Flexible Pumping Strand

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Lifting fluid from the earth by means of a flexible rope had its beginning in antiquity. Many types of material and rope constructions have been tried in the quest for better and more economical production of petroleum but with limited success. Low strength, poor abrasion resistance, fatigue, incompatibility with well fluids, corrosion and by no means least, lack of adequate knowledge and techniques all contributed to the poor success. "Flexirod" overcomes the mechanical shortcomings and as evidenced by trials extending over approximately seven years, can be designed as a practical working tool.

"Flexirod" as shown in Fig. 1 is constructed of a multiplicity of wires twisted together into a strand. Each wire has a minimum tensile strength of 240,000 psi or about twice that of carbon-manganese quenched and tempered sucker rods. Each wire is surrounded with a 10 mil thickness of nylon to overcome corrosion and internal friction. A 25 mil thick jacket of nylon is extruded over the stranded wires to protect the individual wires from field handling damage and abrasion against the well tubing during service.

FLEXIROD CROSS SECTION

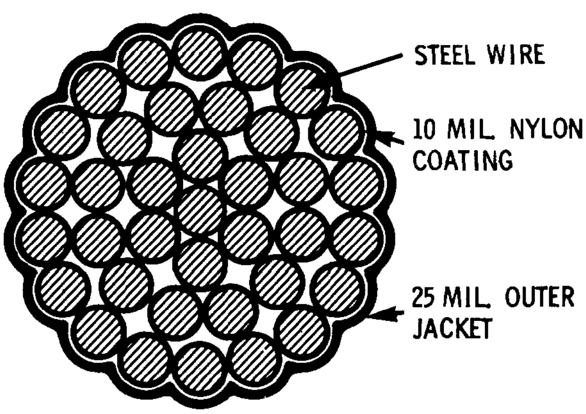

FIGURE 1

Cross Section of "FLEXIROD" Flexible Pumping Strand.

Nylon was selected over other plastics for its unique combination of properties including resistance to petroleum crudes, excellent wet abrasion resistance, toughness, low creep, high softening point and low permeability. Nylon is not a newcomer to the petroleum industry since it has been used for many years for sucker rod guides, scrapers, etc.

Laboratory research backed up by actual well experience indicates "Flexirod" has overcome a major cause of sucker rod failures, corrosion fatigue. Individual wires tested in a five per cent brine solution held at 180° F give equal fatigue properties to duplicate wires tested in air. This, to the author's knowledge, had never been achieved previously.

To explain this fatigue test in more detail, refer to Fig. 2. A straightened wire of known length is bent into a circular arc of measured radius. The degree of curvature determines the test stress. While bent in this arc and submerged in the brine solution, the wire is rotated about its own axis at high speed. The number of revolutions or reversal of stress to failure is recorded. At high stress levels, only a few reversals can be made before rupture occurs. By reducing the stress level on succeeding specimens, a stress will be reached, providing no corrosion is present, where the specimen will run continually without failing. Experience has indicated (for steel) that if 2×10^6 stress cycles are reached, the specimen will run indefinitely. This stress where the S-N curve, Fig. 3, Curve 1, becomes horizontal is called the Endurance Limit. If corrosion is present, a true limit is never reached (Curve 2), for if the specimen remains in the corroding medium long enough, it will fail by corrosion at no applied stress. Nylon-coated "Flexirod" wire when tested in the brine solution, even after a seven-day soak prior to testing, shows the same fatigue limit of 65,000 psi as duplicate wire tested in air. Curve 3 has been plotted just below Curve 1 for clarity but actually, one should be on top of the other.

CORROSION FATIGUE TESTING

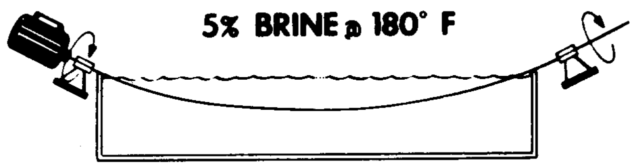

FIGURE 2

Schematic Diagram of Corrosion Fatigue Testing.

