THE FUNCTIONAL EFFECTIVENESS OF FIBERGLASS SUCKER RODS

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INTRODUCTION

A number of major oil companies have begun field tests of the lightweight, non-corrosive fiberglass sucker rods. The tests were generally made using steel sucker rods in a well for a specific time period and replacing the steel rod string with one designed with fiberglass rods. Specific detailed rocords were kept on these "before and after" studies by most companies. Other companies employed an independent testing firm to provide test results. This paper will compare steel sucker rods with two brands of fiberglass sucker rods manufactured by Company A and Company B.

The wells in this study are divided into groups of similar depths with comparable fluid levels, pumping units and bottom-hole pumps. Four standards were developed to compare and evaluate sucker rod performance.

1. Equipment loading
2. Energy consumption
3. Fluid production
4. Failure frequency

Each of these four standards was studied in depth in similar wells to compare each group of sucker rods.

HISTORY

Since fiberglass sucker rods have been under development for eight years and numerous papers have previously been presented, only a very brief history of fiberglass sucker rods is included in this paper.

In the early 1970's, a new era began when the technology of the Space Age allowed engineers to develop the forerunner of today's fiberglass sucker rod. The original idea was to use the non-corrosive fiberglass rod in highly corrosive wells to prolong the life of the rod string. But engineers soon realized the other potential assets of the fiberglass sucker rod, i. e., increased production, decrease in weight, lower gearbox torque and energy savings through use of smaller prime movers. The first fiberglass rods experienced two major problems: end-fitting pinchoffs and body breaks. The steel end-fitting has been redesigned and pinch-offs are no longer a problem. The current manufacturing process has eliminated the looping or knotting of glass rovings in the rod body, one of two major causes of rod body breaks. The second major cause of fiberglass sucker rod failure is mis-application and is discussed in this paper.

ROD STRING DESIGN AND APPLICATION

The lower modulus and lighter weight of fiberglass sucker rods make it necessary for the engineer to have pertinent data to properly predict the rod string performance. A brief review of fundamental rod loading principles is helpful to focus on the differences in fiberglass and steel sucker rods. Since FORCE = MASS X ACCELERATION, the peak polished rod load occurs when the mass is elevated with maximum acceleration. In a rod pumping system, upstroke load consists of fluid load and bouyant weight of the rods. A steel rod sting mass is slightly elastic and there is a time lag between the movement of the polished rod and the corresponding movement of the pump plunger. Normally the acceleration of the mass is greatest as the rods start off the bottom and this force causes the greatest stretch in the rods. Since the modulus of elasticity for fiberglass is 9.0×10^6 lbs/in^2 compared to 30.5×10^6 lbs/in^2 for steel, it is possible for a fiberglass rod string to absorb the full length of the surface stroke and experience little or no bottom-hole pump stroke. For this reason it is necessary to prestress fiberglass rods to obtain optimum benefit from the elasticity. Experience has shown that optimum sucker rod strings range from 50% to 90% fiberglass on top with steel rods on bottom. To calculate these variables by hand is extremely time consuming, but a computer program to assist in designing rod strings is available on G. E. Timeshare. The program is flexible and allows for simulating down-hole friction, incomplete pump fillage, tubing stretch, high-slip prime movers, various tubing gradients and pump intake pressures.

Fiberglass rod strings must be designed to avoid compressive loading. Company A had developed a load range diagram for 7/8 in. fiberglass rods based on experience with rod string failures. See table 1. Company B has developed a larger (.98 in. diameter) rod body which is comparable in strength to a 1 in. steel rod body, but can be used effectively in 2 3/8 in. O. D. tubing. A corresponding load range diagram has been designed for this rod. See table 2. The load range is relevant to rod string longevity. Field experience and laboratory testing prove that rod string longevity is optimized if peak polished rod loads are kept within the boundaries represented by the load range diagram.

