FIBERGLASS SUCKER RODS--AN HISTORICAL OVERVIEW

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ABSTRACT

Fiberglass sucker rods (FSRs) were developed in the early 1970s as an alternative material to help combat problems caused by corrosion. As with most new products introduced to the oil production industry, there were numerous problems to overcome before the product was accepted as a viable tool by oil producers.

Over the past ten years many situations have arisen that have caused aggravating problems to users of FSRs. Many of these situations were caused by improper use of the rods, but some of the problems resulted from poor manufacturing processes.

This paper identifies many of the problems associated with using FSRs and discusses what has been done to overcome these problems. The author details the evolution of the FSR and documents many of the benefits, including increased production, lower lifting costs, gear box torque reduction, and energy savings.

The purpose of this paper is to answer often asked questions about string design, installations, hot oiling, fishing, etc. These answers will provide additional information to users of FSRs, former users who have elected to quit using the rods, and non-users who are reluctant to use fiberglass rods due to reported difficulties.

INTRODUCTION

Fiberglass has been an excellent tool for industry in general for several years. The petroleum industry has been using fiberglass tubulars and tanks very successfully, and it has long been established that fiberglass reduces or eliminates failures caused by corrosion. Originally, FSRs were made to alleviate the problems of corrosion on steel sucker rods. The cost of replacement of corrosion-damaged steel sucker rods is a multi-million dollar expense to oil producers in the United States and is still one of the reasons to use FSRs in beam pumping systems.

HISTORY

There have been several attempts to manufacture fiberglass sucker rods (FSRs). During the late 1960s, an engineer with Amoco Production Company (Amoco) had been working with entrepreneurs in an effort to develop a sucker rod made entirely of fiberglass reinforced plastic, but could not develop a method of connecting the rods together and still maintain the tensil strength necessary for sucker rod pumping systems. (A patent was issued in the mid-1970s for a process to use plastic end-fittings with a fiberglass reinforced rod body, but the process has not been perfected nor field-tested.)

The first practical product came as a result of interest generated when the engineer with Amoco, approached Joslyn Manufacturing Company (Joslyn), a company using pultruded fiberglass reinforced plastic rods as insulators in the electrical industry. Joslyn management refused at first to try to develop a FSR, but after much persuasion agreed to assist the engineer from Amoco. The pultruded fiberglass rod used as an insulator had a metal end-fitting attached which would withstand several thousand pounds tensil load, and it was assumed the rod would work just as well in an oil well. Since Joslyn had no experience in oil production, they had to depend solely on Amoco for advice and guidance. Because of the flexibility of the FSRs, about half of the production engineers with Amoco thought the FSRs would stretch so much that the downhole pump plunger would not move and would not produce any fluid. The others thought the rods would respond properly if sufficient weight bars were added to the bottom of the rod string.

The first attempt to use FSRs in a well was in 1975 when Amoco installed 5 FSRs under 1,875 feet of steel rods with 2,700 feet of steel rods below them in a 4,780-foot well. The rod string worked for 131 days before the first failure of a FSR. This failure occured when the cyclic loading of the rod string set up shear stresses near a flaw caused by poor distribution of the fibers within the cross-sectional area of the rod body. This flaw, actually a knot in the glass fibers, resulted in complete failure of the rod body. The knotting of glass fibers does not effect the pultruded rod body in tension loading. Joslyn had used the pultruded fiberglass rod in tension devices, but had done no cyclic testing. They had every confidence the fiberglass rods would be able to handle the loads and were very disappointed when the first FSR failed in only 131 days. The engineers with Amoco were pleased that the rods lasted that long.

Four string of FSRs were installed in West Texas and all failed within 30 days. One string was repaired and ran for several months without additional failures. Ten other test strings were installed in 1975 and 1976, and a paper was presented at the 52nd Annual Fall Technical Conference and Exhibition of the Petroleum Engineers of AIME in 1977 detailing the results of these tests. Joslyn suspected that many of the early problems with FSRs were caused by misapplication, but they were totally dependent on Amoco for oil field expertise. Joslyn hired an engineer with expertise in the oil field to assist in the FSR operation. This engineer designed and developed a load range diagram for FSRs which reduced the number of the rod failures simply by making sure the FSRs were used properly. The engineer's research showed the longevity of the FSRs was directly related to the range between the peak stress and minimum stress. The wider the range, the shorter the rod life.