FATIGUE

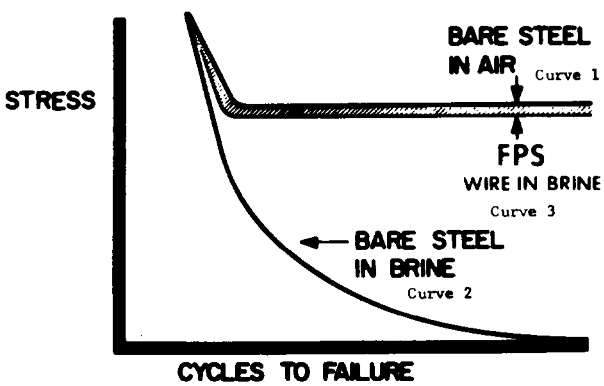

FIGURE 3

Stress vs. Cycles to Failure, Fatigue Testing of Strand.

Another interesting laboratory discovery was the ability of nylon-coated "Flexirod" wire to withstand hydrogen sulfide. Uncoated and nylon-coated wire were stressed to approximately 50 per cent breaking strength and immersed in a 3 per cent salt, plus 1/2 per cent acetic acid solution, saturated with hydrogen sulfide. Uncoated wire ruptured in approximately two hours. Nylon-coated "Flexirod" wires were removed and tensile tested after some seven weeks with both strength and ductility completely unimpaired.

Field experience in operating oil wells appears to confirm laboratory data. The original "Flexirod" installed in a sweet crude Texas well in July, 1962 is still pumping today. Other strands continue to operate successfully in California for periods exceeding three years.

In a sour crude well located in Kansas with a history of early sucker rod failure, a "Flexirod" operated for about 15 months before failure occurred. Failure was due to mechanical abuse, resulting from lack of experience in designing pumping operations with "Flexirod". Insufficient load was placed on top of the pump to overcome buoyancy, hence "Flexirod" was being placed in compression on each stroke. Rupture occurred at 150 ft above the terminal fitting, which by calculation, was the point of 0 load as that length of "Flexirod" was required just to overcome the buoyancy weight deficiency. Sucker rods had failed in shorter service times.

Table 1 presents as of January 31, 1969 some of the wells in which "Flexirod" was installed, together with other pertinent information.

TABLE 1

WELLS OPERATING WITH FLEXIROD

January 31, 1969

Date Installed	Depth Feet	Stroke Inches	Strokes/ Min.	# Cycles x 10^6	Production Bb'l/Day
7-31-62	1569	22	12.0	41.0	20
12-10-65	2831	48	10.3	17.4	35
7- 6-66	2760	78	13.5	15.9	200
8-30-66	2575	86	16.4	15.5	330
1-22-68	2976	54	12.0	6.9	75
1-24-68	2510	54	14.1	6.8	170
1-29-68	2622	56	12.2	6.4	85
9-18-68	3420	144	10.0	2.0	300
9-19-68	2638	120	12.0	2.3	

Certainly there have been failures for only by this means can parameters be determined and optimum designs achieved. The second strand produced was actually designed a failure brought about by gross inexperience on our part both in field handling and well operations. This strand, used in pumping a 4000 ft well, had a steel area equivalent to only a 3/8-in. diameter sucker rod. To aggravate matters, more dead load than designed for was placed on the pump, the nylon jacket was damaged in numerous locations and the outer layer of wires bared at spots. Stroke lengths varied from 64 in. to 96 in. and speeds from 6 to 16 strokes per minute. With this excessive abuse, the strand still ran for 45 days before rupture. Failure occurred where the jacket and wire coatings had been destroyed prior to installation. The broken strand end was secured by pulling tubing. When a tubing length equal to the upper failed length of "Flexirod" was removed from the well, the end was standing upright and easily pulled from the well. We believe it possible to fish ruptured "Flexirod" with either a spear or overshot but neither have been tried. A broken strand will remain upright in the well with no tendency to collapse.