WHY FIBERGLASS RODS REDUCE TORQUE

The pumping units and steel rods in many wells are considerably overloaded. Much of the time, the limiting factor in fluid production is gearbox loading. Fiberglass sucker rods are approximately one-third the weight of steel rods and it is normal to expect a reduction of 50% in bouyant rod weight using a typical fiberglass string design. Test well Number 8 is pumped with a C320-213-120 unit from 6,081 ft. using a 1.75 in. pump plunger. At 7.73 SPM the peak torque with steel rods was 448,100 in/lbs, an overload of 40%. Actual production was 272 BFPD but pump intake pressure of 977 psi indicated more production potential. A 69% fiberglass rod string was installed and unit pumping speed was increased to 11.54 SPM. After production stabilized, the peak torque had been reduced to 278,500 in/lbs and production increased to 363 BFPD. See table 3.

Test well Number 6 is pumped with a C320-256-120 from 6,115 ft using a 1.75 in. pump plunger. At 10.35 SPM, the peak torque with steel rods was 417,500 in/lbs, an overload of 30.4%. Actual production was 313 BFPD but pump intake pressure of 773 psi indicated more production potential. A 71% fiberglass rod string was installed and pumping speed was increased to 11.91 SPM. After production stabilized, the peak torque had been reduced to 272,400 in/lbs and production increased to 324 BFPD. See table 4. Other test wells show similar torque reduction while increasing production. See table 5.

WHY FIBERGLASS RODS REDUCE ROLISHED ROD LOADS

One of the most important benefits of fiberglass rods is it's lightweight. A 7/8 in. steel rod weighs 55.6 lbs calculated at 2.224 lbs per ft. A 1 in. steel rod weighs 72.6 lbs calculated at 2.904 lbs per ft. A 7/8 in. fiberglass rod weighs 26.775 lbs calculated at .714 lbs per ft. A 1 in. fiberglass rod weighs 31.8 lbs calculated at .848 lbs per ft. In test well Number 8, the peak polished rod load was reduced 33% from 18,921 lbs to 12,533 lbs, while increasing production 33% from 272 BFPD to 363 BFPD. See tables 3 and 4.

WHY FIBERGLASS RODS ARE MORE ECONOMICAL THAN STEEL

Since the total weight of a typical rod string is reduced by up to 50%, the horsepower requirements and energy consumption is reduced accordingly. When the speed of the unit is increased to obtain more production, energy consumption is raised, but the lifting cost per barrel of fluid per ft of height raised is reduced. Test well Number 8 required 25.4 HP to produce 272 BFPD with steel rods and 30.1 HP to produce 363 BFPD with glass. Test well Number 6 required 36.3 HP to produce 313 BFPD with steel rods and 27.5 HP to produce 324 BFPD with fiberglass. See tables 3 and 4. Energy consumption tests by a major oil company proved energy savings ranging from 26% to 39% per barrel produced.

WHY FIBERGLASS RODS ARE MORE ECONOMICAL THAN STEEL

Fiberglass sucker rods normally last longer than steel when used properly. The replacement of steel, made necessary by corrosion, is one of the major costs of oil production. The anti-corrosive properties of fiberglass, combined with its superior tensil strength and lightweight, make it preferred over steel rods in a highly corrosive environment. The metal end-fittings are constructed of 4620 K Grade (2% Nickel content) steel. This quality steel, combined with reduced stress due to weight, has reduced rod breaks in every test application.

Maintenance costs with steel rods for test well Number 8 for a period of 12 months was$27,446. Installation of a fiberglass rod string cost $18,624.75 and there was no maintenance cost for the remainder of the test period. See table 7.

Maintenance costs with steel rods for test well Number 6 for a period of 9 months was $27,859. Installation of a fiberglass rod string cost $18,311 and there was no maintenance cost for the remainder of the test period. See table 6.

