusty surfaces with a wire brush until they are clean. Recoat the affected area with a suitable protective coating. Rod coatings are generally oil-soluble and contain an inhibitor. Rod manufacturers can identify a proper, compatible coating.

Good storage practices will protect the surface of the rod. The same general common-sense rules for unloading and loading also apply for storage.

Running and Pulling

At the wellsite, rods should be placed off the ground on supports. Single rods should be tailed into the mast with care, so that no contact is made with the ground or other equipment. The rods should not be raised with elevator latches during tailing. When the pin is stabbed into the coupling, the rod should be positioned directly over the well and hung straight without slack to minimize the possibility of cross threading. The couplings and pin should be brushed with a mixture of oil-soluble, film-forming corrosion inhibitor and refined oil for lubrication and corrosion protection. Use power tongs, calibrated to circumferential makeup values, for the most consistent makeup results.

The joint should never be hammered when the well is pulled or when connections are broken out. Use cheater bars, if necessary, to loosen the joint. Any overtorqued connection should be checked and thrown away if damaged. Rods should be inspected for damage—e.g., kinks, bends, and nicks—and discarded if any are found. The faces of the pins and couplings should be smooth and free of irregularities, such as scratches or nicks, that prevent proper makeup.

Fiberglass Sucker Rods

The first fiberglass rods were introduced in the 1970's. A fiberglass rod consists of long parallel strands of fiberglass embedded in a plastic matrix. Steel end fittings are then placed on the ends of the rods and held in place by wedges formed by an adhesive. The steel end fittings terminate in a standard API sucker rod pin. The rods can

TABLE 9.10—GENERAL DIMENSIONS AND TOLERANCES FOR REINFORCED PLASTIC SUCKER RODS AND PONY RODS (see Fig. 9.10)

Rod Body Nominal Size, ±0.015 in. (in.)	Rod Pin Size (in.)	Pin Nominal Diameter (in.)	Pin Shoulder OD, d_{pb}, +0.005 in. −0.010 in. (in.)	Wrench Square Width, W_{ws} (in.)	Wrench Square Length,* L_{ws} (in.)	End Fitting Maximum Diameter, d_{ef} (in.)	End Fitting Maximum Length, L_{max} (in.)	Extension Maximum Diameter,** d_x (in.)	Pin-and-Pin Sucker Rod Length,† ±0.5 in. (ft)	Pin-and-Pin Pony Rod Length,† ±0.5 in. (ft)
0.625	½	¾	1.000	⅞	1¼	Not to exceed d_{pb}	Not to exceed 10 in. exclusive of extension (if used)		25, 30, 37.5	3, 6, 9, 18
0.750	⅝	15/16	1.250	1	1¼				25, 30, 37.5	3, 6, 9, 18
0.875	¾	1 1/16	1.500	1 5/16	1¼				25, 30, 37.5	3, 6, 9, 18
1.000	⅞	1 13/16	1.625	1 5/16	1¼				25,30, 37.5	3, 6, 9, 18
1.250	1	1⅜	2.000	1½	1⅝				25, 30, 37.5	3, 6, 9, 18

*Minimum length exclusive of fillet.
**The extension is that portion of the rod body or that portion of the end fitting that is immediately adjacent to the smaller end of the elevator taper. If this section of the end fitting is longer than 0.25 in., the maximum OD shall not be more than 0.200 in. larger than the diameter of the rod body. If this section of the end fitting is 0.25 in. or less in length, the OD shall not be more than 0.25 in. larger than the diameter of the rod body.
†The length of pin-and-pin rods shall be measured from contact face of pin shoulder to contact face on the field end of the coupling.

be joined together with standard couplings to form rod strings. The fiberglass rods are lighter in weight than steel rods, about 0.84 lbm/ft for a 1-in. fiberglass rod compared to 2.9 lbm/ft for a 1-in. steel rod, and have a lower modulus of elasticity, about 7.0×10^6 compared to 29.5×10^6 for steel.

