IMPROVING BEAM PUMP EFFICIENCY WITH FIBERGLASS SUCKER RODS AND A SPECIAL GEOMETRY PUMPING UNIT

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ABSTRACT

It has been documented in field test results that in many cases a production increase can be obtained by replacing a steel sucker rod string with a fiberglass and steel sucker rod string. (2) While these tests have demonstrated the value of fiberglass sucker rods, the beam pumping systems were still fairly inefficient because the pumping units that were being used were originally designed for use with steel sucker rods.

A more efficient beam pumping system has been developed that uses fiberglass sucker rods in conjunction with a pumping unit that was designed to take greater advantage of the properties of fiberglass sucker rods. (3)

This paper discusses the unique characteristics and history of fiberglass sucker rods, and examines how this new pumping unit takes advantage of the properties of fiberglass sucker rods to produce a more efficient beam pumping system.

HISTORY OF FIBERGLASS SUCKER RODS

The first fiberglass sucker rods were developed by an engineer with Amoco Production Company and Joslyn Manufacturing Company. At the time, Joslyn was producing a pultruded fiberglass reinforced plastic rod for use in the electrical industry as an insulator. Since the insulating rods could withstand a tensile load of several thousand pounds, they were used as models for the first fiberglass sucker rods. (1)

The original purpose of developing fiberglass sucker rods was to try to reduce sucker rod failures due to corrosion. However, initial testing quickly revealed several distinct advantages of using fiberglass rods in beam pumping applications. Due to the fact that the fiberglass rods weigh 70% less than comparable steel rods, significant reductions in polished rod load, peak torque, and counter-balance requirements were observed. It became apparent that it would be possible to maintain production volumes with a smaller pumping unit and less energy consumption, and to increase production above the capacity of steel sucker rods without the need of a larger pumping unit.

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As with any new technology, there were several problems that had to be overcome. The original insulator type fiberglass rods were quite capable of supporting the large tensile loads, but they had never been tested under cyclic loading conditions such as those present in a beam pumping system. When the rods were first tested under cyclic loading conditions in a beam pumped oil well, they failed after only a short time. The engineers with Amoco examined each of the parted rods and discovered several problems related to the manufacturing of fiberglass sucker rods. (4)

The fiberglass rods are manufactured by combining thousands of glass filaments into glass fiber rovings. The glass rovings are then passed through a polyester resin bath which is kept in a liquid state by a styrene monomer. The wetted strands of glass fiber are then passed through a die which forms the rod body. The rods are then heated to 140 degrees F which causes the styrene monomer to evaporate into a styrene gas. The polyester resin hardens in the absence of the styrene monomer and forms the rod body.

The original curing process utilized conventional heating methods that cured the resin from the outside. This resulted in tiny bubbles of styrene gas getting trapped inside the rod body. Another defect in the rod body resulted from the tendency of the glass fibers to form small knots when they were drawn together. Both the knotted rovings and the styrene gas bubbles caused variations in the load handling characteristics of the rod body. When the rods were placed under cyclic loading conditions, these variations caused them to splinter and fail prematurely.

Another major source of rod failures was in the connecting pin ends. The pins, which are made of 4620 "K" grade steel, were glued onto the ends of the rod body with an epoxy resin. Close examination of the pins revealed that the original method of placing the pins on the end of the rods left gas pockets entrained in the epoxy resin. This also resulted in a considerable number of fiberglass rod failures.

Another problem existed in the actual design of the pin ends. The original design had a large amount of steel at the fiberglass-steel junction. This caused the steel pins to be very stiff at a critical point in the rods. Because of this, most of the bending moment was concentrated at one point in the rod body resulting in many failures at the pin end.

The design and placement of the pin ends was improved to reduce failures. The thick steel at the fiberglass-steel junction was replaced by a thin steel jacket that allowed the steel pin to bend with the fiberglass rod thus transferring the bending moment smoothly from the rod body to the pin. A method of spinning the pin ends onto the rod body resulted in effectively removing any entrained gas from the epoxy resin.