Cost comparison for these wells is shown in tables 8 and 9. These

7/8 in. rods were replaced with 1 in. fiberglass rods after 9 months. The incremental cost of fiberglass rods over steel rods varies according to the grade of steel rods, but average 15% higher. Since rod strings will vary from 50% to 90% fiberglass, the costs vary on each application. The producer should also consider lost production and down time due to rod string repairs. Less down-time and fewer rod string repairs will reduce the cost per barrel of fluid produced.

WHY FIBERGLASS RODS INCREASE PRODUCTION

There is another remarkable property of fiberglass to consider. Since fiberglass rods are more elastic than steel, it is not unusual to experience a longer bottom-hole pump stroke with a properly designed fiberglass rod string. The elasticity of a pre-stressed fiberglass rod string can generate significant production increases due to overtravel. In a cyclic condition, the weight generates a lower downstroke and a higher upstroke relative to the surface stroke. The longest pump stroke will produce the most fluid. Using the computer program for designing fiberglass rod strings, the engineer can predict prime mover requirments, peak and minimum polished rod loads, peak gearbox torque, downhole pump stroke, pump displacement, bouyant rod weight and fluid loads. By manipulating variables, (rod design, pump plunger size, stroke length, and unit speed) it is possible to design for the optimum production and equipment loading. It is advantageous in some applications to reduce the pump plunger size to obtain the overtravel, because net production can be increased. Table 10 shows 5 wells with bottom-hole pump stroke up to 54% longer than the surface stroke. Four of the 5 test wells have small pump plungers and three of the 5 have relative high fluid levels as indicated by the pump intake pressures.

Before and after studies completed by a major oil company showed a 15% increase in production in one district where 17 wells were equipped with 65% to 80% fiberglass sucker rods. In another district a study of 4 wells showed frequency of rod body, rod pin and coupling breaks for a 12 month period using steel rods, was considerably decreased after installing the fiberglass rods. This company reports zero failures in 1 in. fiberglass sucker rods after one year operation.

TECHNICAL SERVICE

Fiberglass rods are designed and manufactured to be compatible with standard oil field tools and equipment, however, some properties are different and require different handling. See table 11 for fiberglass sucker rod characteristics. The end-fitting of both the 7/8 in. and 1 in. fiberglass rods are 1.625 in. in diameter and pins are standard API 1.1875 in./10 thread (same as 7/8 in. steel rod). The 7/8 in. rod has pin and box end-fittings. The rods will screw together without an additional coupling. The 1 in. rod has a pin on each end and accepts a standard API 7/8 in. coupling. Both sizes can be used effectively in 2 3/8 in. O. D. tubing. The rods measure 37.5 ft in length. On work-over jobs they can be pulled in doubles (75 ft) and hung in the derrick. Both size rods require 1 in. elevators, 1 in. rod transfer case and 1 in. rod wrenches (or 1 in. inserts on power tongs). Installation make-up torque requirements are identical to K grade steel sucker rods. Pump spacing with fiberglass rods is similar to proceedures used with steel rods, however, the characteristics of fiberglass requires more pump plunger spacing off the bottom. See table 12 for formulae to calculate pump length and pump spacing. Maximum torque on fiberglass rods is 100 ft/lbs. Should a pump become stuck, it is not recommended to attempt to unscrew fiberglass rods. Normally, a pump can be unstuck by jarring at the surface with 12,000 lbs to 20,000 lbs. See table 13. Some companies have installed J-Locking on/off tools in wells with a history of sticking pumps, but it is recommended to install a shear-pin device on top of the pump.

Properly anchored tubing should be considered to minimize rod on tubing wear. This will also extend the life of the fiberglass sucker rods and optimize net plunger travel. The lower modulus of elasticity fiberglass rods should not be used in highly deviated wells.

There may be times when it is necessary to fish a broken fiberglass rod. Since the rod body is constructed of resins and glass, current fishing tools are not effective on the rod body. However, Company B has developed a fishing tool that can by-pass the rod body and catch the metal end-fitting. This fishing tool is available on a rental or purchase basis.

