A PRACTICAL AND ECONOMICAL APPROACH TO SELECTION, HANDLING, AND PROTECTION OF DOWNHOLE EQUIPMENT*

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INTRODUCTION

Early in 1970 all available pre-1970 subsurface equipment failure data contained in the data banks of Atlantic Richfield's Equipment Performance System were analyzed. Assuming no changes in operations or in failure patterns, it was predicted that in the year 1970:

1. Corrosion and/or equipment mishandling would be the cause of 73% of all subsurfacd equipment failures.
2. Rod failures would account for about 40% of all subsurface failures.
3. About 60% of all rod failures would be rod-body and about 40% pin or coupling failures.

Supervisory production personnel realized that considerable improvements in profitability could be achieved by reducing handling-caused failures and by implementing effective corrosion control programs. They also realized that attempts to control corrosion and handling-caused failures have to be initiated and carried out by personnel responsible for day-to-day operations and that these individuals should, therefore, have the knowledge and the tools to carry out this task of subsurface failure control. This task requires the necessary knowledge to determine causes of failures, available courses of action, and the economic feasibility of carrying out these courses of action.

At the request of these production personnel, a short course was prepared to satisfy these needs. The subject matter was slanted toward rod failure control. It was reasoned that it was economically practical to avoid rod handling-caused failures and that corrosion control of rod failures would benefit other items of subsurface and surface equipment.

This presentation condenses the short course. In sharing our approach with the oil industry, we hope for comments and suggestions to improve this approach.

SUMMARY OF THE CONTENTS OF THE FAILURE CONTROL SHORT COURSE

In the following sections we will present an outline of the subject matter covered by the course. Texts of the covered material exist but are too detailed to be included here.

General Outline

The course consisted of three distinct and separate sections.

1. Care, handling, and selection of subsurface materials and equipment—this section was presented in about two hours.
2. Corrosion problems and corrosion control—this section also lasted for about two hours.
3. The economics of failure control—this section lasted for about thirty minutes.

These were preceded by a short introduction during which the Company-wide economic stakes associated with failure control were spelled out.

Photographic aids were used in abundance throughout the sessions. Handouts were supplied—API "Recommended Practice for Care and Handling of Sucker Rods"[2] (API RP11BR) and an analysis of subsurface failure data for the particular producing area where the meeting was being held. This analysis served to set profitability goals which were attainable in the near future.

Throughout the meeting, samples of failed

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equipment were passed around, and mode and cause of these failures were discussed.

Care, Handling, and Selection of Subsurface Equipment and Material

There are only a few basic causes for failure of sucker rods or boxes, and identifying these is the first step in preventing future failures.

Rod and box failures can be classified simply as due to wear, corrosion, mechanical causes, or mishandling. There are, of course, plenty of cases where two or more of the basic causes are present.

Tension - The simplest mechanical failure is that due to tension when pull, as in trying to free a stuck pump, exceeds the tensile strength of the rod. Failure usually assumes the form of a necked-down area with final failure surface at a 45° angle to the axis. Figure 1 shows an example of this type of failure.

FIG. 1—TENSILE FAILURE

Wear - Wear is simply the removal of metal by frictional rubbing against other metal. It can be serious, particularly in crooked or deviated wells. The softer metal, naturally, is the one that suffers. If we try to prevent coupling wear by using a hardened box, all we have accomplished is a change in location of wear from the coupling to the tubing wall. A better approach is the use of soft rod guides or centralizers which will keep the box or the rod body from contacting the tubing wall. Another help is the use of rod rotators to distribute the box wear evenly.

If an oil film can be maintained between box and tubing wall, enough lubrication can be obtained to reduce friction. Corrosion inhibitors cause the tubing and rods to become oil-wet, and they provide such an oil layer. There are other advantages to the use of corrosion inhibitors. This subject will be discussed later.

In some cases it is almost essential to use hard-banded couplings, but it must be kept in mind that they can cause serious tubing wear, particularly in wells with very high water-cut.

Corrosion - Wherever oil is produced, eventually some water is produced along with it. Water and the various compounds it carries in solution will eventually dissolve almost everything it contacts. This dissolving action is the undesirable and expensive thing known as corrosion.

Corrosion attack on rods can sometimes take the form of general metal loss (see Fig. 2) which removes enough body material so that the remaining steel simply will not support the design loads. Rods then part from simple tensile failure. To control corrosion-caused failures, corrosion inhibitors, not corrosion-resistant materials, should be the first solution attempted.

FIG. 2—GENERAL CORROSION

On the subject of corrosion-resistant rod materials, almost every sucker rod manufacturer makes at least one rod outside the API Standards for which he claims corrosion-resistant properties. To have any real resistance to corrosion, an alloy must contain at least eight to nine percent of nickel or chromium; and even then these alloys are subject to pitting in salt water. This much alloy content doubles or triples the cost of the rods without a corresponding increase in their service life.

Equal or better corrosion protection can usually be obtained by proper selection of chemical inhibitors and at a lower cost. Since inhibitors must be used in corrosive wells to protect the pumps and tubing, it is only common sense to use the least expensive rod that will do the job and to let the same inhibitor furnish protection for the rod string. This is why we have standardized on the carbon-manganese, API Class C or D sucker rod. It takes a very unusual set of conditions to require or justify the use of any other rod material.

