Concepts of Continuous-Rod Pumping

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THE PROBLEM

The concept of continuous-rod pumping is nearly as old as the rod pumping system itself. However, there was a three-fold problem with the concept. First of all, there was a problem of manufacturing the continuous-rod and finding a suitable means of heat-treating the rod. Secondly, after the rods had been welded together to the specified length for a given well, there was the question of transporting the rod string to the well. And finally, there was the difficulty of handling the continuous-rod in running and pulling the rod string in the well.

The solution to this three-fold problem has been resolved, and the concept of the continuous-rod pumping system is now a reality.

THE SOLUTION

Manufacturing

The continuous rod (hereafter called corod) is a solid steel rod made from the same basic steel materials as used for conventional sucker rods.

The basic hot-rolled steel is purchased in coil form in individual lengths of coil, varying from 600-1200 ft depending on the weight per ft. The coils are straightened and flash-butt welded, induction heat treated, rolled to an elliptical shape and re-heat-treated. The two-cycle heat treating process of quenching and tempering gives the corod the mechanical properties as shown in Table 2.

An ultra-sonic inspection is made of the rod before it is shot-peened and reeled onto the transport reel.

Transporting

During the processing of the corod, the rod is rolled into an elliptical cross-sectional area, to provide a means for spooling the rod onto an 18-ft OD transport reel without deformation. The corod is flexed, but not bent during the spooling and unspooling process. The transport reel is trailer-mounted for moving the rod to the well location behind the servicing rig, (Fig. 1). It is mounted on an angle for two reasons: (1) the

TABLE 1

CHEMICAL ANALYSES

Grade and AISI Steel	% C	% Mn	% P	% S	% Si	% Ni	% Mo	% V
"C" 1036	.30/.37	1.2/1.5	.04 mx.	.04 mx.	.20/.30			.025/.045
"K" 4621 Md	.18/.23	.70/.90	.04 mx.	.04 mx.	.20/.35	1.65/2.0	.20/.30	

TABLE 2

MECHANICAL PROPERTIES

Grade	Yield 1000 psi	Tensile 1000 psi	Elongation % – 2"	Elongation % – 8"	Reduction in Area %	Brinell Hardness
"C"	110/120	125/130	30/35	15/20	55/65	225/235
"K"	110/120	125/140	25/30	10/15	55/65	225/265