Running "Flexirod" requires somewhat different procedures and equipment than for sucker rods. The flexibility of strand allows a complete well length to be wrapped on a 48-in. diameter drum reel. This reel is positioned in a motor-operated reel stand and the "Flexirod" end, with mill-attached terminal fitting, taken over a 48-in. diameter sheave to the wellhead. The terminal fitting is screwed into a shear release joint attached to the pump. The strand is then allowed to run down the well under controlled conditions. Speeds as high as 350 ft per minute have been achieved with unsophisticated handling equipment. In many instances, 3000-ft wells had been run or pulled in 8 to 10 minutes, once equipment was in place. Since "Flexirod" is continuous, there is no stopping every 25 or 30 ft to make or break joints. Figure 4 is a diagram of such a setup.

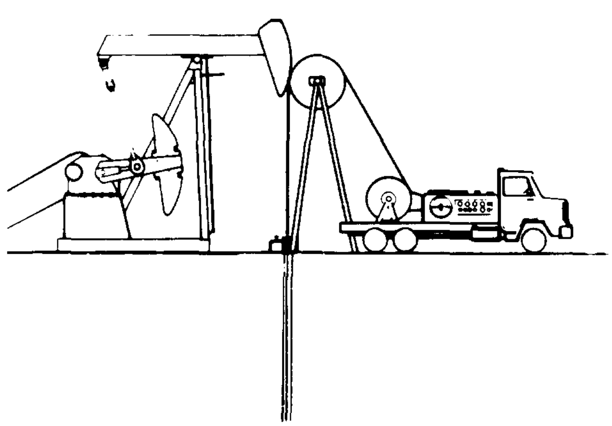

FIGURE 4

Diagram Showing Procedure and Equipment Used in Running Flexible Strand.

In order to bring the top end of "Flexirod" out of the well, it is threaded through a polish rod liner. This liner with a top packing is held in the carrier bar. Not required, but strongly recommended, is a load cell placed between the liner packing nut and the bolted terminal clamp placed around "Flexirod". The terminal clamp transmits the entire load from "Flexirod" to the pumping unit. The polish rod liner carries no load and only acts as a sliding packing through a conventional stuffing box. Figure 5 is a diagram of this type installation.

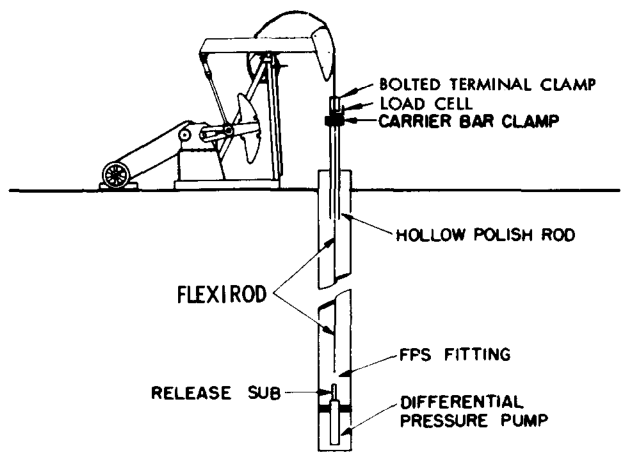

FIGURE 5

Diagram of Flexible Strand Well Installation.

Pulling "Flexirod" for pump change or other well servicing is relatively simple; all required is to pass the loose strand end over the head sheave and fasten it to the reel. After removing the terminal clamp, polish rod liner packing and loosening the wellhead stuffing box, the strand can be reeled. When the terminal fitting hits against the polished rod liner, it lifts it from the well. At this point, pulling is stopped and "Flexirod" disconnected and pushed to one side. Connecting pony rods, pump, etc, now can be removed from the well by sand line or auxiliary line from the truck winch. A 3000-ft well has been pulled, pump changed and the well put back in operation in less than one hour.