A typical fiberglass-reinforced plastic rod string contains about 50 to 70% fiberglass rods at the top of the rod string and 50 to 30% steel rods at the bottom. Sometimes heavy sinker bars replace the steel rods. The steel mass on the bottom of the string helps the fiberglass rods achieve overtravel and keeps the fiberglass rods in tension. Fiberglass rods are generally used in wells with relatively high fluid levels so that excessive rod stretch (also the result of high elasticity) does not destroy the efficiency of the installation.

Physical Dimensions

API has published a specification for reinforced plastic sucker rods.[4] This document covers materials, performance, quality control, general dimensions, packaging, inspection, and recommended practice for care and handling of rods.

The general dimensions for a plastic rod published by API[4] are listed in Table 9.10 and Fig. 9.10.

Plastic Sucker Rod Chemical and Mechanical Properties

Unlike steel, which has an infinite fatigue life when applied at stresses in a noncorrosive environment below the endurance limit, fiberglass has a finite life. If a given maximum and minimum load is cyclically applied to a plastic rod, the rod will eventually fail in fatigue. If a higher load combination is applied, the rod will fail in fewer cycles. In addition, the plastic rod is subject to loss of strength caused by increasing temperature. A stress-range diagram for plastic rods should always state the number of cycles to first expected failure and the corresponding temperature. API specifies that a basic stress-range diagram be constructed for 7.5 million cycles (1.8 years at 8 cycles/min) and 160°F. Modifiers for 5, 10, 15, and 30 million cycles to first expected failure and modifiers for other temperatures should be listed.

The end fittings for the rods are designated Grades A and B. The classifications are similar to designations for steel rods. Table 9.11 lists the end-fitting chemical and mechanical properties.

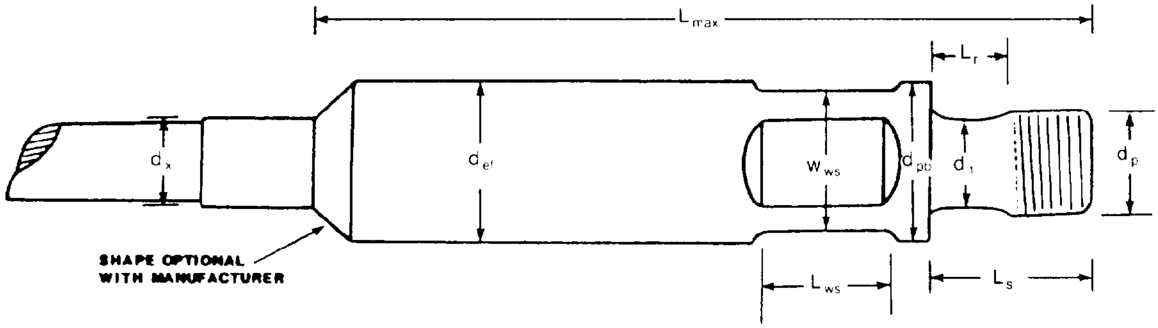


Fig. 9.10—General dimensions for reinforced plastic sucker rods (see Table 9.10).

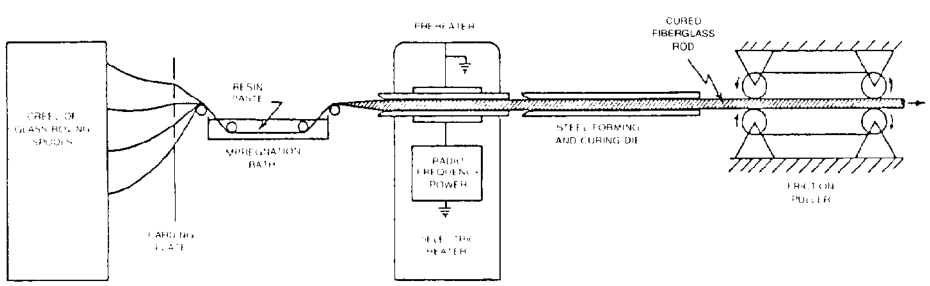


Fig. 9.11—Schematic of pultrusion process.