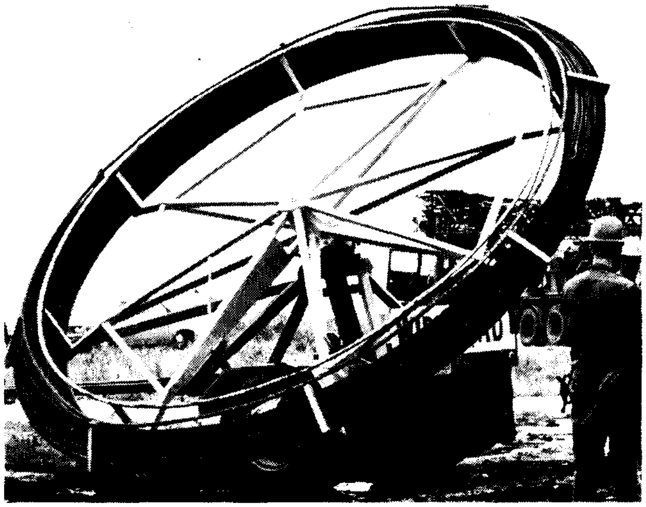

FIGURE 1

Transport Reel

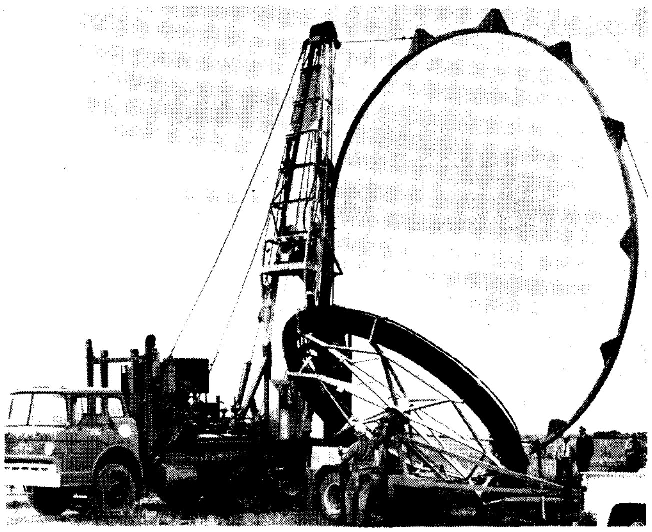

FIGURE 2

Corig With Rod Guide and Transport Reel

angle is needed for unspooling and (2) it meets the allowed highway clearances.

Field Handling

The corod is spooled out of the transportation reel into a rod guide (Fig. 2), and out of the guide into a special servicing rig (the Corig). The Corig is fitted with a small mast, independent power supply, hydraulic equipment, and operators' console.

Traction for handling the corod is provided by specially designed, variable speed, continu-

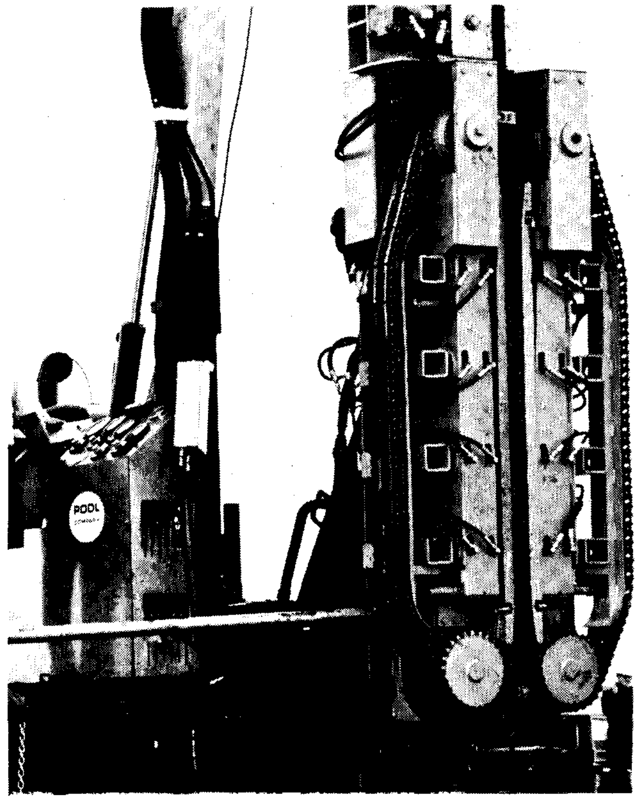

FIGURE 3

Gripper Mechanism and Operator's Console

ous, chain-driven gripper mechanisms with a rated pulling capacity of 40,000 pounds, (Fig. 3). Hydraulically operated pistons vary the gripping pressure to make adjustments for tapered rod strings when the rod is being run or pulled. A fail-safe device operates automatically in case of rod slip or failure of the main hydraulic system.

When pulling the rod for a pump repair, the rod is spooled onto a portable, collapsible 26-ft OD servicing reel, which travels with the Corig. The work crew consists of two men—the operator and a serviceman.

Accessory Equipment.—In order to connect the corod to the pull rod of the pump, a special pump connector is required. The corod uses a special polished rod liner to operate the corod through the stuffing box. In clamping off the corod above the carrier bar, a special self-aligning set of bearing washers are used below an aluminum insert for gripping the corod inside a conventional polished rod clamp.

ADVANTAGES AND LIMITATIONS

Advantages

Reducing Rod Failures.—Eliminating the pin and couplings used in a conventional rod string reduces the probability of rod failure, since 65-80 per cent of the failures in a conventional rod string are in the pins or couplings. The elimination of this type of connection overcomes this problem.