Fiberglass sucker rods were introduced into the marketplace in October, 1976, at the Permian Basin Oil Show in Odessa, Texas. The first FSRs were marketed in May, 1977. There was a total of 15 FSR strings installed in 1977. The first years of research and development for FSRs had to address myriad concerns, including the following:

(1) How to attach an end-fitting which would grasp the rod tightly enough to prevent it from slipping without crushing the rod body.

(2) How to deal with lower modulus of elasticity which allows about four times as much stretch as with steel rods.

(3) How to define stress limitations.

(4) How does cyclic loading affect fiberglass.

(5) What effect excessive compression has on the rods.

(6) How to calculate the number of sinker bars to open the traveling valve.

(7) Would rod-on-tubing wear damage the rod body?

(8) How to predict peak polished rod loads, minimum polished polished rod loads, downhole pump stroke and production capabilities.

(9) How to calculate pumping speeds to maintain production volumes to offset the effects of increased rod stretch.

Some of the advantages of using FSRs also became apparent during the early tests.

(1) All the wells showed a significant reduction in the peak polished rod load.

(2) Peak torque was reduced in all but one of the first test wells.

(3) Production volumes could be maintained with smaller pumping units.

(4) Early tests showed power consumption was reduced thirty percent when FSRs were installed.

One disadvantage of using FSRs in the early years, was the splintering of the glass fibers when the rod body failed. This made it difficult to recover the broken rods with conventional fishing tools. Most of the time, the tubing had to be pulled to recover the broken rod. Pulling costs were about twice that of a pulling job in which the broken rod could be recovered with an overshot.

Some conclusions of the early tests:

(1) The much lighter weight of FSRs results in reduced peak loads, torque, and counterbalance requirements.

(2) The inherent strength of fiberglass is adequate for rod pumping applications.

(3) With proper use of sinker bars, production is not affected adversely by increased rod stretch found with fiberglass rods.

(4) Manufacturing defects, (end-fitting pinch-offs, end-fitting pull-outs, knots and loops, surface and internal cracks, air voids in the rod body and end-fitting adhesive), encountered in the first tests of these rods must be eliminated before the rods are acceptable for widespread use.

(5) Assuming manufacturing defects are eliminated, FSRs will be economically attractive where severe corrosion and/or heavy loading causes steel rods to fail frequently.

The company sold and installed approximately 150 rod strings between May, 1977, and September, 1979, with various degrees of success. One rod string installed September 4, 1979, in a 2,325-foot well is still operating as of this writing and has had no rod failures since it was installed. The well is producing 450 barrels of water and 28 barrels of oil per day with a 2.25" tubing pump. The unit has a 96" stroke and is running 9 SPM. The rod string has 48 FSRs, 21 3/4" steel rods and 9 sinker bars.

On September 1, 1979, a devastating fire destroyed Joslyn's FSR manufacturing plant, and management elected to discontinue their efforts to further develop a practical FSR.

On October 16, 1978, a new manufacturing company developed a superior end-fitting that eliminated end-fitting pinch-offs and began marketing FSRs in May, 1979. This firm installed 13 rod strings between May, 1979, and January, 1980, and experienced the same problems of knots and loops in the rod body. The new firm solved the knotting and looping problems and developed manufacturing processes that eliminated the other problems experienced by the first manufacturer.

Since 1979 there have been seven other FSR manufacturers actively engaged in sales and installations of FSRs. It is estimated that an average of three FSR strings per day were installed in 1984.

None of the manufacturers feel the ultimate FSR is being marketed today. There have been numerous improvements in the manufacture of the rod body during the past five years and many more, less dramatic, improvements are on the way.

QUESTIONS

In the ten years since FSRs were first installed, numerous questions have arisen concerning the use and capabilities of the rods.

HOW DEEP CAN FIBERGLASS SUCKER RODS PUMP?

Originally FSRs were successful only in shallow and/or lightly loaded wells. But with changes in design and manufacturing processes, FSRs are much stronger and can be used in applications where steel rods are not suitable. The shallowest oil well using FSRs is 600 feet deep and the deepest well using FSRs is over 17,000 feet deep. Table No. 1 lists some recommendations for stroke length and pumping speeds to insure success in pumping deeper wells. There have been some problems with excessive downhole friction reducing production when using a shorter stroke length than the one recommended in the table. It is important to work within the manufacturer's recommended stress range (Figure No. 1) when using FSRs and to consider production volume as well as depth when designing a FSR string. Properly designed FSR strings will work in shallow or deep wells.

