ABRASION RESISTANCE AND CORROSION PROTECTION FOR OIL PUMPING WELLS

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ABSTRACT

Abrasion and corrosion create costly problems in oil pumping wells. The cyclic action of the sucker rod string causes the rods, couplings and tubing to wear away. At the same time, they are being corroded away by the chemicals in the produced fluid. Eventually, the rods, couplings and tubing will fail and must be replaced. The resultant down-time to repair or replace the system is a great expense for the well operator.

Techniques to reduce down-time caused by abrasion and corrosion in oil pumping wells have been developed in recent years. These include the use of abrasion and corrosion resistant sucker rod couplings, coated sucker rods, coated tubing and rod guides. The use of these products, in combination with a reduced inhibition program, lowers the operating and maintenance costs for the wells. Sucker rod parts and holes in the tubing caused by abrasion and corrosion can virtually be eliminated.

Through laboratory simulation, the relative abrasion resistance of such systems can be shown. In a controlled study, mild steel sucker rod couplings were compared head-to-head with spraymetal couplings to assess their abrasion resistance on bare and coated tubing. In addition, bare and coated sucker rods were abraded against bare and coated tubing with and without lubrication. The stroking actions, stresses and time were held constant for all comparisons. The amount of wear was determined by measurements before and after each test. Through this test matrix, it was shown conclusively that losses due to abrasion could be reduced significantly through the use of spraymetal couplings, spraymetal-plastic coated rods and coated tubing.

In a related study, the coatings were evaluated in a high temperature, high pressure autoclave environment simulating down-hole conditions. Even at temperatures and pressures in excess of expected working conditions, no corrosive attack occurred. The coatings showed no evidence of blistering, swelling or disbonding. From this test series, it was concluded that the specially formulated coatings would withstand the chemical attack of the produced fluids.

The laboratory experiments have been confirmed, down-hole, in oil pumping wells. Through thousands of installations, the cost savings attributable to reduced abrasion and freedom from chemical attack have been proven. Operating and maintenance costs have been reduced in excess of thirty percent on average. In critical, highly deviated wells, which had a history of frequent rod parts and holes in the tubing, these systems have performed successfully for years. A survey of some of the major users of this approach has confirmed that a quick return on the initial investment can be realized. In some cases, the use of this approach is the standard operating procedure for all pumping units.

INTRODUCTION

Losses due to abrasion represent a considerable expense for the operators of oil pumping wells. Once sufficient abrasion has occurred, the sucker rod string will break under its own weight and the tubing string will have holes in it. The rods and tubing must be pulled, inspected, and replaced. The combination of pulling unit costs and production down-time takes money out of the unit operator's pocket. These losses are magnified in wells with improper sucker rod string designs and in highly deviated wells. In any pumping well, the amount of abrasion is governed by:

- Cyclic speed of the pumping unit
- Straightness of the hole
- Fluid environment present
- Abrasion resistance measures taken

In addition to the loss of metal due to abrasion, corrosion contributes to the problem. Un-protected metal will eventually corrode, causing sucker rod string parts and holes in the tubing. The rate at which corrosion will cause pumping well failure is governed by the amount of:

- Dissolved salts
- Dissolved gases
- Fluid production

The effects of corrosion are magnified by dissolved gases like hydrogen sulfide (H_2S) and carbon dioxide (CO_2). The presence of dissolved salts (like sodium chloride) will also accelerate corrosion. While corrosion has always been a problem in oil pumping wells, the coming of CO_2 floods will add significantly to this problem. Catastrophic failures can be expected on the producing side.

Currently, most tubing on the producing side is internally bare. The steel sucker rods are also bare. Only inhibitors stand between successful pumping unit operations and certain failure due to corrosion. The use of inhibitors is a big expense for pumping well operators.

In the last few years, more emphasis has been placed upon abrasion resistance and corrosion protection for oil pumping wells. The well operators grew tired of wasting their money. Many have determined that techniques are available to solve these problems. The use of such systems requires a higher initial investment, but the money is returned many times through the reduction or elimination of down-time. The best approach to abrasion resistance and corrosion protection includes the use of:

- Spraymetal and plastic coated steel sucker rods
- Spraymetal sucker rod couplings
- Internally coated tubing
- Sucker rod guides

Millions of dollars have been saved by pioneering oil companies which have tested and adopted these approaches. Others are understandably hesitant to use the more expensive systems, considering the lack of scientific data regarding the relative abrasion and corrosion resistance properties of these new systems.