Both of these modifications to the connecting ends virtually eliminated pinch-offs in the second generation of fiberglass sucker rods.

The manufacturing process of the rod body was modified considerably for the third generation of fiberglass sucker rods. The conventional heating system used to cure the polyester resin which forms the rod body was replaced with a radio frequency heater. The radio frequency system heats the rods from the inside like an ordinary microwave oven. This has the effect of forcing the styrene gas bubbles to the outside as the resin cures thereby producing a much stronger resin matrix around the glass fibers. An elaborate system of ceramic guides was designed to properly align the glass rovings and draw them through the curing process without knots forming in the strands.

The third generation of fiberglass sucker rods has been on the market since about 1980. Although some feel that there is still some room for improvement, the new fiberglass sucker rods have become an economical and reliable alternative to steel sucker rods.

PROPERTIES OF FIBERGLASS SUCKER RODS

Fiberglass sucker rods are becoming more popular because they have tensile strengths roughly equivalent to that of steel sucker rods, yet they weigh 70% less. This difference in weight is even more pronounced when buoyancy is taken into consideration. The lighter weight of the fiberglass sucker rods directly results in lower polished rod loads. Since gearbox torque is partially a function of polished rod load and is also a limiting design criteria, fiberglass sucker rods can often increase the potential production volume of a pumping unit. Another advantage of fiberglass sucker rods that is directly related to weight is the low inertia force exerted by the rods during acceleration. This means that fiberglass sucker rods can be accelerated much quicker than steel sucker rods with the same amount of force. The new pumping unit design that will be discussed in greater detail later in the paper takes advantage of this concept.

Although fiberglass sucker rods weigh about 70% less than steel rods, the fiberglass rods can handle greater tensile loads then steel rods. The maximum working stress of fiberglass sucker rods is 34,000 psi compared to 30,000 psi for steel sucker rods. Fiberglass rods do, however, have an inherent compressive strength weakness. Fiberglass sucker rods should never be used where they might be put under a compressive load. For this reason, fiberglass sucker rods are usually used in conjunction with either steel sucker rods of steel sinker bars at the bottom of the fiberglass rod string. The heavy steel at the bottom of a fiberglass rod string also adds the weight necessary to actuate the pump on the downstroke of the pumping cycle. Fiberglass sucker rods are also relatively weak in terms of torque loads. They can only withstand about 200 ft-lbs. of torque. This should only be a consideration if a rod rotator is desired at the surface.

The low modulus of elasticity is another major consideration in the design of a fiberglass sucker rod string. The modulus of elasticity for fiberglass rods varies from 6.2×10^6 psi to 8.1×10^6 psi depending on the composition of the rods. Since there are several fiberglass sucker rod manufacturers, it is advised that the specifications be obtained prior to designing any fiberglass rod string. A rod string will stretch under a given load according to the following formula:

$$\text{deformation} = \frac{FL}{AE}$$

where: F = force
L = length
A = cross-sectional area
E = modulus of elasticity

Since the modulus of elasticity (E) is in the denominator, greater stretch will correspond with a smaller value of E. The modulus of elasticity for steel sucker rods is 30.6×10^6 psi. By comparing E for fiberglass and steel, it can be seen that fiberglass will stretch four to five times more than steel under identical loading conditions. This large amount of stretch that is inherent in fiberglass rods can greatly reduce production if the pumping system is improperly designed. On the other hand, a properly designed system can take advantage of the stretch factor to actually increase the downhole pump stroke. This phenomenon is called overtravel and can be achieved by operating near the resonant frequency of the rod string.