DO CHEMICAL AND HOT OIL TREATMENTS AFFECT FIBERGLASS SUCKER RODS?

A major oil company did extensive tests on rod bodies submitted by FSR manufacturers and reports that no corrosion-inhibiting chemical currently being used has any effect on the rod bodies. There was one instance, reported by a FSR manufacturer, that showed hydrofluoric acid was used to acidize a well and not swabbed out. FSRs were installed, but the pumping unit was not installed. After several months with the FSRs hanging in the static hydrofluoric acid, the acid began to leech the rod body.

The early FSR bodies and adhesives used in the end-fittings were susceptible to damage from temperatures higher than 200 degrees F. At the present time manufacturers recommend a maximum design temperature for FSRs. Normally, FSRs are affected by high temperatures only in cyclic loading, and FSRs can normally withstand temperatures in excess of the manufacturer's recommendations in static conditions. The hot oiling process is usually accomplished by pumping a heated solution into the tubing/casing annulus, while pumping it back to the surface through the pump and tubing. The purpose is to dissolve salt and/or paraffin deposits that are restricting the flow of fluid through the tubing. Normally the temperature of the solution as it is pumped into the well is 300 degrees F. or less. By the time it is pumped back to the surface, the heat has dissipated and it is no longer hot enough to exceed the recommended design temperature of the FSRs. The hot oil process is usually accomplished in a short enough time that there is no effect on the FSRs. There is no record of damage to any FSR body as a result of hot oil treatment. However, the adhesive used to attach the metal end-fittings in the early FSRs was susceptible to heat damage and there have been reports of end-fitting pull-offs after a hot-oiling operation when the hot oil was pumped directly into the tubing and over the FSRs.

DO FIBERGLASS SUCKER ROD INSTALLATION PROCEDURES DIFFER FROM STEEL RODS?

The FSR manufacturers make the end-fitting to be compatible with existing tools and equipment in most instances, but because of special engineering, the larger FSRs require special tools which are usually supplied by the manufacturer for the initial installation. The tools are commercially available for purchase by operators and servicing companies. FSRs are generally installed similar to steel sucker rods, but pump spacing requirements are different and are provided by the manufacturer.

CAN FIBERGLASS SUCKER RODS BE FISHED?

The early FSRs would splinter so severley when the body of the rod broke that the splinters would "broom-out" and literally fill the tubing, making it impossible to use a conventional overshot fishing tool. The modern FSRs have a much stronger rod body that does not have the same "brooming" effect. A standard overshot with a cut-lip guide attached is sufficient to fish a broken FSR. It is difficult to fish the body of a FSR because the resins used to bond the glass fibers will not allow the conventional fishing tool to grip the rod body. If there are several feet of FSR body left in the tubing, a hollow pipe or pump barrel of adequate length to swallow the broken FSR body, with a proper size overshot attached to catch the end-fitting or coupling, will usually do the job.

IS COMPRESSION A PROBLEM WITH FIBERGLASS SUCKER RODS?

The pultruded fiberglass reinforced plastic rod was designed as a tension member, and early experiments with FSRs proved they had very little compressive strength. Modern FSRs are much stronger in compression than the first rods but are still susceptible to damage from severe fluid pound, gas pound or continuous pump tagging. A stress range diagram was developed in July, 1979, and was designed to keep the rods from being loaded in compression. The stress range diagram (Fig. No. 1) has been refined and adapted so that users of modern FSRs can design and utilize FSR strings successfully. If the peak and minimum stresses do not fall within the parameters of the diagram, there may be danger of compression loading which could damage the FSRs.

IS ABRASION A PROBLEM WITH FIBERGLASS SUCKER RODS?

The end-fittings of most FSRs are made from softer material than the tubing used in most wells, and any abrasion caused by end-fitting-on-tubing wear will displace the surface of the softer material. The end-fittings are designed for "slim-hole" installations and "full-hole" couplings will prevent the end-fitting from rubbing against the tubing. The resins used in manufacturing the rod body is softer than the steel tubing and will naturally wear away but the glass fibers in the rod body will damage the steel tubing. The diameter of the end-fitting is much larger than the diameter of the rod body and there is usually no surface contact except in severely deviated wells. Rod guides have been used successfully in some test applications, but manufacturers do not recommend using FSRs in wells with severe "dog-leg" or "corkscrew" deviations.