Most pumping unit operators wish to be convinced with field performance data, before adopting these new approaches. To satisfy these requirements, our research was done. Our evaluation program included the following steps:

Abrasion resistance tests in the laboratory

- Spraymetal plastic coated rods versus bare steel sucker rods
- Spraymetal versus mild steel sucker rod couplings
- Internally coated versus bare tubing

Corrosion resistance tests in an autoclave

- Sucker rod coating
- Internal pipe coatings

Field performance data

- Spraymetal/Plastic coated rods
- Plastic coated rods
- Internally coated tubing

ABRASION RESISTANCE TESTS

The relative abrasion resistance properties of sucker rods, rod couplings, and tubing can easily be documented in the laboratory through simulation testing. In order to obtain the maximum benefit from such testing, all variables should be compared "head-to-head" under conditions which closely simulate, if not duplicate, the actual field conditions.

To simulate the abrasion in a pumping well, an abrasion tester was constructed. (See Drawing No. 1) This tester evaluates two samples simultaneously. Either couplings or rods can be abraded against tubing on this test equipment. The tests can be run with or without lubrication. Both test samples have the same weight applied above them to accelerate the effects of abrasion. During each test, the test samples were abraded back and forth, in a two inch stroke, across the tubing. For the tests, sucker rods were abraded at 60 strokes per minute, while couplings were evaluated at 80 strokes per minute. The test duration was 24 hours, even, for each set of samples, giving all comperable samples the same number of strokes. All samples were measured before and after the tests using a micrometer or ferromagnetic film thickness gauge. Color photographs were taken to further document the test results.

Spraymetal/Plastic Coated Versus Mild Steel Sucker Rods

For this series of tests, small sections were cut out of SC-750 coated sucker rods. To determine the effect of the spraymetal and the plastic coatings, bare rods were also evaluated, in addition to plain rods which had the wax-based inhibitor removed. In addition to abrading these rods on bare tubing, they were abraded against tubing which had been internally plastic coated with two types of fusion bond applied, oilfield tubular coatings: SC-650 Epoxy and SC-850 Cresol-Novolac. For the results of these tests, please see Table No. 1.

As shown in Table No. 1, the most abrasion loss occurred when bare rods were abraded against bare tubing. The presence of a wax-based amine-type inhibitor reduced the abrasion considerably. It must be kept in mind, however, that through time, the wax will be worn away, leaving a bare rod, in-service. The least amount of loss due to abrasion occurred when SC-750 coated rods were abraded against internally coated tubing. The SC-650 Epoxy and the SC-850 Cresol-Novolac on the tubing not only reduced the abrasion losses, but provided a corrosion resistant barrier at the same time. The SC-750 coating on the sucker rods did likewise.

Spraymetal Versus Mild Steel Sucker Rod Couplings

In order to compare Spraymetal (stainless steel) couplings to plain, mild steel couplings, random samples of each were chosen. For the tests, the entire coupling was attached to the abrasion tester, such that only one side was exposed to the tubing. All couplings had bevelled edges to prevent gouging of the tubing. (Some inferior quality spraymetal couplings do not have a bevel on the ends. These will cut the tubing. For our tests, high quality, bevelled couplings, which are commercially available, were used.)

For twenty-four hours, under twenty pounds of load, a Spraymetal coupling was compared, head-to-head, versus a plain, mild steel coupling. Each was evaluated on bare and coated tubing, with and without lubrication. Please refer to Table No. 2 for the results of these tests.

This test series showed the same relationships as the sucker rod abrasion tests. The most loss due to abrasion occurred when mild steel rod couplings were abraded against bare, mild steel tubing. This confirms the belief that metals of similar hardness abrade one another, while metals of dissimilar hardness polish one another. Mild steel has a Moh Hardness of 4.5 to 6.0, while Spraymetal is 6.5 to 8.0.

Couplings which were abraded against internally coated tubing showed much less loss due to abrasion. The corresponding tubing samples also showed less wear. Decreased abrasion was brought about due to the hardness of the filler pigments which comprise about one-half of the coating formulas. These filler pigments have a Moh Hardness of 8.0 to 9.5. They will wear away the steel, before the steel will wear them away. These fusion bond applied powder coatings are not to be confused with the thin film, liquid applied coatings which are also used in the oilfield. The thin film coatings have a much lower filler level in them (generally less than 25% of the total formula). These are applied at 5-8 mils while fusion bonded powder coatings are applied at two to three times this thickness.