OPERATION AND COMPARISON OF PUMPING UNITS

Fiberglass sucker rods can be used with most of the major types of pumping units to obtain satisfactory results. However, each unit takes advantage of the characteristics of fiberglass rods to a varying degree. They do not all perform equally. The conventional pumping unit converts the motion of the crank to an almost sinusoidal motion of the polished rod. The other three types of units depart from this idea of simple up and down motion. Because the crank shaft is not directly underneath the tail bearing (or cross yoke bearing), these units have a slower upstroke and a quicker downstroke. This type of motion is obtained by offsetting the crank, such that more than 180 degrees of the crank rotation is devoted to the upstoke when polished rod loads are greater, and less than 180 degrees of the crank rotation is used on the downstroke when polished rod loads are less. These types of geometry result in a more even distribution of gearbox torque throughout the rotation of the crank.

The Type I pumping unit shown in Figure 1 utilizes a cross yoke bearing to lift the load on the upstroke as opposed to the traditional lever action where the pitman pulls down on a tail bearing to lift the load. The Type I unit works very well with steel rods, mainly because the crank is angled to obtain a maximum counterbalance effect earlier in the upstroke when the peak polished rod load usually occurs. However, it is not always advantageous to combine a Type I pumping unit with fiberglass rods. Figures 2 and 3 shows a typical dynamometer card for a 100% steel rod string and a fiberglass-steel rod string. The permissible load diagram of the Type I unit as shown in Figure 1 compliments the dynamometer card of the steel rod string which is low on the right and high on the left. However, the fiberglass-steel rod string has a dynamometer card that is high on the right and low on the left. This does not match the Type I permissible load diagram very efficiently. Because of the large amount of stretch that occurs with fiberglass rods, the peak polished rod load occurs late in the upstroke past the point of maximum counterbalance effect on the Type I unit. In certain cases, replacing steel rods with fiberglass rods can actually increase peak gearbox torque on a Type I unit. The Type II pumping unit, shown in Figure I, looks very similar to a conventional pumping unit. The major geometrical difference is that the crank is not directly below the tail bearing. This gives the desired effect of a slower upstroke and a quicker downstroke.

The Type III pumping unit, illustrated in Figure 4, departs from traditional pumping unit designs in an attempt to attain the most desirable polish rod motion for a fiberglass sucker rod string. The construction of the Type III unit is also different from traditional pumping unit designs. The standard gearbox has been replaced by a system of belts and wheels. The large wheels add to the overall efficiency of the system by their ability to store large amounts of rotational kinetic energy. The belts tend to increase the overall life of the system because they tend to dampen any mechanical vibrations that may occur in the system. A typical gearbox depends upon many metal to metal contacts to transfer power from the motor to the crank. This creates considerable vibrational energy that is easily transferred to the rod string. The motion of the tail bearing also differs from traditional pumping units. The tail bearing of the Type III unit operates from a nearly horizontal position to an almost vertical position. The other types of units have the tail bearing (or cross yoke bearing) operating between nearly equal distances above and below the horizontal.

Figure 1 also shows a polished rod velocity comparison of these four types of pumping units. The plot to the right of each unit shows the polished rod position on the vertical scale versus the dimensionless polished rod velocity on the horizontal scale. It is apparent from these plots that the maximum velocity on the upstroke is much slower than the downstroke for the three nonconventional units. This is a direct result of having more than 180 degrees of the crank angle devoted to the upstroke. This slower speed on the upstroke makes it much easier for the pumping unit to lift the weight of the fluid, and since the acceleration loads are reduced, the maximum rod stresses are also reduced. As the plots illustrate, the Type III unit design achieves a greater maximum velocity on the downstroke. The maximum velocity also occurs much closer to the bottom of the stroke than it does with the other units. Therefore, the Type III geometry results in a much greater acceleration of the sucker rods at the bottom of the stroke. In other words, the sucker rods are very close to a free fall with relatively constant acceleration for the majority of the downstroke. At the bottom of the stroke, the sucker rods are stopped very quickly which causes them to stetch out. This has the effect of preloading the rods prior to the upstroke. Therefore, very little surface stroke is utilized on the upstroke to stretch the rods prior to lifting the fluid load. This type of motion causes very efficient use of the energies present. The kinetic energy that is generated in the free fall of the rods is converted to potential energy in the stretch of the rods at the bottom of the stroke. The upstroke begins to slow near the top of the stroke which allows the fiberglass rods to shorten giving an extra push to the fluid load prior to the downstroke.