Abrasion is not the only problem caused by severe deviation. Because of the lower modulus of elasticity, the downhole pump stroke is affected by the increased friction caused by rod-on-tubing wear. By using the predictive design program, excess downhole friction can be simulated to assist in designing a proper rod string. Additional weight bars can be used to overcome the extra friction and develop an adequate downhole pump stroke to maintain production.

ARE PREDICTIVE DESIGN PROGRAMS ACCURATE?

A predictive design program was offered to users and manufacturers of FSRs which made it possible to predict downhole pump stroke, rod loading, gearbox torque and prime mover requirements. This program made it possible to design a rod pumping system to optimize production from a specific well without danger of overloading any part of the system. This program has been refined and updated as manufacturers have made changes in the quality of FSRs. At the present time there are several sophisticated predictive programs, available to users of FSRs, that have been proven to be accurate within one percent. Most users of FSRs are confident the modern predictive programs are reliable.

IS CORROSION STILL A PROBLEM?

Corrosion was the original reason for trying to develop FSRs and is still one of the reasons to use FSRs. A typical FSR string design consists of FSRs in the top portion and steel rods in the bottom portion of the string. Since the well still has metal rods, metal tubing, metal pump and metal casing, it is obvious that an adequate corrosion control program must be maintained; but the FSRs have eliminated the corrosion/stress problems in the top portion of the rod string.

Considerable analyses have been performed in an effort to understand why the 4620 steel made into FSR end-fittings does not corrode as rapidly as it normally does in steel sucker rods, but no reason has been agreed upon. Oil producers are reporting fewer rod parts with FSR strings than with steel rod strings in the same well. This indicates that corrosion control is still a good reason to use FSRs in corrosive wells, but it is also important to maintain a good chemical program for the metal rods, tubing, pump and casing.

CAN FIBERGLASS SUCKER RODS INCREASE PRODUCTION?

Production is a function of size of the pump bore, length of downhole pump stroke, and pumping speed. Assuming there is more fluid available, increased production can result from one or more of the following reasons:

(1) Since FSRs are more elastic than steel, it is not unusual to experience a longer downhole pump stroke with a properly designed FSR string. In a cyclic condition, the weighted elastic rod string generates a lower downstroke and a higher upstroke relative to the surface stroke. The elasticity of a pre-loaded FSR string can generate significant production increases due to overtravel.

(2) One of the most important benefits of a FSR string is its light weight. The total weight of a typical rod string can be reduced up to 50%. By reducing the rod string weight and the polished rod load, the pumping unit speed can usually be increased to increase fluid production.

(3) Also, because of the lighter bouyant rod weight, a larger bore pump can be utilized without overloading the pumping unit structure.

A test well in New Mexico was chosen because the gas engine, steel sucker rods and pumping unit were all loaded to capacity. See Table No. 2. The well was 7,896 feet deep and was pumped with an American conventional 456-256-120 pumping unit, with an Ajax gas engine rated at 40 horsepower. Pump intake pressure was calculated at 1,700 psi. The operator was using a 1.75" pump, API 86 rod string and pumping speed was 9.8 SPM. Reported production was 292 BFPD (145 oil, 147 water) indicating 80% pump efficiency. The steel rods were loaded at 97.3%, assuming a service factor of .9. The well experienced three rod parts in two months in the three year-old-rod string. The gearbox was 94.4% loaded. The minimum horsepower requirement was 39.9 HP. The peak polished rod load was reduced from 25,060 pounds to 14,868 pounds by installing a typical 70% fiberglass sucker rod string. Gearbox torque was reduced from 94.4% to 63.5%. The FSRs were lightly loaded at 75.3%, and the downhole pump stroke increased from 105.3" to 124.4". The production increased from 292 BFPD to 354 BFPD. Because of the reduction of the bouyant rod weight, it is possible to increase the pump bore size from 1.75" to 2.0" without overloading the prime mover, pumping unit or rod string, and production can be increased to 423 BFPD. Assuming the pump intake pressure remained constant, the operator could change the pumping speed from 10 SPM to 12.5 SPM and increase production to 544 BFPD without overloading the gearbox, prime mover or rod string.