From these series of tests, we note that greater resistance to abrasion can be achieved through the use of Spraymetal/Plastic Coated Rods and Internally Coated Tubing. This resistance to abrasion will translate into dollars of decreased well maintenance and more freedom from pumping unit down-time.

CORROSION RESISTANCE TESTS

Even though these coatings provide resistance to abrasion, they will be of no value, in-service if they are not resistant to the effects of chemical attack. If the down-hole environment causes the coatings to blister, soften, disbond, or dissolve, they will not provide the required abrasion resistance. In order to show the effects of the down-hole chemistry upon these coatings, a high pressure, high temperature autoclave was used. Samples were carefully measured before all tests. After completion of these tests, each sample was re-evaluated. Test conditions which are much more severe than those encountered down-hole, were used to accelerate these tests. The chemical environments were intentionally harsh, but chosen to simulate down-hole conditions. (See Drawing No. 2 for a description of the autoclave test vessel.)

First of all, the sucker rod coating, SC-750, was evaluated. The autoclave test conditions were, as follows, for this modified-epoxy coating:

SC-750 Autoclave Test Conditions

Variable	Value
Time	24 Hours
Temperature	250°F
Pressure	6500 p.s.i.
Immersion	1/3 in each phase
Phases:	
1. Gas	A. 50%, CO_2
	B. 50%, CH_4
	C. 50 p.p.m., H_2S
2. Hydrocarbon	A. 50%, Kerosene
	B. 50%, Toluene
3. Aqueous	A. 95%, Tap water
	B. 5%, Sodium Chloride
Decompression	At 160-180°F

After exposure to these very harsh conditions, SC-750 did not show any swelling, blistering, or disbonding. Although the presence of hydrogen sulfide (H_2S) did cause a change in color (beige to light grey) of the coated rod, the chemical resistance properties remained un-changed. The coating was still hard, yet flexible, and had an excellent bond to the sucker rod. Another, inferior grade of fusion bond applied coating, run in the same test showed severe blistering, swelling, and disbonding. Care must be taken when selecting a sucker rod coating. SC-750, a modified-epoxy, was specially formulated for sucker rod applications.

Next, SC-650, a bis-phenol-A-epoxy coating, designed for down-hole injection tubing was evaluated in an autoclave. This is also a thick-film, fusion bond applied powder coating. It is commonly used to protect the internal diameter of injection tubing and to withstand the effects of brackish, produced water. As shown in the following autoclave test, it is also resistant to the effects of hydrocarbons and corrosive gases.

SC-650 Autoclave Test Conditions	
Variable	Value
Time	24 Hours
Temperature	300°F
Pressure	3000 p.s.i.
Immersion	1/3 in each phase
Phases:	
1. Gas	A. 90%, CH_4
	B. 10%, CO_2
	C. 50 p.p.m., H_2S
2. Hydrocarbon	A. 50%, Kerosene
	B. 50%, Toluene
3. Aqueous	A. 95%, Tap water
	B. 5%, Sodium Chloride
Decompression	At 160-180°F

SC-650 showed no blistering, swelling, or loss of adhesion after exposure to these severe test conditions. It was still bonded tightly to the pipe. The color change (beige to grey), caused by the hydrogen sulfide, did not adversely affect the chemical resistance properties of the coating.

The last coating in this series to be tested was the SC-850. This coating was formulated to protect the internal diameter of tubing and line pipe from the harsh effects of carbon dioxide (CO_2), mixed with water. Like the other coatings in these tests, it is a fusion bond applied, thick film coating. Unlike the other coatings, however, it is based upon a new generation of resin chemistry: Epoxidized-cresol-novolac. This resin can endure a wide range of temperatures, in-service, and a wide range in pH environments (acidic to basic). It was evaluated in the following autoclave test:

SC-850 Autoclave Test Conditions	
Variable	Value
Time	6 Days (6 each, 24 Hour Cycles)
Temperature	225°F
Pressure	4000 p.s.i.
Phases:	
Days 1, 3, and 5	
Aqueous	A. 95%, Tap water
	B. 5%, Sodium Chloride
Gas	A. 50%, CH_4
	B. 49%, CO_2
	C. 1%, H_2S
Days 2, 4 and 6	
Gas	100%, CO_2
Decompression	At 160-180°F

This test was designed to simulate the harsh effects of a water alternating gas (WAG) well operation. The extremely harsh cycles will destroy most coatings after one or two cycles. In this test series, SC-850 showed no disbonding, blistering, or swelling. There was also no decrease in adhesion. With the exception of a slight darkening in color, caused by the hydrogen sulfide (H_2S), the SC-850 looked as good after the test, as it did before.