Manufacture of Fiberglass Sucker Rods

Fiberglass sucker rods are manufactured in three separate steps. The fiberglass rod body is produced by the pultrusion process. The metal end fittings are then assembled on the rod and locked in place with an adhesive.

The fiberglass rod body consists of high-strength fibrous glass reinforcement held in place by a resin system. A single strand of fiberglass may contain thousands of individual glass filaments. A fiberglass rod body is produced with many single-strand or multistrand glass rovings. Consequently, when a load is applied to the rod body, the load is distributed over many thousands of individual glass filaments.

The resin system protects the glass fibers and generally is the component that determines the chemical resistance and temperature performance. The resins used in fiberglass rods are thermoset resins that react during processing to form a cured material that cannot be remelted or reprocessed. Thermoset resins used in fiberglass rods, such as vinyl ester, isothalic, or epoxy, have different physical and chemical properties. This is similar to the different grades of steel, which have different physical properties and chemical resistance. The resin system also contains additives and fillers for either enhancement of properties or aids in processing.

The fiberglass rod body is manufactured by a process called pultruding. The schematic of the pultrusion process, Fig. 9.11, illustrates the manufacturing operations. Fiberglass roving spools are held on a creel and fed through a carding plate. The glass is then impregnated with the resin system paste and then preheated by a radiofrequency preheater. The final forming of the shape and curing of the rod occurs in the metal die. The power for the system is provided by the friction pullers. The rod is cut to length by a flying saw after it leaves the friction pullers.

The metal end connectors are machined with an API pin thread on one end and an internal bore with a series of wedges on the other end. Mold release is sprayed into the ID of the steel end connector. Adhesive is then placed in the box and the rod is inserted into the cavity. The adhesive fills the machined wedges. After the adhesive has cured, the rod is then pulled on each end. Because of the mold release that was applied to the steel, the adhesive breaks loose from the steel and adheres to the fiberglass rod; thus the internal wedges are set. Fig. 9.12 shows the geometry of this unique connection.

Application

There can be several advantages to the use of fiberglass sucker rods. Because these rods cost more than steel rods, their use has to be justified. The most common and generally sought-after advantage is to increase production. The lower modulus of elasticity, about one-fourth that of steel, allows greater overtravel of the plastic rods compared to steel rods. If the fiberglass/steel rod string is operated as close to the natural frequency of the system as possible, subsurface pump stroke lengths can be achieved that are significantly longer than the surface stroke.[5] Because the reduced modulus of elasticity is responsible for increased overtravel, it also is responsible for increased rod stretch caused by the fluid load of the pump. To decrease the effects of rod stretch, applications with fluid levels above the pump, with smaller-bore pumps, and well depths in excess of 3,000 ft are more favorable toward greater net downhole-pump-stroke length.

TABLE 9.11—END FITTING GRADES

Grade	Chemical Composition	Tensile Strength (1,000 psi) Minimum	Tensile Strength (1,000 psi) Maximum
A	*	90	115
B	**	115	140

*The material shall be such as to resist sulfide-stress corrosion cracking per NACE MR-01-75. See Ref. 6.
**Any composition that can be heat treated to give the specified tensile strength.

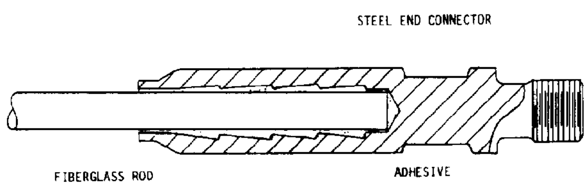


Fig. 9.12—Typical fiberglass-reinforced plastic rod-body-to-steel connector-joint design.