HOW DO FIBERGLASS SUCKER RODS REDUCE POLISHED ROD LOAD AND GEARBOX TORQUE?

An API 86 rod string, used with a 1.25" pump, weighs 2.035 pounds per foot. Bouyant rod weight in an 8,000-foot well is 14,917 pounds. The bouyant rod weight of a FSR string designed to produce the same amount of fluid is only 7,650. This is primarily due to the fact that FSRs weigh less than one-third that of steel rods. For example, a 1" FSR weighs .785 pounds per foot in air and a 1" steel rod weighs 2.904 pounds per foot in air. Due to the difference of the average denstiy of steel and fiberglass, the difference of the bouyant rod weight is much more pronounced. In fluid, with a specific gravity of 1.0, FSRs weigh .4 pounds per foot and steel rods weigh 2.56 pounds per foot. In this example, the fiberglass rod string consists of 5,600 feet of 1" FSR and 2,400 feet of 7/8" steel sucker rods. The peak polished rod load for the steel rod string design is 23,318 pounds and only 15,729 pounds with the fiberglass rod string. In a previous test, the peak polished rod load was reduced 33% from 18,921 pounds to 12,533 pounds, while increasing production 33% from 272 BFPD to 363 BFPD. See Table No. 3.

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 and rod loading. After replacing steel rods with lighter weight FSRs, the gearbox torque on one test well (Table No. 3) was reduced 37.8% while increasing production 33%. Gearbox torque is a function of polished rod load, torque factor and counterbalance moment. Since polished rod load is only one of the factors of gearbox torque, reducing the peak polished rod load will not necessarily reduce gearbox torque. Figure No. 2 shows a dynamometer card from a test well using steel rods and a Lufkin Mark II unit. The polished rod load is 16,327 poumds, but the card fits into the permissible load diagram without overloading the gearbox. After installing FSRs, the peak polished rod load decreased from 16,327 pounds to 14,002 pounds, but the shape of the dynamometer card does not permit it to fit into the permissible load range for this particular pumping unit without overloading the gearbox. The permissible load diagram for any comparably sized conventional pumping unit or air-balanced pumping unit would permit the dynamometer card to fit into the permissible load diagram without overloading the unit.

It is important to note that FSRs can work well with Mark II units, just as steel rods can work well with conventional and air-balanced units.

Tests indicate that use of FSRs generally can reduce torque requirements for new installations and can eliminate the need to buy larger pumping units for existing overloaded installations. Major pumping unit manufacturers are selling more pumping units with long stroke length capabilities with smaller gearboxes and smaller structure ratings. Table No. 4 shows a test well with a:

(1) 100% steel rod string

(2) 70% FSR and 30% steel rod string

(3) 60% FSR and 40% steel rod string.

By changing the rod string design from 100% steel to a combination of fiberglass and steel, the peak torque is reduced from 705,100 inch-pounds to 444,900 inch-pounds and 471,200 inch-pounds respectively. The polished rod load is reduced and the production is increased in both instances, but the pumping speed and pump bore size is unchanged. The increase in production comes from a longer downhole pump stroke as a result of rod overtravel. The horsepower requirements are also reduced.

CAN FIBERGLASS SUCKER RODS REDUCE ELECTRICAL COSTS?

Since the total weight of a typical rod string is reduced by up to 50%, the horsepower requirements and energy consumption are reduced accordingly. Energy consumption tests by a major oil company proved energy savings ranging from 26% to 39% per barrel produced. In one test well, the horsepower reduction was 25% while the fluid production increased by 36%. In a previous test, (Table No. 3) the power required increased 4.7 HP to lift an additional 91 BFPD from 300 feet deeper. In this instance it takes .0000243 HP per barrel of fluid per foot raised with steel rods, and it takes .0000201 HP per barrel of fluid per foot raised with FSRs. This is a 17% improvement in horsepower consumption.

ARE FIBERGLASS SUCKER RODS ECONOMICAL TO USE?

The costs to manufacture and market FSRs are higher than for steel rods, but by using the more expensive rods the operator can

(a) produce more fluid from deeper depths without overloading surface equipment,

(b) reduce energy costs, and

(c) use smaller surface equipment.