Except for reasonable care in handling, there are only three precautions that must be exercised:

1. "Flexirod" should not be bent around a diameter less than 48 in. It is possible to

bend "Flexirod" around much smaller diameters but the larger diameter is specified in order not to place excessive bending stress in the individual wires. Such stresses when added to operating stresses could produce high fatigue loads.

2. Location where the top operating clamp has been placed must never be allowed to get into the operating length. In order to keep the clamp as short as possible for clearance requirements, high pressure must be exerted in the clamp area to develop adequate holding power. This high pressure tends to cold flow the nylon and possibly distort the strand construction and bare the steel wires. If this clamp section length comes in contact with well fluid, corrosion fatigue can take place, resulting in premature failure. If for any reason there is a possibility that this previously clamped section will contact well fluid, add one or more pony rods on top of the pump before rerunning.

3. At present, the maximum continuous operating temperature is specified as 250° F. Nylon melts at about 420° F but there is a tendency to hydrolyze below this and 250° F is selected as being safe.

The usual design formulae for well calculations are applicable to "Flexirod" with one addition—a calculation for safety factor. Since "Flexirod" has a definite known corrosion fatigue value, we believe this determination is warranted as it leads to a more positive design. A safety factor can be determined by a modified Goodman diagram as shown in Fig. 6. The tensile strength of the wire, 240,000 psi, is plotted on the horizontal axis with endurance limit of 65,000 psi as the vertical component. Connecting these extremes determines the boundary conditions. For any well, the average stress developed in usual fashion is plotted along the horizontal axis. Plotted along the vertical axis is the alternating stress which is one-half the difference between maximum and minimum stress. A line is drawn from the origin through the point of intersection of these values to the boundary line. Length of Line "A" divided by "B" is the safety factor by graphical solution. Actually the safety factor can be calculated mathematically by the formula:

$$S.F. = \frac{240{,}000}{\text{Aver. Stress} + 3.7\ (\text{Alt. Stress})}$$

For the present, we suggest a minimum safety factor of 3.0. As additional experience is gained, possibly this can be reduced.

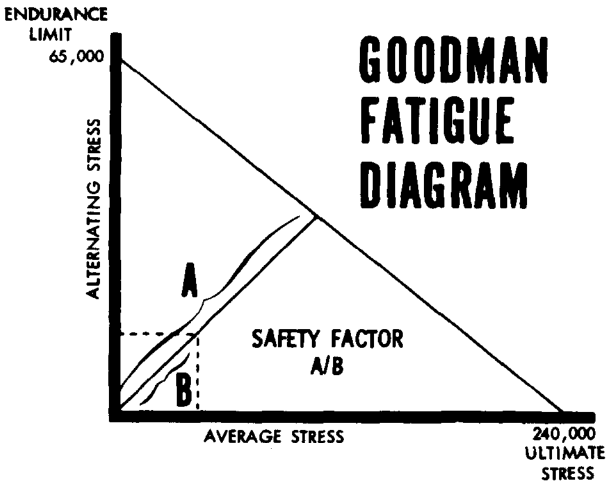

FIGURE 6

Goodman Fatigue Diagram for Modified to Determine Flexible Strand Safety Factor.

A critical consideration in designing for "Flexirod" is to assure sufficient dead load to overcome fluid buoyancy. "Flexirod" has little stiffness and therefore, must be maintained in tension at all times or a node of 0 load will result. The several failures to date have resulted from not thoroughly understanding this criterion and allowing the strand to become unloaded, creating an excessive range of alternating stress. These failures occurred in the lower third of the length and not at the top where maximum loading occurs in a properly designed well.

There are numerous ways to maintain tension in "Flexirod" at all times. An obvious method is to use sufficient sucker rods or sinker bars on top of the pump to overcome buoyancy. This has been tried successfully but stiff members remain in the well, creating corrosion and well pulling problems. Another procedure is use of a differential load or positive pull pump, several of which are on the market. The type shown in Fig. 7 has proved successful. Two conventional pumps are connected by a ported section of tubing. The larger pump is placed over the smaller with the differences in plunger areas creating a positive downpull at all times. By varying the combination of pump sizes, different degrees of downward loading can be achieved.