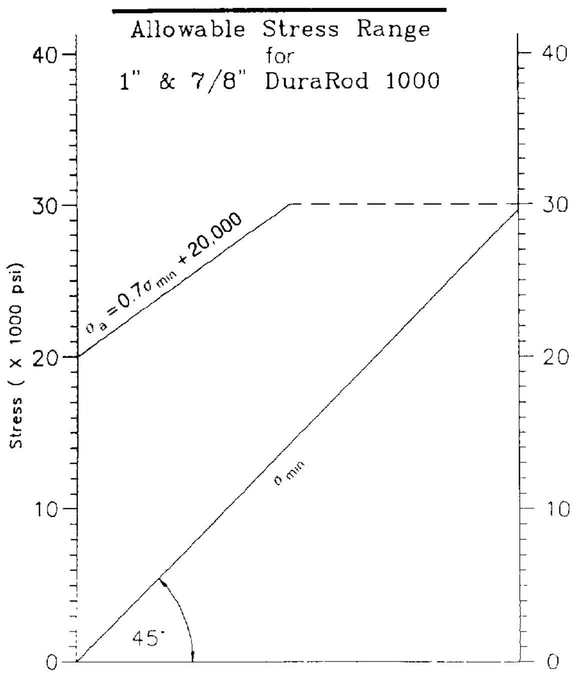


Fig. 9.13—Typical fiberglass stress-range diagram.

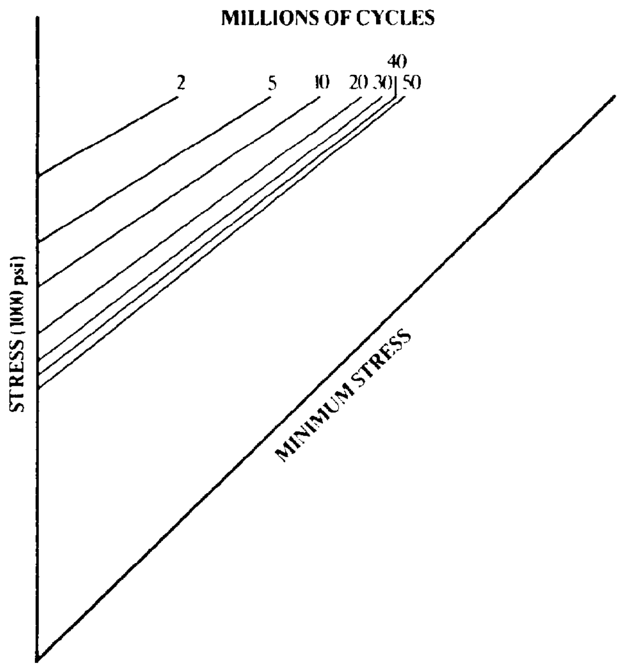


Fig. 9.14—Expected life of fiberglass rods.

The lighter weight of fiberglass, about 30% that of steel, can also translate into cost savings. The total effect of the dynamics is reduced, which in turn requires less horsepower and lower power costs. In addition, the lighter weight of the total rod string means reduced pumping unit requirements, which allow smaller pumping units to be used.

Another advantage is the inherent corrosion resistance of the fiberglass. Corrosion inhibition should be used to protect the well system, casing, tubing, flowlines, and sucker rods. In many cases, however, inhibition of the rod string is ineffective. This can be a result of the physical breakdown of the film on the rod caused by rubbing against the tubing. In some instances, maintaining a film is not cost-effective. The corrosion resistance of the fiberglass rod can reduce pulling costs and well downtime. The end connectors are made from steel, and corrosion can occur on these fittings. The stresses in the connectors are relatively low, and corrosion generally has not been a factor in their performance.

Predictive well-performance calculations are made with a computer program using the wave equation discussed in the section on steel rod application. The selection of rod size is a function of stress on the rod. In practice, the most popular rod diameters by far are 1 and 1¼ in.