Through these autoclave tests, and dozens more of a varied nature, all of these coatings have domonstrated that they will withstand the corrosive attack of down-hole oilfield environments. In addition, all have been used successfully for many years, in other, similar applications in the oilfield.

The corrosion resistance properties of stainless steel are well known. No attempt was made to evaluate the chemical resistance of the stainless steel which is used for the Spraymetal couplings or rods. Basically, the properties of the stainless steel on the rods falls between 302 SS and 304 SS. The grade of stainless steel on the couplings exceeds 316 SS, falling in the chemical resistance class of a ceramic. After years of down-hole service, there has never been a reported corrosion failure which was attributable to the lack of chemical resistance of the stainless steels used for our rods or couplings.

FIELD PERFORMANCE

Many major oil companies are now using abrasion and corrosion resistant systems for their rod pumping wells. In some cases, only partial protection was required. In other cases involving "problem" wells, the optimum methods for protection were used. The latter includes the use of Spraymetal Couplings, Spraymetal/Plastic Coated Rods, Rod Guides, and Internally coated tubing. (Refer to Drawing No. 3) Whenever such approaches were used, the oil companies reduced their pulling unit costs and down-time. The following examples describe various approaches used by major oil companies, to minimize their abrasion and corrosion problems in rod pumping wells. (The inclusion of these examples is not meant as endorsement of our Company's products, but is offered in support of laboratory data regarding abrasion and corrosion resistance of these systems, and how these translate into a longer service life for the rod pumping well.)

A lot of the testing of Spraymetal/Plastic Coated sucker rods was done in the Mean's Field in Andrews, Texas. After a test period of one year, the oil company reported a decrease in pulling unit costs, in excess of 70%. Sucker rod replacement was decreased in excess of 90%. The total number of sucker rod parts was decreased by over 80%. While some of this savings was attributable to the fact that these were new rods, most of the savings was due to the abrasion and corrosion resistant nature of the system which was used. This oil company uses Spraymetal/Plastic Coated Rods, Spraymetal Couplings, Rod Guides when absolutely necessary, and Internally Bare tubing. Since 1980, over 2,000,000 feet of Spraymetal/Plastic Coated Rods have been used in the surrounding area, by this major oil company. This includes over 500 separate installations. Because of these successes, this oil company plans to expand the use of this approach to their Fullerton Unit and their CO_2 Flood at the Cornell Unit in Denver City, Texas.

Another pioneering oil company did not feel that the additional abrasion resistance of Spraymetal was required for the rods. They chose to use "Plastic Coated-Only" sucker rods. This coating is the same, modified-epoxy, that is used over Spraymetal rods.

The only difference is that no Spraymetal jacket is around the mild steel rod. For this study in the Odessa area, eleven new wells were selected. For the twelve months before switching to coated rods, these eleven wells had experienced 64 rod failures and 31 tubing leaks. All of these rod strings were pulled and replaced with Plastic Coated Rods and Spraymetal Couplings. In the first twelve months after installation, these pumping wells showed only 15 failures: Five of the failures were rod parts and ten were tubing leaks. All of the rod failures were at the rod boxes. These probably occurred because of the rods slapping against the tubing and the couplings un-screwing enough to break. With these successes, the oil company plans to expand their use of the Plastic Coated Rods and Spraymetal Couplings.

Still another major oil company operating in the Goldsmith, Texas area, evaluated bare versus Spraymetal/Plastic Coated sucker rods in 19 wells, This company, because of the severe abrasion problem, needed the additional protection of the Spraymetal jacket on the sucker rods. They also used Spraymetal couplings. Their tubing strings were internally bare. For these wells, before conversion to Spraymetal, 645 combined months of rod performance was available. Table No. 3 shows the performance of the bare rods versus the Spraymetal/Plastic Coated rods.