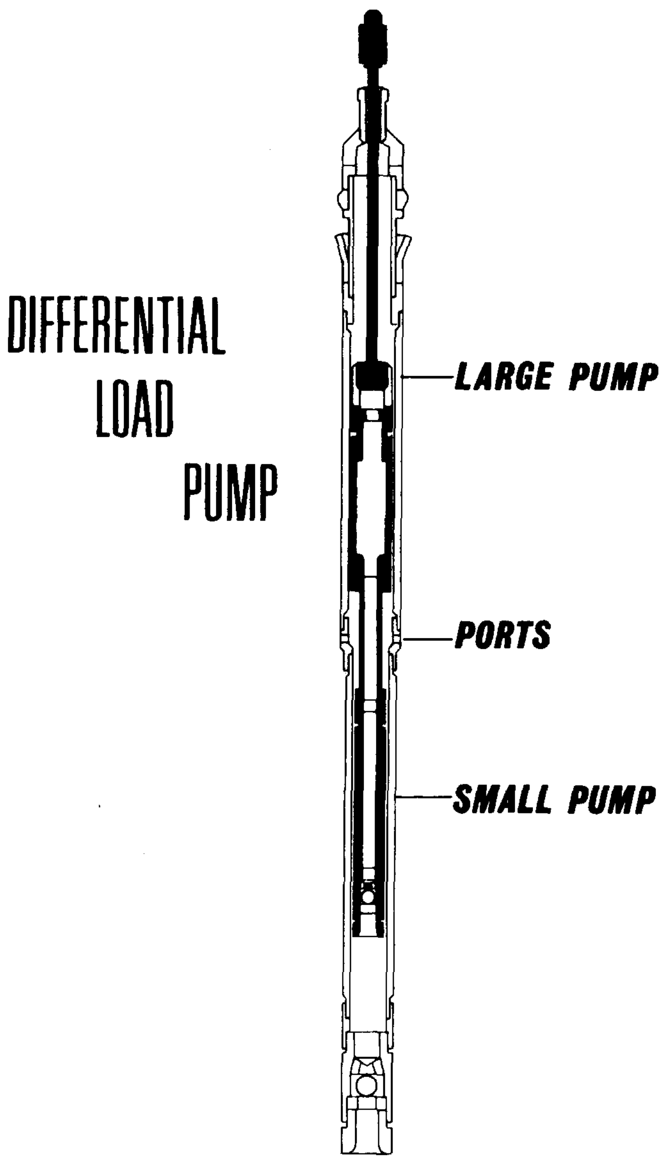

FIGURE 7

Differential Load Pump.

The main disadvantage in using "Flexirod" is its greater stretch compared to sucker rods. First, because of stranding, the modulus of elasticity is reduced from 29×10^6 to 24×10^6; second, there is less steel area in "Flexirod" to carry the loads. Three-quarter-inch "Flexirod" has an area of 0.186 sq. in. or approximately the equivalent of a 1/2-in. sucker rod, while the strength of 43,900 lbs approximates a 3/4-in. sucker rod. The 7/8-in. "Flexirod" has an area of 0.291 sq. in. and strength of 68,600 lbs, while for 1 in. the values are 0.404 sq. in. and 93,900 lbs.

Obviously, the way to overcome stretch is to go to longer stroke units; "Flexirod" makes this possible and practical. Strokes of 50, 100 or even 1000 ft are entirely conceivable, Fig. 8. Picture an elevator for a pumping unit where cable is spooled and unspooled on a reel to whatever length and at whatever speed is required to economically pump a well. Also, picture the possibility of having an electronic switch that triggers the reel only when the pump barrel is full of fluid. All this is possible with "Flexirod" and in fact, designs are underway for a 50-ft stroke unit.