The Type III pumping unit and fiberglass sucker rods form two parts of what Allen and Svinos(3) call the Fiberglass Sucker Rod System (FSRS). The remaining part of the FSRS is a modified insert pump. The modifications consist of a larger I.D. valve seat (Texas Seat)(3), a larger plunger bore, and the replacement of the flexible valve rod with a more rigid valve tube.

TEST RESULTS OF FIBERGLASS SUCKER RODS AND THE FSRS

Prior to the development of the Type III pumping unit, an actual field test of fiberglass sucker rods was conducted by Treadway and Focazio(2) of Amoco Corporation. In this study, several steel sucker rod strings were replaced with a 60% fiberglass and 40% steel sucker rod string. Only the rod strings were changed, the rest of the equipment was kept the same as before the test. The results of the study are printed in Table 1. In most cases, reduced polished rod loads allowed an increase in the pumping speed which resulted in an increase in production. In all cases, the installation of the fiberglass sucker rods was economical, and each new rod string performed as expected without failure.(2)

A computer program which is commercially available to aid in the design of fiberglass sucker rod strings, contains all of the necessary dimensional and dynamic information of the four major types of pumping units. A comparison of four different beam pumping designs was made for a 6000 ft. well using this program(10). Each design used identical well conditions to obtain an accurate comparison. These four designs are shown in Figure 5. The first design is an all steel API 86 rod string. It requires a torque output of 712,000 in-lbs. and a power output of 63.5 HP. Total fluid production from this design is 572 BFPD. The same total fluid production is obtained from the Type III pumping unit with 88% fiberglass rods and 12% steel sinker bars. But with this design, maximum torque is 291,000 in-lbs. and power required is 37HP. Since the additional cost of fiberglass sucker rods is offset by the lower cost of the smaller pumping unit and electric motor, the initial investment of either system is comparable to the other. The economic advantage of the FSRS is realized in the reduction of operating costs. Over the long term, this can amount to a substantial profit increase for a well.

The first FSRS was installed February 25, 1983(3). This system replaced a high working stress steel sucker rod string. Table 2 shows an economic comparison of the FSRS that was installed, the high working stress system that was removed, and calculated values of an equivalent API system design. This table shows that the FSRS had a much lower initial investment and a much higher energy efficiency than the other two systems.

SUMMARY

Fiberglass sucker rods were originally developed as a method of reducing corrosion related failures in sucker rod strings. When the first fiberglass rods were tested, it became apparent that several other advantages could be gained by using fiberglass sucker rods. Over the past decade, many improvements have been made in fiberglass sucker rod technology. With the advent of better predictive techniques, fiberglass sucker rods are becoming very important in the oil industry. A more efficient beam pumping system called the Fiberglass Sucker Rod System (FSRS) has been developed(3) which uses a fiberglass sucker rod with steel sinker bars rod string design and a new pumping unit design. The new Type III pumping unit design provides a polished rod motion that is most suitable for the fiberglass rod string. Field tests

and computer simulation tests have revealed that fiberglass sucker rods and the FSRS are economical and more efficient methods of beam pumping.

REFERENCES

1. Hicks, Alan W.: "Fiberglass Sucker Rods - An Historial Overview," Paper presented at 32nd Annual Southwestern Petroleum Short Course, Texas Tech University, Lubbock, Texas, April 23-25, 1985.

2. Treadway, R.B. and Focazio, K.R.: "Fiberglass Sucker Rods - A Futuristic Solution to Today's Problem Wells," SPE 10251, Paper presented at 56th Annual Technical Conference and Exhibition, San Antonio, Texas, October 5-7, 1981.

3. Allen, L.F. and Svinos, J.G.: "Rod Pumping Optimization Program Reduces Equipment Failures and Operating Costs," SPE 13247, Paper presented at 59th Annual Technical Conference and Exhibition, Houston, Texas, September 16-19, 1984.