Tapered Rod Strings.—Better control is possible in designing tapered rod strings with the corod because the nominal size increases in 1/16-in. increments, instead of the 1/8-in. graduations of conventional sucker rods. Table 3 shows the weights and dimensions of both the continuous and conventional rods for comparison.

The use of a 4-way corod taper in place of a conventional 2-way taper results in a significant decrease in rod weight. For example, a conventional 2-way taper of 7/8-in. and 3/4-in. rods, using a 1-1/2-in. plunger, would require 30.9 per cent 7/8-in. rods and 69.1 per cent 3/4-in. rods, with an average rod weight of 1.816 lb/ft. This conventional string could be replaced with a 4-way taper consisting of 15.3 per cent 7/8 in. rods, 16.5 per cent 13/16-in. rod, 17.8 per cent, 3/4; and 50.4 per cent 11/16-in. rods, which would have an average weight of 1.507 lb/ft. This would result in a static weight reduction of .309 lb/ft or 17 per cent. The following case histories serve to illustrate the load reduction potential of the corod.

Case History No. 16C (Fig. 4).—The following tabular information illustrate case history No. 16C:

Rods:	Conventional	Continuous	% Difference
Design	2947' – 3/4	2980' – 3/4	negl.
Scrapers	on top 1000'	none	—
Pump Cycle	16 x 54" SPM	16 x 54" SPM	—
F.L. from Surf.	1280'	1280'	—
Production	668 BOPD	678 BOPD	new pump
Max P.R. Load	7530 lb	6456 lb	–14.3%
Min P.R. Load	3630 lb	2856 lb	–21.2
P.R. Load Range	3900 lb	3600 lb	–7.7
P.R. H P	4.9 hp	2.8 hp	–42.9
Motor H P – Demand	8.3 hp	4.8 hp	–42.2
Peak Torque	84,000 in-lb	67,000 in-lb	–20.2

Case History No. 13C (Fig. 5).—The following tabular information illustrates case history No. 13C:

Rods:	Conventional	Continuous	% Difference
Design	1", 7/8", 3/4"	13/16", 3/4"	—
Depth	4139'	4950'	+19.6%
Pump Cycle	10 x 86" SPM	10 x 86" SPM	—
Production	172 BFPD	184 BFPD	New pump
Max P.R. Load	16,080 lb	14,756 lb	–8.3%
Min. P.R. Load	6,000 lb	6,155 lb	+2.5
P.R. Load Range	10,080 lb	8,601 lb	–13.7
P.R. HP	9.35 hp	7.88 hp	–15.7
Friction HP	4.4 hp	1.3 hp	–70.5
Peak Torque	216,000 in-lbs	185,000 in-lb	–9.8

Paraffin Accumulation Reduced.—Because of the pressure drops and subsequent gas breakout that occurs around couplings and scrapers in a conventional rod pumping system, a localized cooling action takes place in these areas of the rod string which initiates paraffin deposition. This results in an accumulation of paraffin concentrated around the couplings and scrapers. Very little paraffin is found on the rod body itself, leading to the conclusion that without couplings the corod installation will have little paraffin deposition accumulating in the pumping system. This is verified by Case History No. 16C

TABLE 3

WEIGHTS AND DIMENSIONS

SIZE IN	AREA IN^2	COROD WGT. lbs/ft	CONVENTIONAL WGT. lbs/ft	REDUCTION lbs/ft	REDUCTION %
11/16	.3712	1.262	—	—	—
3/4	.4418	1.502	1.63	.13	8%
13/16	.5185	1.763	—	—	—
7/8	.6013	2.044	2.22	.18	8.2%
15/16	.6903	2.347	—	—	—
1"	.7854	2.670	2.90	.23	7.9%