In yet another study, a major oil company, operating in the Permian Basin evaluated "Plastic Coated-Only" rods and Spraymetal couplings, in conjunction with SC-650 internally coated tubing. They reported that during the 18 month test period, they had reduced their well maintenance costs in excess of 30%, due to a reduction in abrasion and corrosion.

An oil company, operating in the SACROC Basin has chosen to use Spraymetal/Plastic Coated sucker rods and Spraymetal couplings for another application: Added weight at the bottom of fiberglass sucker rod strings. The great expense of sinker bars limits their use. It is more economical to use steel sucker rods for the necessary weight to get the fiberglass rods to fall properly on the down-stroke of the pumping unit. Because of the highly corrosive nature of the CO_2, a corrosion resistant system must be used. This company uses the Spraymetal/Plastic Coated steel sucker rods and Spraymetal/Coated sinker bars at the bottom of each fiberglass rod strings. Rods and sinker bars weighing 3000-3600 lbs. are used for each well. The oil company has reported that this approach is working very well. The Spraymetal/Plastic Coated rods and sinker bars are at a location in each well where the most abrasion and corrosion occur.

These are just a few of the many examples which demonstrate the abrasion and corrosion resistance properties of the Spraymetal and Plastic Coatings approach for rod pumping wells. As the word of there successes spread throughout the industry, the use of such systems will increase dramatically. In addition to combatting abrasion and corrosion, this approach offers a more consistent and reproducible approach to sucker rod string design, than fiberglass rods.

SUMMARY

Through laboratory simulation testing, we have shown that metals of similar hardness abrade one another, while metals of dissimilar hardness polish one another. We have also shown that it is possible to formulate thick-film, fusion bond coatings which have the necessary properties to provide corrosion and abrasion resistance for oil pumping wells. Taken from the laboratory and put into down-hole service, the Spraymetal and Plastic Coatings approach has demonstrated its utility. The higher initial investment for these systems is returned many times through freedom from pulling unit costs and pumping unit down-time. This translates into decreased lifting costs for the well operator. As the producing side of the oilfield becomes more corrosive, due to an increase in dissolved gases such as CO_2 and H_2S, measures must be taken to preclude well failures. At the same time, abrasion resistant systems must be used. The systems described in this paper provide the necessary protection for the future.

Table No. 1

Rod Abrasion Test Results

Lubrication	Rod Protection	Tubing Protection	Loss Due to Abrasion (Mils)	
			Rods	Tubing
No	Bare	Bare	26.0	33.0
No	Inhibitor	Bare	6.3	0.7
No	SC-750	Bare	5.7	0.3
No	Inhibitor	SC-650	1.7	3.3
No	SC-750	SC-650	0	2.3
No	Inhibitor	SC-850	5.7	2.0
No	SC-750	SC-850	2.3	3.7
Yes	Inhibitor	Bare	5.0	4.7
Yes	SC-750	Bare	1.0	1.0
Yes	Inhibitor	SC-650	4.3	4.7
Yes	SC-750	SC-650	0	2.7
Yes	Inhibitor	SC-850	7.7	6.7
Yes	SC-750	SC-850	0.7	2.3

Lubrication used = Produced fluid

Table No. 2

Coupling Abrasion Test Results

Lubrication	Coupling	Tubing Protection	Loss Due to Abrasion (Mils)	
			Coupling	Tubing
No	Plain	Bare	30.5	30.0
No	Spraymetal	Bare	0	6.5
No	Plain	SC-650	2.0	0.5
No	Spraymetal	SC-650	0.5	1.5
No	Plain	SC-850	3.0	+1.0
No	Spraymetal	SC-850	0.0	+1.5
Yes	Plain	Bare	0.5	1.0
Yes	Spraymetal	Bare	0	1.0
Yes	Plain	SC-650	0.5	0
Yes	Spraymetal	SC-650	0	0
Yes	Plain	SC-850	0.5	0
Yes	Spraymetal	SC-850	0	0