4. Watkins, D.L. and Haarsma, J.: "Fiberglass Sucker Rods in Beam Pumped Oil Wells," Journal of Petroleum Technology, May 1978.

5. Craft, Holden, and Graves: "Well Design: Drilling and Production," copyright 1962, Prentice-Hall Inc., Englewood Cliffs, New Jersey. (pg. 290)

6. Tripp, H.A.: "Mechanical Performance of Fiberglass Sucker Rod Strings," SPE 14346, Paper presented at 60th Annual Technical Conference and Exhibition, Las Vegas, Nevada, September 22-25, 1985.

7. Hallden, D.F.: "Modulus of Elasticity and Fatigue Life Considerations in the Design and Use of Fiberglass Sucker Rods," Paper presented at 32nd Annual Southwestern Petroleum Short Course, Texas Tech University, Lubbock, Texas, April 23-25, 1985.

8. Watson, J.: "Comparing Class I and Class III Varying Pumping Unit Geometries," copyright 1983, Paper presented at 30th Annual Southwestern Petroleum Short Course, Texas Tech University, Lubbock, Texas, April 27-28, 1983.

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NOMENCLATURE

A - Area
E - modulus of elasticity
F - force
L - length

Table 1
Summary of Field Test Data-Fiberglass Sucker Rods (Ref. 2)

	Depth (Ft.)	Pump Unit Size	Peak Torque (in.-lb.)	Strokes Per Minute	Stroke Length (in.)	Peak Polish Rod Load (lbs.)	Minimum Polish Rod Load (lbs.)	Production (BFPD)
FIELD TEST 1								
100% Steel	5,400	A456	561,400	10.8	120	19,138	5,661	489
Fiberglass/Steel	5,400	A456	430,920	12	120	16,529	2,140	590
FIELD TEST 2								
100% Steel	8,960	**						
Fiberglass/Steel	8,960	C320	313,000	11	120	21,496	7,890	130
FIELD TEST 3*								
100% Steel	5,500	C456	386,600	7.8	144	16,617	5,363	387
Fiberglass/Steel	5,500	C456	364,000	7.8	144	12,608	2,739	695*
FIELD TEST 4								
100% Steel	6,400	A456	524,000	8	144	24,976	8,364	290
Fiberglass/Steel	6,400	A456	405,800	10.5	144	15,697	4,512	345
FIELD TEST 5								
100% Steel	8,900	**						
Fiberglass/Steel	8,900	C320	265,000	10	100	22,000	9,681	160
FIELD TEST 6								
100% Steel	5,100	A640	871,000***	10.5	145.2	21,301	3,380	780
Fiberglass/Steel	5,100	A640	627,000	11	145.2	15,683	1,487	790
FIELD TEST 7								
100% Steel	5,100	A640	663,000	9.5	168	23,592	3,100	754
Fiberglass/Steel	5,100	A640	548,000	11	168	14,994	1,925	770
FIELD TEST 8								
E.S.P.	7,100							400
Fiberglass/Steel	7,100	C320	321,000	12	100	17,065	3,072	400

* Installation of Fiberglass Rods Allowed Well To Partially Flow, Sometimes As Much As 900 BFPD.
** New Well - No Previous Data.
*** Temporary Condition

Table 2
Cost and Efficiency Comparison of FSRS (Ref. 3)

	Fiberglass Sucker Rod System (FSRS)	High Working Stress Steel Sucker Rod System	API BUL 11L3 Suggested Conventional Steel Sucker Rod System
CAPITAL INVESTMENT FOR ALL SYSTEM COMPONENTS	$55,762	$73,600	$65,251
CAPITAL INVESTMENT TO SYSTEM CAPACITY RATIO	$135/BFPD	$220/BFPD	$163/BFPD
SYSTEM EFFICIENCY	27.7 bbls / HP	19 bbls / HP	17.3 bbls / HP