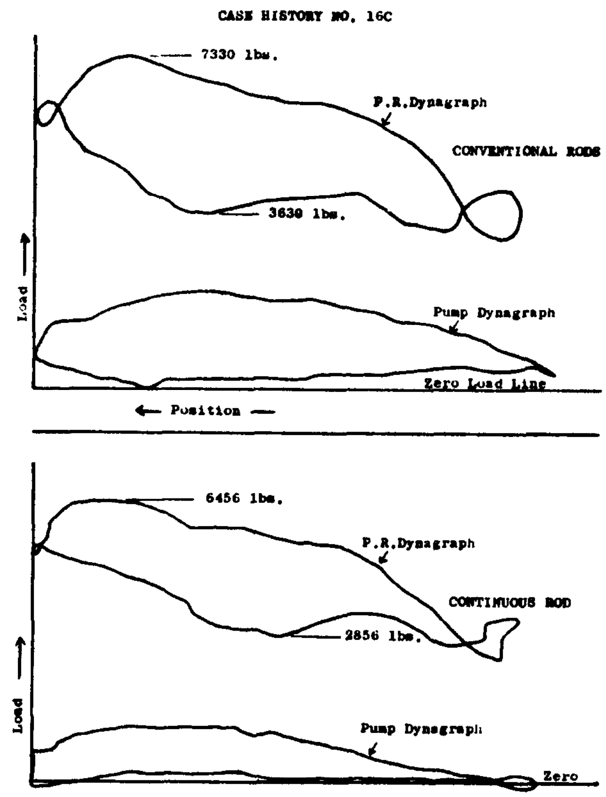

FIGURE 4

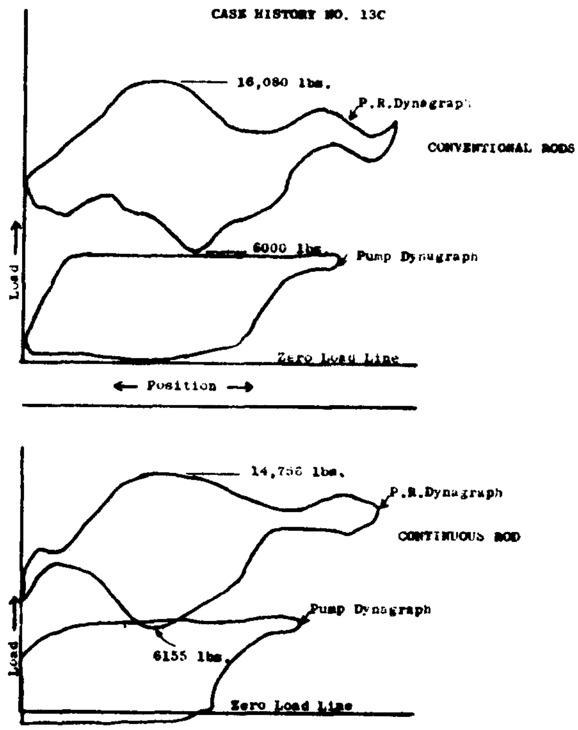

FIGURE 5

cited above. Note that the continuous rod has no scrapers and has been operating since June, 1968. The corod has been pulled for inspection twice; no paraffin accumulation was present.

Reduction of Friction Horsepower.—Severe crooked hole conditions are responsible for a high frequency of rod and tubing failures, mainly due to wear, in a great many wells throughout the world. The continuous rod should greatly alleviate this problem. The absence of couplings reduces the unit pressure between the rods and tubing and should, therefore, reduce the rate of wear.

Case History No. 13C (details above) concerns a severe crooked hole problem. From May, 1967 to August, 1968, the operator had a total of 21 tubing failures (splits) and replaced a total of 49 rods (coupling breaks) due to the rubbing action of the couplings in the tubing. In September, 1968, a corod string was run. Since then, the operator has had no rod or tubing failures. The friction horsepower was reduced from 4.4 to 1.3 HP, a reduction of 70 per cent. Assuming that the rate of rod and tubing wear is a function of the drag force (friction horsepower) these measurements are encouraging.