These benefits, derived from using FSRs, usually will justify the use of the more expensive rods. In addition, FSRs will have fewer rod parts, which mean less expense for fishing, and less downtime. Less downtime usually means more production.

CONCLUSIONS

Any new product introduced into the petroleum industry must have a period of field testing and adjustment before it is accepted as a viable tool by oil producers. The problems experienced by the users of the early fiberglass sucker rods no longer exist due to improved manufacturing processes and proper application techniques learned from field testing.

Many of the reasons given by oil producers for not using FSRs are no longer valid and many of the problems of producing oil could be eliminated if FSRs were utilized properly.

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Table 1

DEPTH	STROKE LENGTH	MAXIMUM S.P.M.
4,500 - 6,000	74	17
6,000 - 7,500	86	15
7,500 - 9,000	100	13.5
9,000 - 10,500	120	12.5
10,500 - 12,000	144	10.5
12,000 - 13,500	168	9
13,500 - 15,000	192	8
15,000 - 16,500	216	7
16,500 - 18,000	240	6

Table 2

	100 % Steel Rod String	70% Fiberglass 30% Steel	70% Fiberglass 30% Steel
Well Depth (ft.)	7,896	7,896	7,896
Peak Torque (in. lbs.)	430,300	289,700	290,800
Pumping Speed (SPM)	9.8	10.0	9.9
Min. HP Req'd (HP)	39.9	29.8	30.8
Peak Rod Load (lbs.)	25,060	14,868	16,851
Production (BFPD)	292	354	423
Pump Intake Pressure (psi)	1,700	1,700	1,700
Surface Stroke (in.)	120	120	120
Down Hole Pump Stroke (in.)	105.3	124.4	114.8
% Rod Loading	82.1	75.3	83.0
Pump Bore Size (in.)	1.75	1.75	2.0

Table 3

	100 % Steel Rod String	69% Fiberglass 31% Steel
Well Depth (ft.)	6,081	6,081
Peak Torque (in. lbs.)	417,100	257,600
Pumping Speed (SPM)	7.73	11.54
Min. HP Req'd (HP)	25.4	30.1
Peak Rod Load (lbs.)	18,921	12,533
Production (BFPD)	272	363
Pump Intake Pressure (psi)	977	847
Surface Stroke (in.)	121.0	121.0
Down Hole Pump Stroke (in.)	107.1	92.2
Pump Bore Size (in.)	1.75	1.75

Table 4

	100 % Steel Rod String	70% Fiberglass 30% Steel	60% Fiberglass 40% Steel
Well Depth (ft.)	8,000	8,000	[illegible],000
Peak Torque (in. lbs.)	705,100	444,900	471,200
Pumping Speed (SPM)	10.3	10.3	10.3
Min. HP Req'd (HP)	57.7	47.3	50.3
Peak Rod Load (lbs.)	26,077	15,729	17,709
Production (BFPD)	194	261	275
Pump Intake Pressure (psi)	100	100	100
Surface Stroke (in.)	145.9	145.9	145.9
Down Hole Pump Stroke (in.)	129.2	174.2	182.8
% Rod Loading	100.2	88.2	86.4
Pump Bore Size (in.)	1.25	1.25	1.25