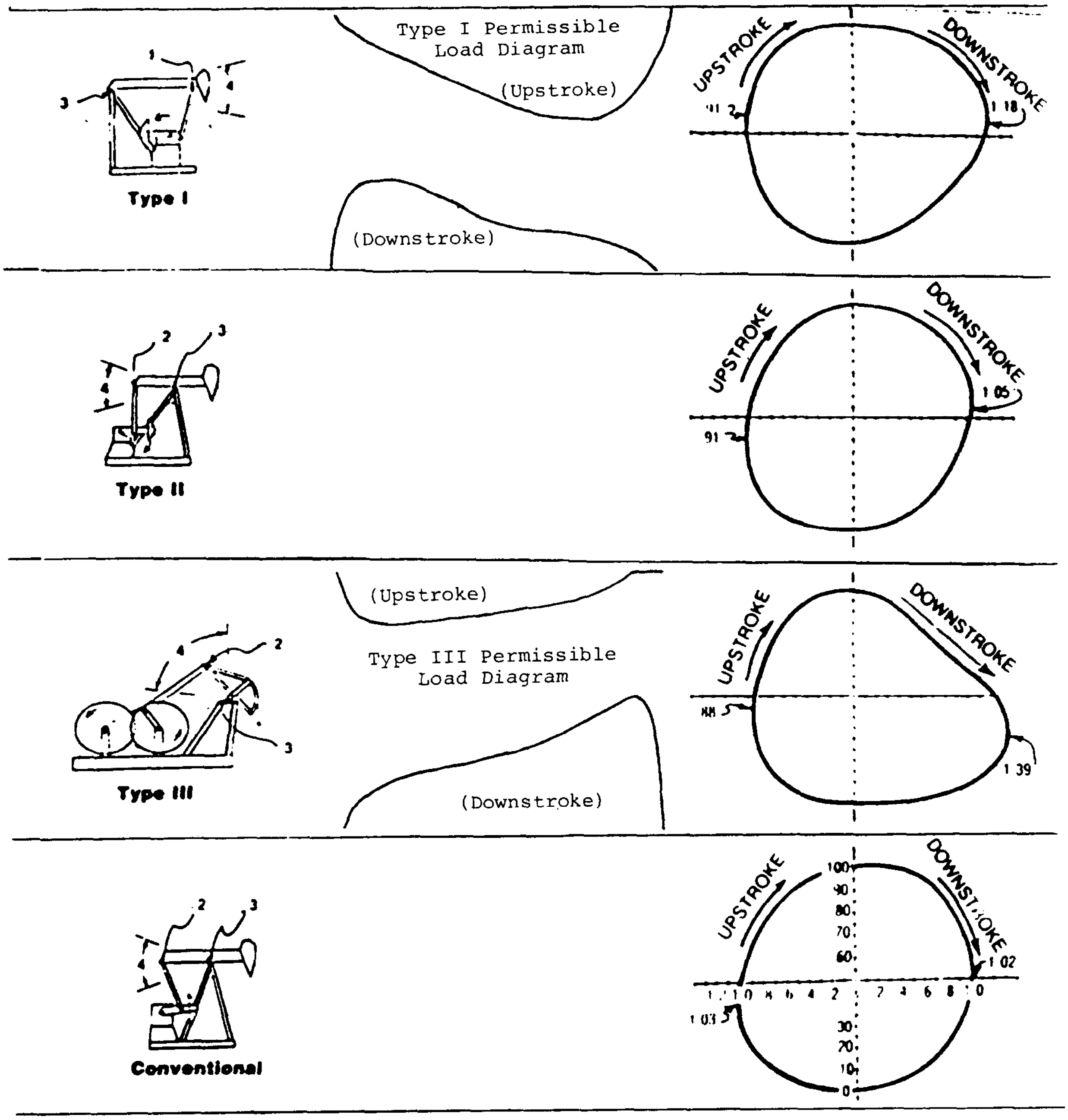


Figure 1 - Dimensionless polished rod velocity vs. polished rod position

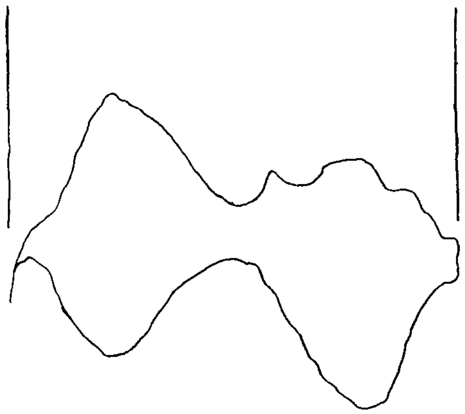


Figure 2 - Dynamometer card for 100% steel sucker rod string