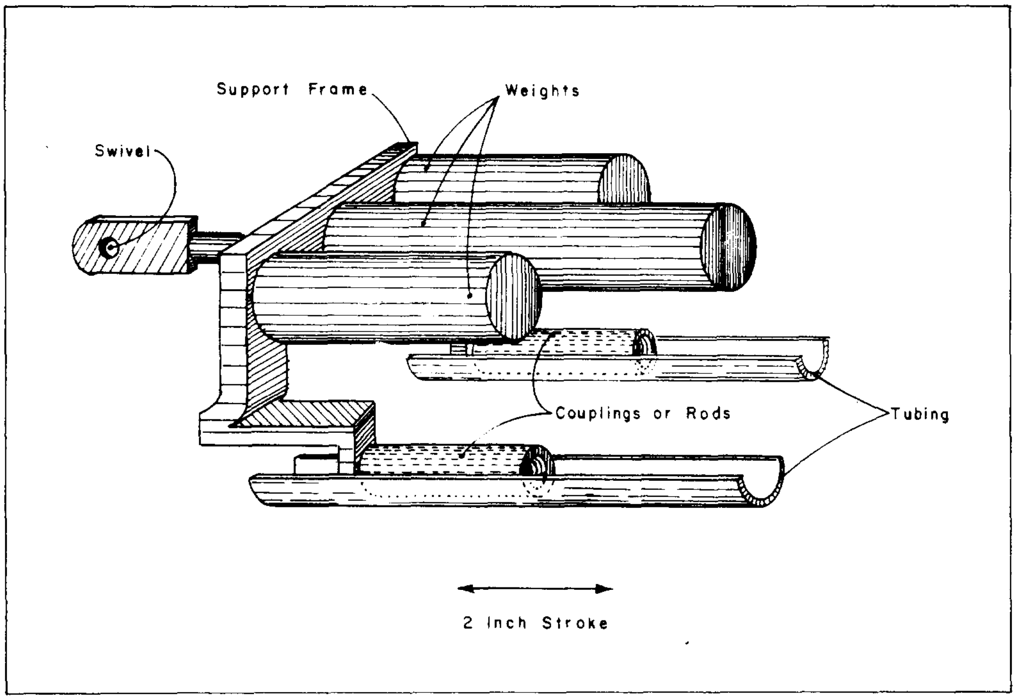
Lubrication used = Produced fluid

Table No. 3

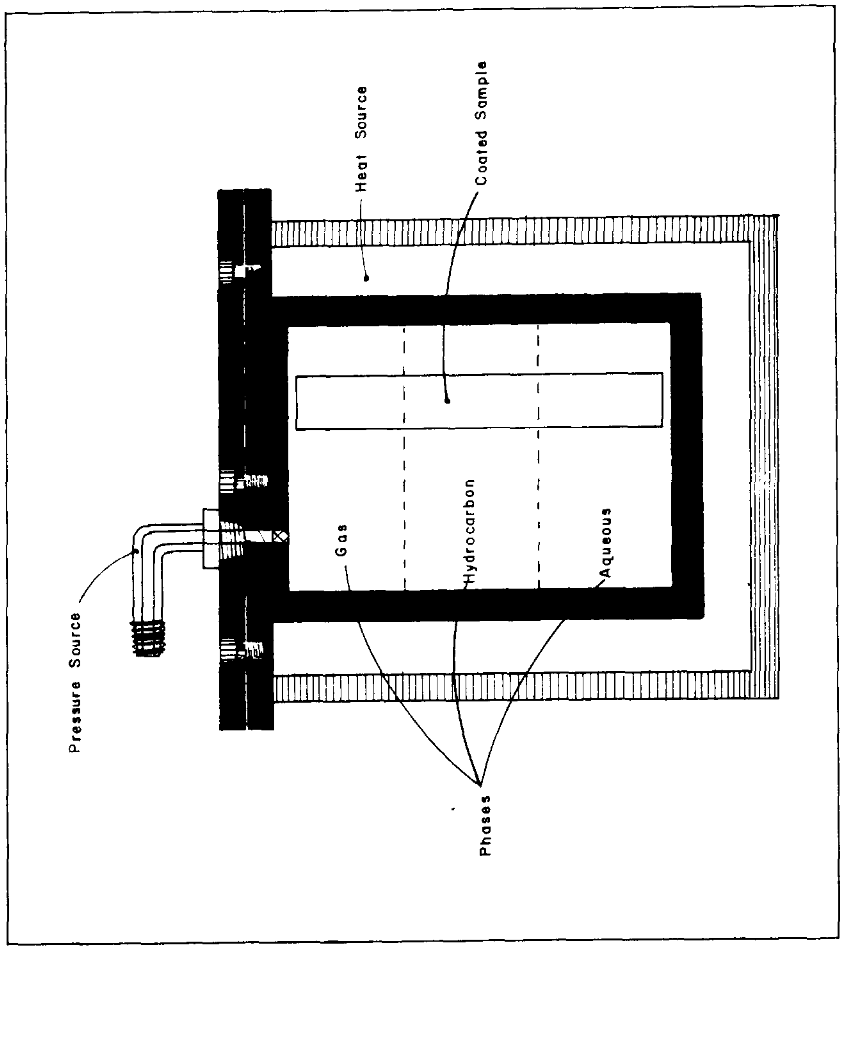
Bare Versus Spraymetal/Plastic Coated Sucker Rods