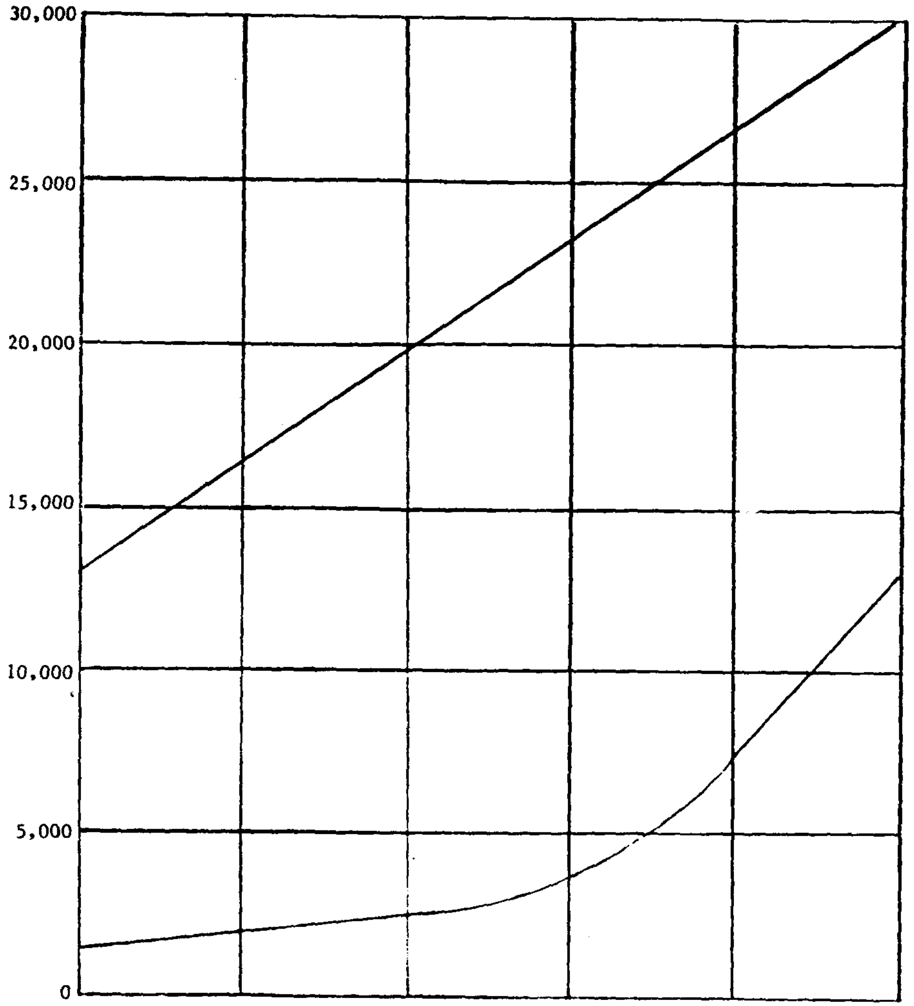

Figure 1 - Stress range diagram

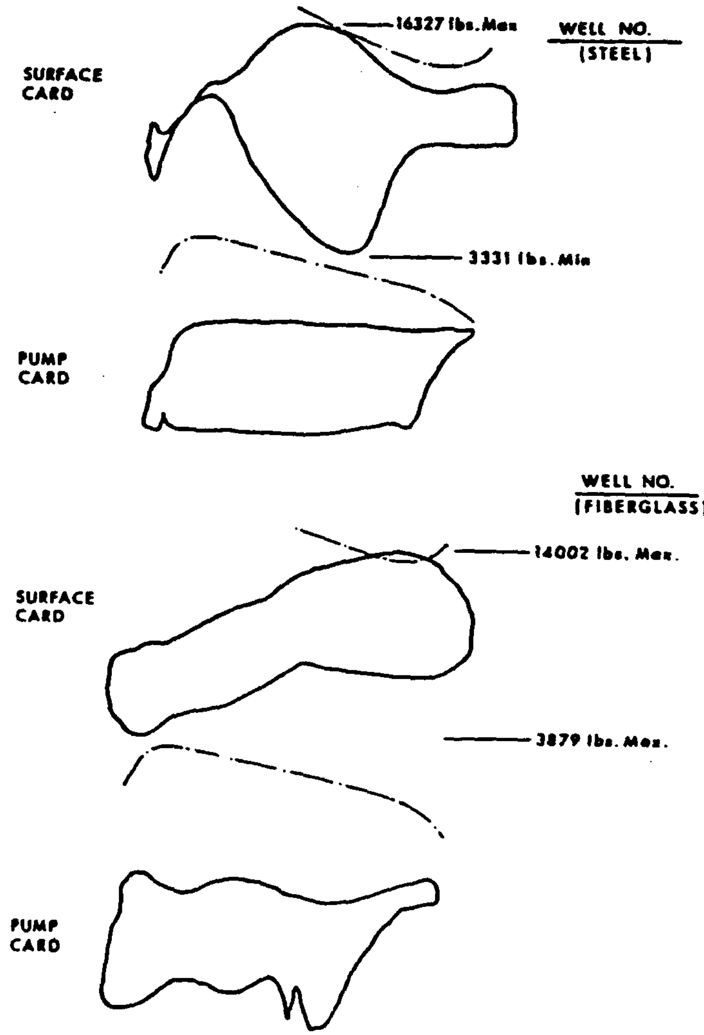

Figure 2