CONCLUSIONS

Fiberglass rod strings, when properly designed, reduce maximum loads, torque requirements and energy consumption. Because the units experience lighter loads, it is possible to produce more fluids by changing the pumping speed. Downhole pump stroke can be longer than the unit's maximum stroke and, therefore, produce more fluid. The lighter loads require less counter-balance and further reduce energy requirements. Fiberglass rods are less susceptible to corrosion and experience fewer parts in corrosive environments. Rod strings last longer when used in accordance with the load range diagrams. Fiberglass sucker rods, when used correctly, will out-perform and out-last steel sucker rods.

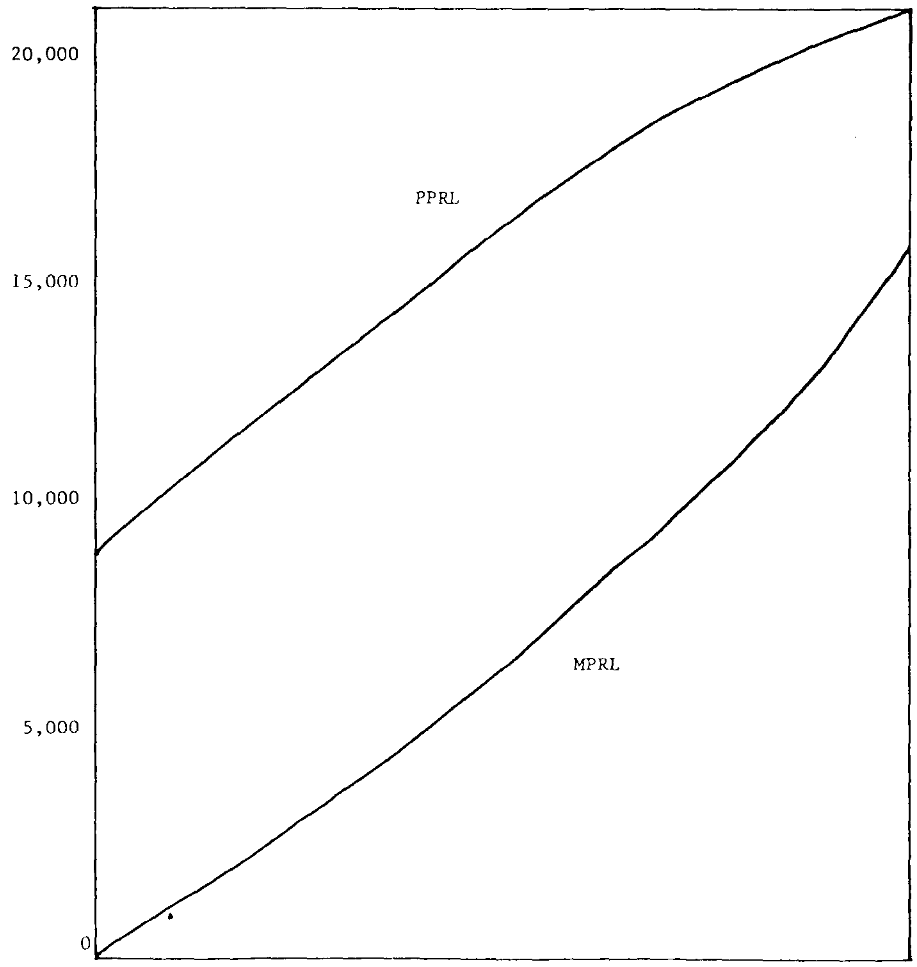
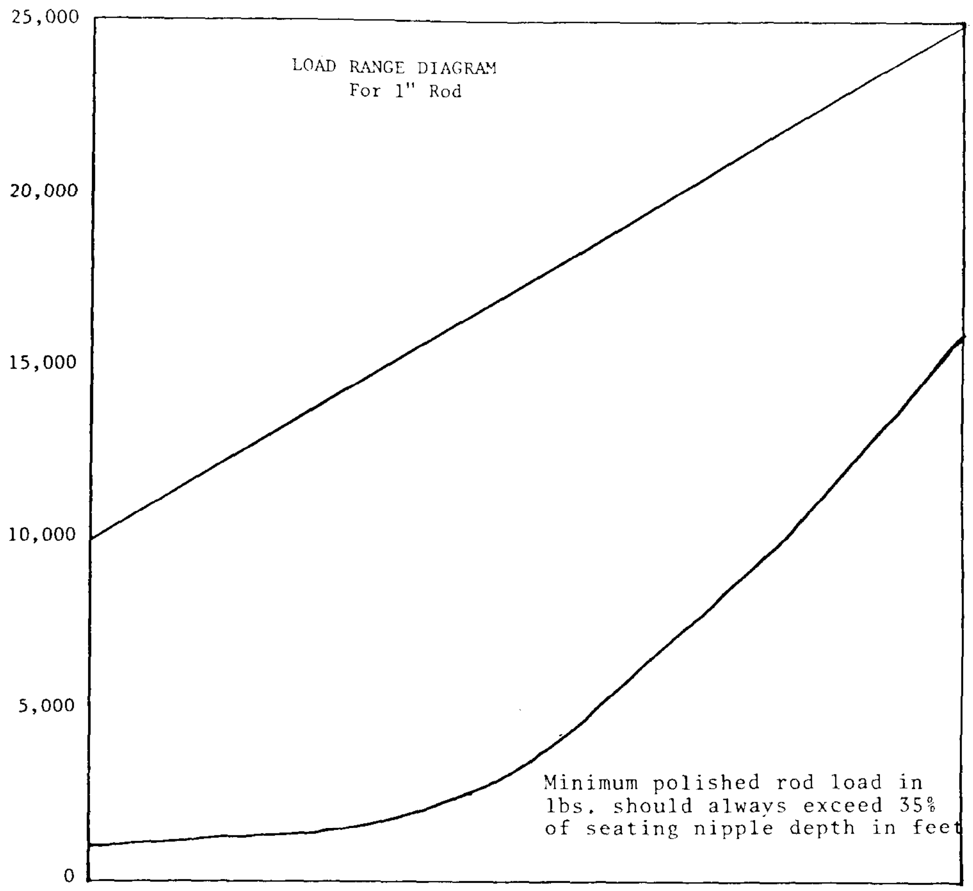