(Field Evaluation - Goldsmith Area)

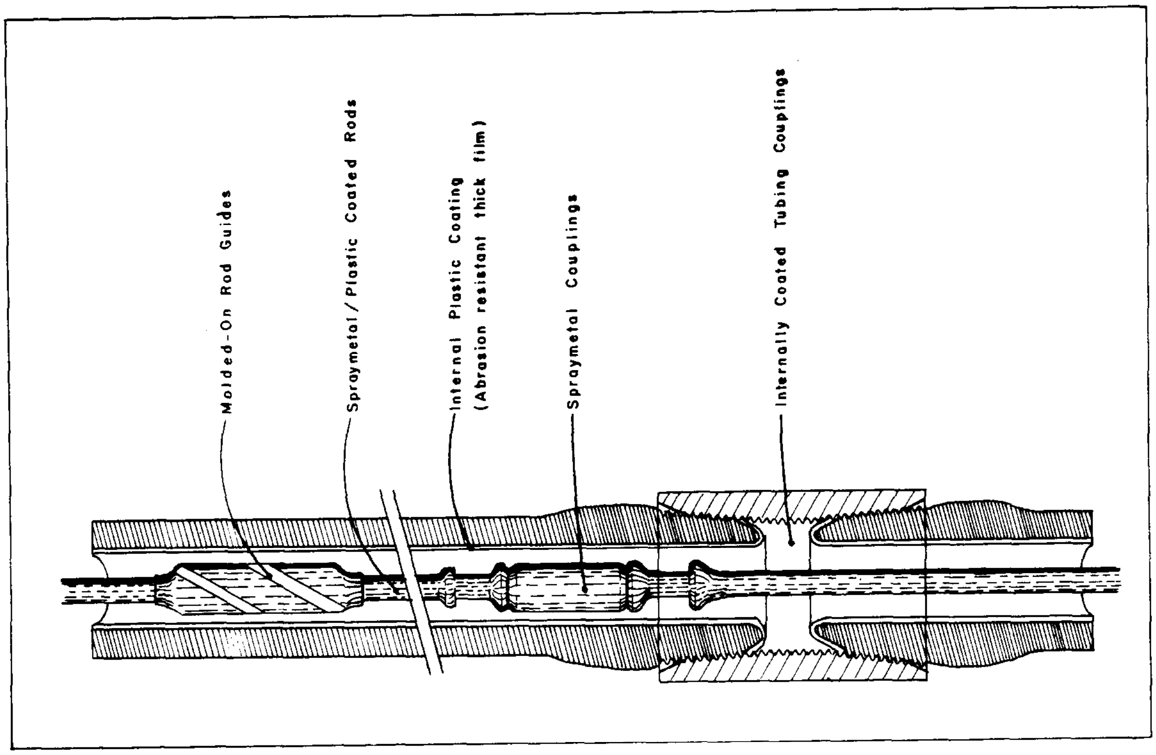
Well No.	Bare Rods Months	Bare Rods Rod Breaks	Spraymetal Rods Months	Spraymetal Rods Rod Breaks
1	37	9	17	0
2	0	0	7	0
3	38	13	16	0
4	30	6	18	0
5	32	13	23	0
6	33	10	21	0
7	39	17	16	0
8	30	8	24	0
9	32	6	22	1
10	30	12	24	0
11	31	12	22	0
12	24	16	30	0
13	34	12	19	0
14	32	3	22	0
15	33	12	21	1
16	33	11	21	0
17	50	18	4	1
18	54	12	0	0
19	53	17	1	0
Total	645	207	328	3
Breaks/Op. Month	0.3209		0.0091	
Rod Break Frequency	4.9 Days		173.5 Days	



Drawing No. 1 - Abrasion tester



Drawing No. 2 - Autoclave test



Drawing No. 3 - Abrasion resistance and corrosion protection for oil pumping wells