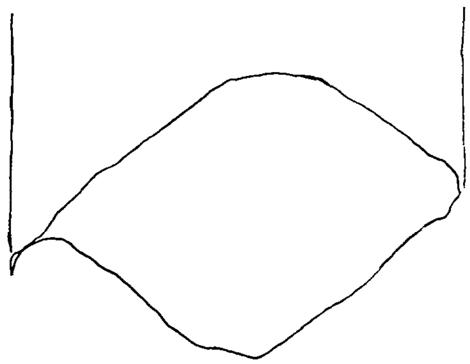


Figure 3 - Dynamometer card for fiberglass/ steel sucker rod string

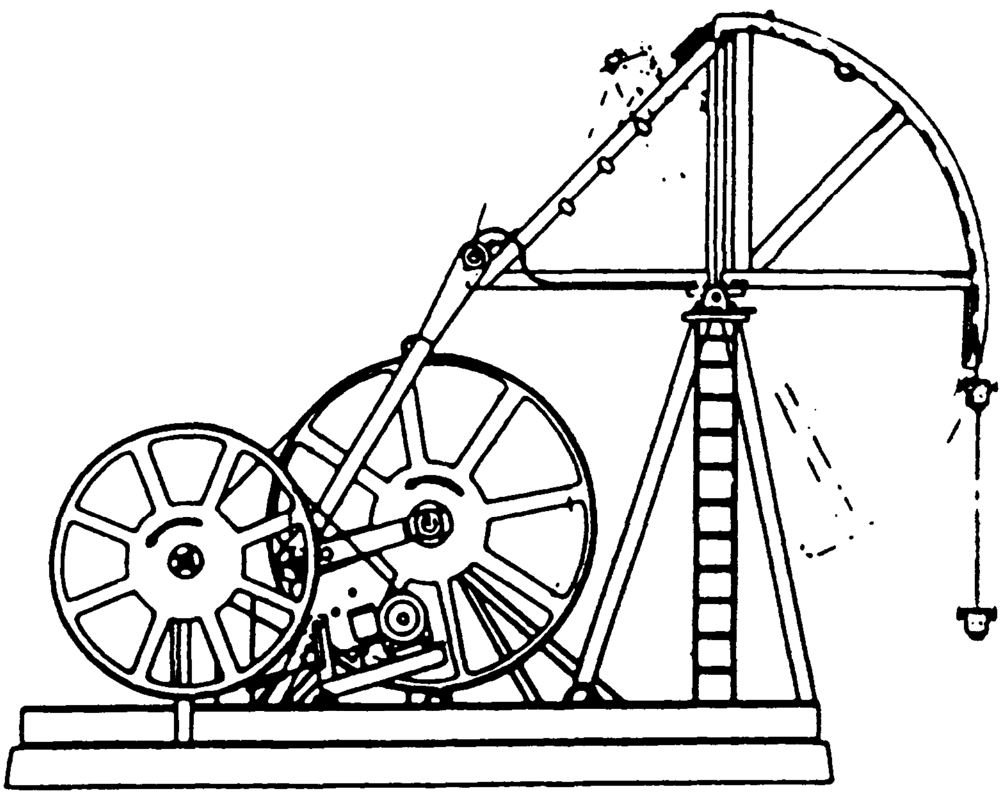
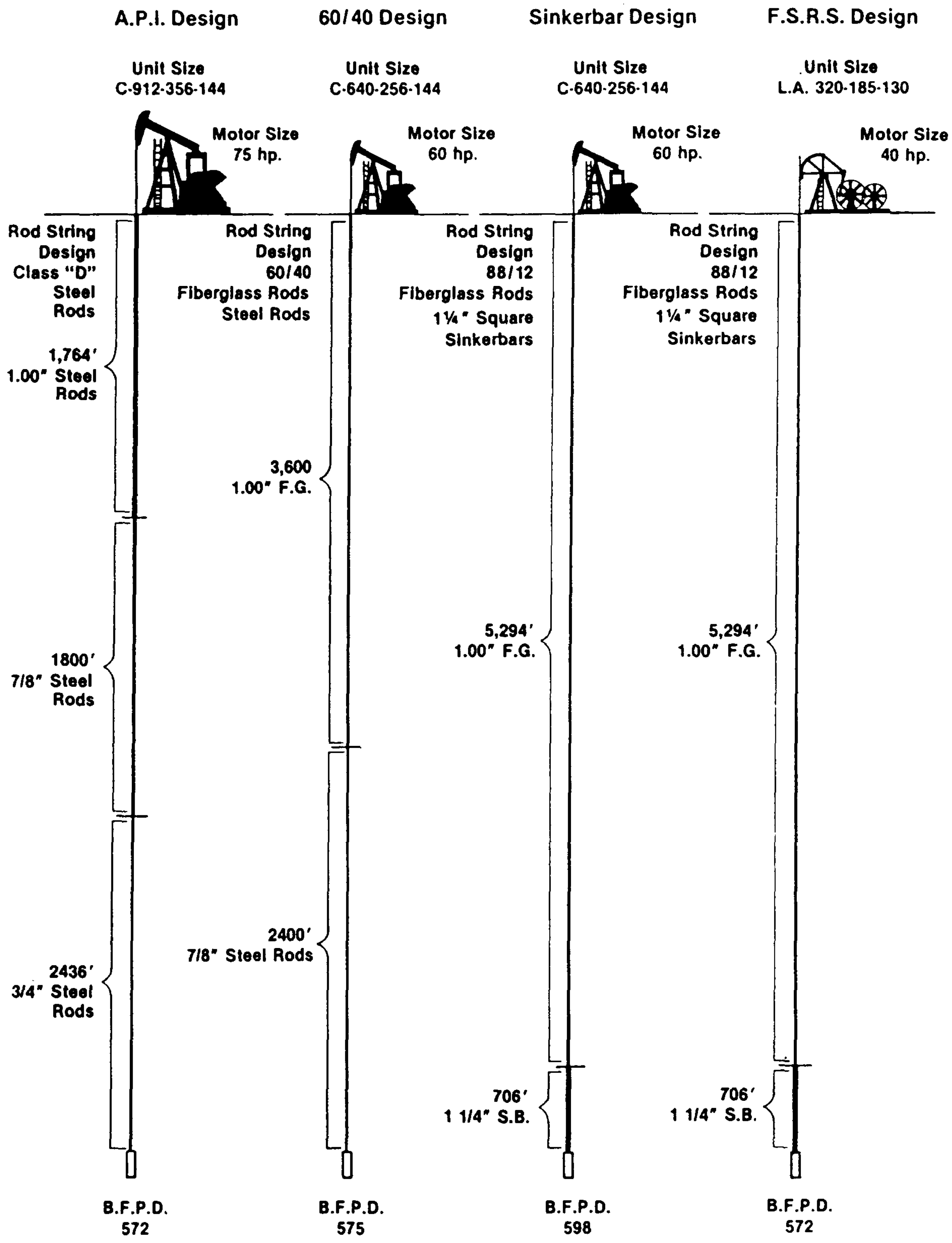


Figure 4 - Type III special geometry pumping unit



*Above Analysis Made With Identical Well Conditions.

Figure 5 - Comparison of four different beam pump designs-
6,000 foot well, identical conditions