TABLE 1

TABLE 2



LOADS SHOULD BE CALCULATED WITH LOWEST PUMP INTAKE PRESSURE.

TABLE 3—WELL NO. 8

Table of Equipment Performance

	100% Steel Rods*	69% Fiberflex
Existing Peak Torque, in-lbs.	448100	278500**
In-balance Peak Torque, in-lbs.	417100	257600**
Pumping Speed, SPM	7.73	11.54
Polished Rod Power, HP	13.1	15.6
Cyclic Load Factor	1.737	1.715
Minimum Req'd. Power, HP	25.4	30.1
Peak Rod Load, lbs.	18921	12533
Min. Rod Load, lbs.	6664	3453
Reported Production, BFPD	272	363
Calculated Pump Intake Pressure, psi	977	847
Gross Pump Displ., BPD	296	380
Net Pump Displ., BPD	283	323
Unit Stroke, ins.	121	121
Gross Pump Stroke, ins.	107.1	92.2

TABLE 4—WELL NO. 6

TABLE OF EQUIPMENT PERFORMANCE

	100% Steel Rods*	71% Fiberflex Rods
Existing Peak Torque, in-lbs.	417500	272200
In-balance Peak Torque, in-lbs.	416600	217400
Pumping Speed, SPM	10.35	11.91
Polished Rod Power, HP	17.8	18.7
Cyclic Load Factor	1.835	1.308
Minimum Req'd. Power, HP	36.3	27.5
Peak Rod Load, lbs.	18288	12600
Min. Rod Load, lbs.	4984	3273
Reported Production, BFPD	313	324
Calculated Pump Intake Pressure, psi	773	692
Gross Pump Displ., BPD	400	458
Net Pump Displ., BPD	312	345
Unit Stroke, ins.	121	121
Gross Pump Stroke, ins.	108.2	107.8

*See analysis dated 12-28-79.