Slim-Hole Completions.—The absence of couplings increases the availability of rod pumping in slim-hole and dual completions. For example, using 1-1/2-in. tubing, the largest standard size coupling that could be used would be a 5/8-in. standard or a 3/4-in. slim hole. Using a corod string it would be possible to go up to a 15/16-in. corod in a 1-1/2-in. tubing.

Limitations

The most obvious limitation, of course, is that the special corig must be used to pull the rods for pump change-outs. However, as time progresses, this particular limitation will become less of a problem. To illustrate this, consider the petroleum marketing industry. A few years ago, there were hundreds of thousands of service stations equipped for handling millions of tires with tubes in them. As the use of tubeless tires became more and more prevelant, the service stations changed over their equipment to handle the tubeless tires. Today, every service station in the free world has the equipment to handle tubeless tire repairs. As the oil industry accepts the continuous rods as a means for artificial lift, the servicing aspect of the continuous rod will take care of itself.

Another limitation which is currently being researched with top priority is the problem of repairing a corod break. Because of the re-heat treating problems, it is not practical to flash-butt weld the rod break in the field; therefore, a mechanical splicing tool is presently being used. Using the corod taper and properly designing a rod string with sufficient safety factors and using the Goodman Diagram in design procedure, the fatigue failures of a corod string can be alleviated considerably.

DESIGN CONCEPTS

Corod Taper Design

Table 4 shows various corod taper combinations and plunger sizes, showing the per cent of each corod section to be used. This table is based on equal stress in the top rod of each section. The corod number shown in Table 4 is an adaptation of the API rod number and refers to the largest and smallest rod size in sixteenths of an inch with the "one" deleted. For example, corod No. 31 is a 3-way taper of 13/16, 3/4, and 11/16. No. 51 has as the largest rod size 15/16 and the smallest 11/16, with 7/8, 13/16 and 3/4 in between. The lighter loads inherent in the corod installation could result in the use of a smaller pumping unit and prime mover on a new installation. On an existing installation, the use of corod could result in increased oil production without having to increase the pumping unit and prime mover size.

Pumping Speeds

The corod has no couplings which affect the over-all elasticity of the string and no fluid surrounding the joints which add to the effective mass in movement during vibration of the rod string. Therefore, Young's modulus of elasticity for steel, 29,000,000 psi is used for corod. The weight of corod per ft/sq. in. (Wr/a) is 3.4 lb/ft/in^2, just as for steel. (Conventional sucker rods, Wr/a = 3.73 lb/ft/in^2.

Using these values, Slonneger's synchronous speed formulas are as follows:

Where: V = Velocity of stress transmission, ft/sec

F = Fundamental frequency, vib/min

λ = Wave length, ft

d = Mass per unit volume

E = Young's Modulus of Elasticity

= $29.0 \times 10^6 \times 144$ lbs/sq ft

Wr = Wgt. rods/ft, lbs.

a = Area of rods, sq in

g = Accel. due to gravity

= 32.2 ft/sec^2

D = Length of rod string in 1000 ft

N = Harmonic Order

Basic Equations:

$F = V/\lambda$, $= 4D \times 10^3$ (one end fixed)

$V = E/d$, $d = (144 \times Wr)/(g \times a) = 15.205$

$V = 29 \times 10^3 \times 144/15.205 = 16{,}572$ ft/sec $= 994.348$ ft/min

$F = 994{,}348/4D = 248{,}600/D$ (for straight strings)

For tapered strings:

$F = 208.5/\sqrt{e}$

$N = F/SPM = 208.5/(SPM \times \sqrt{e})$

Where: e = static elongation of the tapered string

TABLE 4

COROD COMBINATIONS AND PLUNGER SIZES

Rod String — Percent of each Size

Plunger Dia. (in.)	COROD No.*	6 1	5 15/16	4 7/8	3 13/16	2 3/4	1 11/16	Lb/Ft
ALL	11						100.0	1.262
1.06	21					18.0	82.0	1.305
1.25	21					19.6	80.4	1.309
1.50	21					22.2	77.8	1.315
1.75	21					25.2	74.8	1.322
ALL	22					100.0		1.502
1.06	31				14.7	15.9	69.4	1.374
1.25	31				16.1	17.4	66.5	1.384
1.50	31				18.2	19.6	62.2	1.400
1.75	31				20.7	22.3	57.0	1.419
1.06	32				16.2	83.8		1.544
1.25	32				17.5	82.5		1.547
1.50	32				19.5	80.5		1.553
1.75	32				21.8	78.2		1.559
2.0	32				24.6	75.4		1.566
2.25	32				27.7	72.3		1.574
ALL	33				100.0			1.763
1.06	41			12.4	13.3	14.4	59.9	1.461
1.25	41			13.6	14.5	15.7	56.2	1.479
1.50	41			15.3	16.5	17.8	50.4	1.507
1.75	41			17.4	18.7	20.2	43.7	1.540
1.06	42			13.4	14.4	72.2		1.613
1.25	42			14.5	15.6	69.9		1.621
1.50	42			16.2	17.4	66.4		1.635
1.75	42			18.2	19.5	62.3		1.651
2.00	42			20.5	21.9	51.6		1.670
2.25	42			23.0	24.7	52.3		1.691
1.25	43			15.8	84.2			1.807
1.50	43			17.4	82.6			1.812
1.75	43			19.3	80.7			1.817
2.00	43			21.5	78.5			1.823
2.25	43			24.0	76.0			1.830
2.50	43			26.7	73.3			1.838

TABLE 4 (cont.)

Plunger Dia. (in.)	COROD No.*	6 1	5 15/16	4 7/8	3 13/16	2 3/4	1 11/16	Lb/Ft
ALL	44			100.0				2.044
1.06	51		10.7	11.4	12.3	13.2	52.4	1.560
1.25	51		11.6	12.4	13.4	14.4	48.2	1.587
1.50	51		13.2	14.1	15.1	16.3	41.3	1.630
1.75	51		15.0	16.0	17.2	18.5	33.3	1.680
1.06	52		11.4	12.2	13.1	63.3		1.699
1.25	52		12.3	13.2	14.2	60.3		1.715
1.50	52		13.8	14.7	15.8	55.7		1.739
1.75	52		15.5	16.5	17.7	50.3		1.768
2.0	52		17.4	18.5	20.0	44.1		1.802
2.25	52		19.6	20.9	22.5	37.0		1.839
2.50	52		22.0	23.5	25.3	29.2		1.882
2.75	52		24.8	26.4	28.4	20.4		1.929
1.06	53		12.4	13.2	74.4			1.872
1.25	53		13.2	14.2	72.6			1.880
1.50	53		14.6	15.6	69.8			1.892
1.75	53		16.2	17.3	66.5			1.906
2.0	53		18.0	19.3	62.7			1.923
2.25	53		20.1	21.5	58.4			1.941
2.5	53		22.5	24.0	53.5			1.962
2.75	53		25.1	26.8	48.1			1.985
3.0	53		27.9	29.8	42.3			2.010
3.50	53		34.3	36.6	29.1			2.066
3.75	53		37.9	40.4	21.7			2.098
1.25	54		14.4	85.6				2.088
1.50	54		15.7	84.3				2.092
1.75	54		17.3	82.7				2.096
2.0	54		19.0	81.0				2.102
2.25	54		21.1	78.9				2.108
2.5	54		23.3	76.7				2.115
2.75	54		25.8	74.2				2.122
3.0	54		28.6	71.4				2.131
3.50	54		34.7	65.3				2.149
3.75	54		38.2	61.8				2.160
4.25	54		45.8	54.2				2.813
4.75	54		54.4	45.6				2.209
5.75	54		74.4	25.6				2.269
ALL	55		100.0					2.347
1.06	61	9.3	9.9	10.6	11.4	12.3	46.5	1.670
1.25	61	10.2	10.8	11.5	12.4	13.4	41.7	1.707
1.50	61	11.5	12.2	13.1	14.0	15.2	34.0	1.765
1.75	61	13.1	13.9	14.8	15.9	17.2	25.1	1.834

TABLE 4 (cont.)