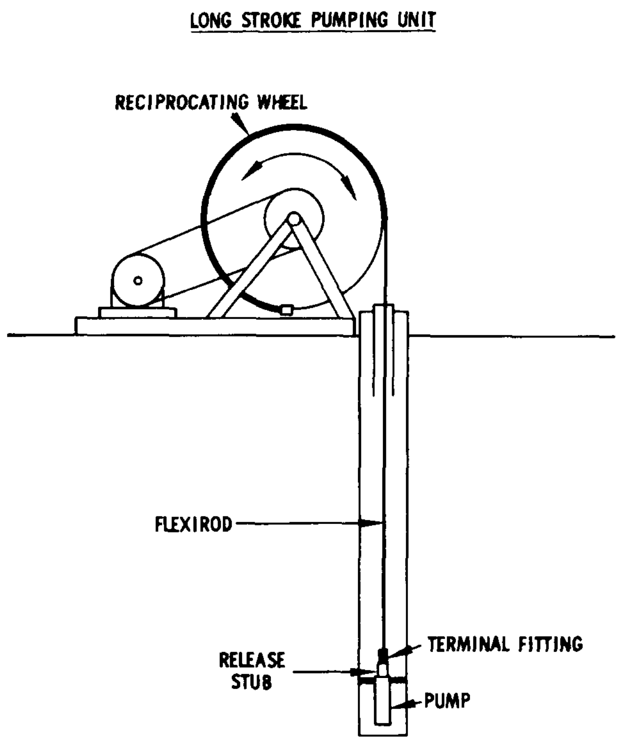

FIGURE 8

Long Stroke Pumping Unit Incorporating Flexible Strand.

ADVANTAGES OF "FLEXIROD"

Ease and speed of handling. The continuous length and flexibility make it possible to install and pull wells at speeds in excess of 300 ft per minute.

Simplified, less costly handling equipment. Being able to spool "Flexirod" makes it possible to simplify well pulling equipment and make it less costly.

Reduced labor. There is less manual labor required for handling "Flexirod". One machine operator and a helper can run the strand with the men doing little manual labor and wearing white coveralls.

Long life. Corrosion fatigue appears to be of no consequence. There also are no couplings to fail.

Less tubing wear. The smooth continuous surface of "Flexirod" without joints and low coefficient and excellent abrasion of nylon should reduce tubing wear to a minimum.

Plastic-lined tubing practical. Several wells utilizing "Flexirod" have had plastic-lined tubing installed with minimum signs of wear.

Less paraffin troubles. The smooth surface and uniform diameter of "Flexirod" can mean less paraffin buildup. Present sucker rod joints act as nucleating areas for start of paraffin buildup as well as throttling fluid flow.

Savings in corrosion inhibitors. "Flexirod" does not require use of inhibitors. If plastic line tubing and pumps of corrosion-resisting material are used, possibly no inhibitor will be required.

Reduced horsepower. "Flexirod" weighs less than one-half that of comparable sucker rods. The smooth continuous nylon surface and constant cross section not only reduce fluid friction but also fluid turbulance. Less dead weight means less counterbalance weight and less pumping torque. All these mean less operating horsepower. In two installations where careful checks were made, horsepower savings of 12-1/2 per cent and 15 per cent were achieved.

Additional pumping unit capacity. The reduced weight of "Flexirod" means less counterbalance weight, hence less pumping unit torque. This could lead to more production with existing units and/or longer strokes by use of extenders or multipliers.

New production units. The continuous length, flexibility and uniform cross section make possible all types of new production equipment. Long, slow stroke units are distinct possibilities. By just pushing a button, pumping could be stopped and "Flexirod" withdrawn for pump removal or other well workover. Well operation ultimately may be practical from a central location. Such things as an electric cable incorporated into "Flexirod" are not beyond possibility.

New horizons are ahead for petroleum engineers and equipment manufacturers, limited only by their vision, ingenuity and foresight.