TABLE 5

	100% Steel	Fiberglass Steel	100% Steel	Fiberglass Steel	100% Steel	Fiberglass Steel	100% Steel	Fiberglass Steel	100% Steel	Fiberglass Steel
Pumping Unit Size	A456	A456	C320	C320	C320	C320	C456	C456	C456	C456
Peak Torque, In.-Lbs.	524,000	405,800	417,500	272,200	448,100	278,500	561,400	430,920	386,600	364,000
Strokes Per Minute	8	10.5	10.35	11.91	7.73	11.54	10.86	12	7.8	7.8
Strokes Length, In.	144	144	120	120	120	120	120	120	144	144
Peak Polish Rod Load, Lbs.	24,976	15,697	18,288	12,600	18,921	12,533	19,138	16,259	16,617	12,608
Minimum Polish Rod Load, Lbs.	8,364	4,512	4,984	3,273	6,664	3,453	5,661	2,140	5,363	2,739
Production, BFPD	290	345	313	375	272	363	489	590	387	695

TABLE 6

MAINTENANCE COST - TEST WELL NO. 6 FOR NINE MONTHS

Pulling Unit Cost - $1,250 per job.		
Six Body Failures at $1,250 each		$ 7,500.00
Cost of String W/Couplings		
7/8" Grade D Steel - $2.51/ft x 2,525 =	$6,337.75	
3/4" Grade D Steel - $2.12/ft x 3,075 =	$6,519.00	
1" Grade D Steel - $3.30/ft x 250 =	$ 825.00	
Total Cost		$13,681.00
Replaced all 3/4" rods cost $2.12/ft x 3,150		$ 6,678.00
Total Cost for nine months		$27,859.00

MAINTENANCE COST - TEST WELL NO. 6 FOR SEVEN MONTHS

FIBERGLASS SUCKER RODS

Pulling Unit Cost - $1,250 per job		
No rod failures.		
Cost of String W/Couplings		
1" Grade D Steel - $3.30/ft x 150 =	$ 495.00	
7/8" Grade D Steel - $2.51/ft x 1,600 =	$ 4,016.00	
7/8" Fiberglass - $3.20/ft x 4,312.5 =	$13,800.00	
Total Cost		$18,311.00
Total Cost for seven months		$18,311.00

TABLE 7

MAINTENANCE COST - TEST WELL NO 8 FOR TWELVE MONTHS

Pulling Unit Cost - $1,250 per job	
Three Rod Failures at $1,250.00	$ 3,750.00
Cost of String W/Couplings	
3/4" Grade K Steel - $2.50ft x 3,925 = $9,812.50	
7/8" Grade K Steel - $3.00ft x 2,350 = $7,050.00	
1" Grade K Steel - $3.74ft x 250 = $ 935.00	
Total Cost	$17,797.50
Replaced all 7/8" rods cost $2.51/ft x 2,350	$ 5,898.50
Total cost for twelve months	$27,446.00

Most of this cost incurred in the first three months.

MAINTENANCE COST - TEST WELL NO. 8 FOR SEVEN MONTHS

Pulling Unit Cost -	
No Rod Failures	
Cost of String W/Couplings	
1" Grade D Steel - $3.30/ft x 150 = $ 495.00	
7/8" Grade D Steel - $2.51/ft x 1,725 = $ 4,329.75	
7/8" Giberglass - $3.20/ft x 4,312.5 = $13,800.00	
Total Cost	$18,624.75
Total cost for seven months	$18,624.75

TABLE 8—COST COMPARISON

Test Well No. 6

Initial cost difference

Fiberglass/Steel	$18,311.00	
Steel	$13,681.75	
Difference		$ 4,629.25

Cost over initial installation

Fiberglass/Steel	$ 0.00	
Steel	$14,177.25	
Difference		$14,177.25

Payout

Total cost = initial set-up cost plus maintenance costs.