Plunger Dia. (in.)	COROD No.*	6 1	5 15/16	4 7/8	3 13/16	2 3/4	1 11/16	Lb/Ft
1.06	62	9.9	10.5	11.3	12.1	56.2		1.799
1.25	62	10.7	11.4	12.2	13.0	52.7		1.823
1.50	62	11.9	12.7	13.6	14.6	47.2		1.860
1.75	62	13.4	14.2	15.2	16.3	40.9		1.903
2.0	62	15.0	16.0	17.1	18.4	33.5		1.954
2.25	62	16.9	18.0	19.3	20.7	25.1		2.011
1.06	63	10.6	11.3	12.1	66.0			1.959
1.25	63	11.4	12.1	12.9	63.6			1.973
1.50	63	12.5	13.3	14.2	59.9			1.994
1.75	63	13.9	14.8	15.8	55.5			2.020
2.0	63	15.5	16.5	17.6	50.4			2.049
2.25	63	17.3	18.4	19.6	44.7			2.082
2.5	63	19.3	20.5	21.9	38.3			2.119
2.75	63	21.5	22.9	24.4	31.2			2.160
1.06	64	11.5	12.2	76.3				2.153
1.25	64	12.2	13.0	74.8				2.160
1.50	64	13.3	14.2	72.5				2.170
1.75	64	14.6	15.6	69.8				2.183
2.0	64	16.2	17.2	66.7				2.197
2.25	64	17.9	19.0	63.1				2.213
2.5	64	19.8	21.1	59.1				2.231
2.75	64	21.9	23.3	54.8				2.252
3.0	64	24.2	25.8	50.0				2.274
3.5	64	29.5	31.4	39.1				2.323
3.75	64	32.4	34.5	33.1				2.351
1.25	65	13.3	86.7					2.390
1.50	65	14.3	85.7					2.393
1.75	65	15.6	84.4					2.397
2.0	65	17.1	82.9					2.402
2.25	65	18.8	81.2					2.407
2.5	65	20.6	79.4					2.413
2.75	65	22.7	77.3					2.420
3.0	65	24.9	75.1					2.427
3.5	65	27.4	72.6					2.435
3.75	65	30.0	70.0					2.444
4.25	65	32.9	67.1					2.453
4.75	65	46.2	53.8					2.496
5.75	65	62.7	37.3					2.549
ALL	66	100.0						2.669

*Corod No. shown refers to the largest and smallest rod size in sixteenths of an inch with the "one" deleted. For example, Corod No. 31 is a three-way taper of 13/16, 3/4, and 11/16. No. 51 has as the largest rod size 15/16 and the smallest 11/16, with 7/8, 13/16 and 3/4 in between.

It is beyond the scope of this paper to derive the equations for static elongation. Numerous papers and books have covered this subject adequately. (see Bibliography)

Predicted Loads

Using the data in Table 4, it is possible to use the empirical load formulas of Mills or Slonneger to arrive at the predicted maximum and minimum loads and stresses and estimated peak torque.

Or with only a few additional hand calculations the design of a corod installation can be obtained from the API RP 11L. For example, it is necessary to solve for (1) the fundamental frequency which leads to the N/No ratio and (2) the spring constant (1/Kr). Once those values are obtained, the remaining parameters of RP 11L can be applied.

SUMMARY

The basic problems connected with implementing a continuous rod string: manufacturing, transporting and field handling, have been solved.

The use of the corod in the field has shown that lower loads, fewer failures, and longer life of the corod pump system can be obtained. The absence of couplings reduces the probability of failure by 65-80 per cent, reduces paraffin accumulation and downhole friction.

This new approach to an old method of pumping may very well revolutionize the artificial lift industry.

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