After the maximum and minimum stresses are determined, the allowable stresses are specified from a stress-range diagram. As an example, Fig. 9.13 is a stress-range diagram for 7.5 million cycles and 110°F for ⅞- and 1-in. rods. Fig. 9.14 illustrates the general relationship between stress, stress range, and expected life. A small lowering of the maximum stress can result in a significant increase in rod life. Each manufacturer publishes data and modifiers for cycles, temperature, and rod size.

Some operating and well conditions should be avoided with plastic rods. High temperatures cause a loss of strength. While bottomhole temperatures of slightly more than 200°F have been pumped with fiberglass rods, the limiting factor is the temperature that the lowest fiberglass end connector reaches. In these hot wells, more steel rods are used on the bottom of the string to reduce the operating temperature of the fiberglass rod connections. Hot oiling of wells should be done down the tubing/casing annulus.

Compression loading and wear of the rods must be avoided. These conditions can result in early failure. To prevent overstressing the fiberglass rod string when an attempt is made to pull a stuck pump, shear pin tools are usually run above the subsurface pumps.

Failures

Because fiberglass sucker rods do not have a finite endurance limit, the rods can be expected to fail eventually. The actual life of the rod can be many years and depends on the maximum and minimum stresses. The point of expected eventual failure is a breakdown of the end-connector joint, which results in the metal end connector separating from the rod. This type of failure can be fished with an overshot.

Body breaks do sometimes occur and are generally the result of mishandling, which causes nicks or damage to the surface. Occasionally, body breaks are caused by misalignment of the fiberglass rovings. Body breaks can be fished with special overshots.

Care, Handling, and Storage

The surface of the fiberglass rod is much more easily damaged than a steel rod. Therefore, it is even more important to keep the rod from contacting the ground or any object that could scratch or injure the surface.

The rods need to be protected from ultraviolet light if they are going to be exposed to the sun longer than a few months. This can be achieved by covering the rods with a dark plastic blanket.

Nomenclature

d_b = diameter of sucker rod bead, in.
d_{ef} = maximum diameter of end fitting, in.
d_{oc} = outside diameter of coupling, in.
d_p = plunger diameter, in.
d_{pb} = outside diameter of sucker rod pin shoulder and box, in.
d_x = maximum diameter of extension, in.
F_d = derating factor, dimensionless
F_s = service factor, dimensionless
l_{wf} = distance between coupling wrench flats, in.
L_{max} = maximum length of end fitting, ft
L_{min} = minimum length of coupling, in.
L_{rb} = total length of sucker rod box, in.
L_{wf} = length of coupling wrench flat, in.
L_{ws} = length of sucker rod wrench square, in.
m = slope of curve
r_a = outer radius of sucker rod bead, in.
r_c = inner radius of sucker rod bead, in.
w_{ws} = width of sucker rod wrench square, in.
W_r = sucker rod weight, lbm/ft
σ_a = maximum allowable stress, psi
$\Delta\sigma_a$ = maximum allowable range of stress, psi
σ_{min} = minimum stress, psi
σ_T = minimum tensile strength, psi

References

1. *API Specification for Sucker Rods,* 21st edition, API Spec. 11B, Dallas (May 1985).
2. *API Recommended Practice for Design Calculations for Sucker Rod Pumping Systems,* third edition, API RP 11L, Dallas (Feb. 1977).
3. *API Sucker Rod Pumping System Design Book,* first edition, *Bull.,* API 11 L3, Dallas (May 1970).
4. *API Specification for Reinforced Plastic Sucker Rods,* first edition, API Spec. 11C, Dallas (Jan. 1, 1986).
5. Tripp, H.A.: "Mechanical Performance of Fiberglass Sucker Rod Strings," paper SPE 14346 presented at the 1985 SPE Annual Technical Conference and Exhibition, Las Vegas, Sept. 23-26.
6. "Sulfide Stress Cracking Resistant Metallic Material for Oil Field Equipment," NACE MR-01-75, Natl. Assn. of Corrosion Engineers, Houston (1984).

General Reference

API Recommended Practice for Care and Handling of Sucker Rods, seventh edition, API RP 11BR, Dallas (May 30, 1986).