Fiberglass/Steel	$18,311.00
Steel Only	$27,859.00

$$\text{Payout} = 9\text{months} \times \frac{\$18,311.00}{\$27,859.00} = 5.92 \text{ months}$$

TABLE 9—COST COMPARISON

Test Well No. 8

Initial cost difference

Fiberglass/Steel	$18,624.75	
Steel	$17,797.50	
Difference		$ 827.25

Cost over initial installation

Fiberglass/Steel	$ 0.00	
Steel	9,648.50	
Difference		$9,648.50

Payout

Total cost = initial set-up cost plus maintenance costs.

Fiberglass/Steel	$18,624.75
Steel Only	27,446.00

$$\text{Payout} = 12 \text{ months} \times \frac{\$18,624.75}{\$27,446.00} = 8.14 \text{ months}$$

TABLE 10

Well No.	B #48	B #2	14-A	H-1	M-1
Unit Stroke, ins.	120	86	168	120	72
Pump Stroke, ins.	161.5	102.5	189	171	111.5
Pumping Speed, SPM	11.9	12.4	8.9	13	15.2
Peak Rod Load	19557	14690	19460	19279	17567
Min. Rod Load	7461	4380	6302	5970	7376
Rod String Design	8547	8677	8607	8656	8667
Pump Bore Size, ins.	1.25	1.25	1.5	1.0625	1.25
Production, BFPD	280	184	352	233	247
Pump Depth	8738	7550	8694	11275	9195
Pump Intake Pressure, psi	100	25	1000	500	2000

TABLE 11

FIBERGLASS ROD CHARACTERISTICS

Average Modulus of Elasticity	9.0×10^6 lbs/in^2
Density	.074 lbs/in^3
Maximum Torque	100 ft/lbs
Coupling Material	4620 "K" Grade

OPERATING DATA

Maximum Working Load	25,000 lbs
Maximum Working Stress	34,000 lbs/in^2
Maximum Load (Short Term)	40,000 lbs
Maximum Stress (Short Term)	53,000 lbs/in^2
Maximum Design Temperature	200^o

TABLE 12

PUMP LENGTH CALCULATION GUIDE

Pump length should be calculated with highest pump intake presure.

Pump Length (working) $= \frac{9'' \times \text{Footage of Glass Rods} \times 1.75}{1000} =$ ____________ inches

Maximum anticipated downhole pump stroke or surface stroke (whichever is greater) = ____________ inches

Plunger Length = ____________ inches

$\frac{2 \times \text{Seating nipple depth}}{1000}$ = ____________ inches

Add these four figures to obtain total length of pump. ____________ inches

PUMP SPACING GUIDE

$\frac{(9'' \times \text{Footage of Glass Rods})}{1000} + \frac{(2'' \times \text{Seating nipple depth})}{1000} =$ ____________ inches off bottom

TABLE 13

MAJOR OIL COMPANY MECHANICAL OPERATIONS REPORT

Fiberglass Rods Are Used to Unstick Pump On April 6,1980, it was determined that a problem had been encountered with the pumping equipment on the Test Well No. 6. Preliminary indications implied that a rod part had occured in this 71% fiberglass rod string.

The fiberglass rod manufacturer was contacted and arrived on location on April 7, 1980, when the pulling unit rigged up. After rigging up, it was determined that the rods were not parted, but that the pump was stuck. The rod string had been acting like a yo-yo with the pump stuck, stretching the full 120 inches of the stroke. The pump was unstuck by jarring at the surface with 13,000 - 15,000 pounds (recommended by the manufacturer of the fiberglass rods).