The choice of the Class C rod as standard was based on an extensive series of comparative "mixed-string" tests where rods are compared by running various types alternately in the same string. In these tests two or more types of rods are run in alternating sequence for the entire length of the string. When a rod fails, it is replaced by one of the other types, never by the same type. In this way positional effects can be distinguished and allowed for. Theoretically, if the test is run long enough, all the inferior rods will have failed and will have been replaced by the best type leaving an entire string made up of the superior rod. This extensive test is not economically sound so the test is arbitrarily limited to a definite number of failures or a definite time limit.

In a classic test of this kind, Class C (carbon-manganese), Class K (nickel-moly), and intermediate alloy rods were compared in a highly corrosive well in the Bloomer Field, Kansas. The test well was inhibited through the life of the test. At the end of a year, 14 rod-body breaks had been experienced. Of these, nine were in Class K rods, four in the intermediate alloy rods, and only one in Class C. Pitting attack in the alloy rods, even with inhibition, was responsible for the results.

In another test in the South Ward Field, Texas, Class C, Class K, and nickel-chromium alloy rods were compared. In 14 months, seven rod breaks occurred: three in the Class K, two in the nickel-chromium, and two in the Class C rods.

All tests conducted showed the same fact—if effective inhibitors are applied properly, the cheapest available rod will do the job.

Far more common than uniform attack is the form of attack known as pitting corrosion. In this case attack occurs on separated, relatively small areas scattered along the rod-body such as shown in Fig. 3. Pits grow with time until they may eventually grow together. Often the pits do not have time to cause this type of failure since they can bring about accelerated failure through a combination of corrosion and the fatigue effects due to the cyclic nature of the loading. This type of failure combining pitting corrosion and fatigue will be discussed later.

Fatigue - Any metal under cyclic stress has an endurance limit which is lower than its strength under static load. As load decreases, the number of cycles to failure increases until at some load the number of cycles to failure becomes so large that

FIG. 3—PITTING CORROSION

we need not fear failure. This stress is called the endurance limit. The endurance limit is lowered when the metal is immersed in fresh water; it is lowered still further in salt water. In addition, the range of stress plays a big part in fatigue. At high loads a very narrow stress range can cause failure, while at low loading the range can be fairly wide.

By using the Modified Goodman Diagram shown in Fig. 4 (and also on page 8 of API RP11BR[2]), we can better understand the relationship between load and range of stress.

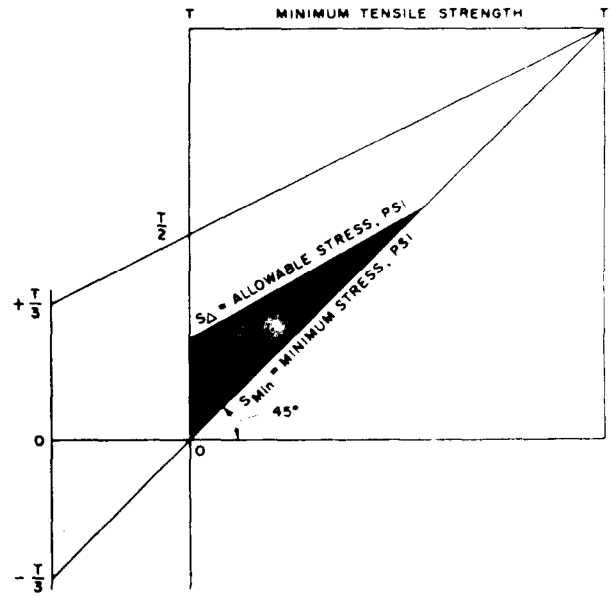

FIG. 4—MODIFIED GOODMAN DIAGRAM

In pumping, the rod string should not be put into compression because of column buckling so that the Modified Goodman Diagram in Fig. 4 cuts off at neutral rather than reversed stress. Also, yield strength should not be exceeded so that the upper boundary of the shaded portion cutting off at about 60% of ultimate strength is used. In the left hand portion of the diagram where maximum stress is only half the tensile stress, it is possible to operate safely through the range of maximum to zero; but, as the yield stress is approached, the range narrows down so that there is no safety margin at that point. It is, therefore, necessary to determine the maximum allowable loading on the basis of calculated or measured minimum load in order to operate in the safe range. This is why, when failures appear to be caused by pure fatigue, it pays to run dynamometer checks on range of load. Some change in pumping operation, maybe stroke length or speed or both, can restore the load to safe load range without cutting production.

Pure fatigue failures are most common at a change in cross-section at the first point of uniformly small cross section. In a rod, this point is where the upset or heavy section tapers into the rod body. The heavy section is more rigid, and all flexing takes place at the end of the runout in the smaller diameter body adding to the cyclic loads.

Properly balanced rod string design is the only solution to pure fatigue in rod bodies.

Fatigue failures also occur in pins and boxes, but this subject will be discussed as a separate topic.

Corrosion-Fatigue - It was said earlier that corrosion often takes the form of pitting attack. The pits will vary in form with different corrodents and in different metals. Carbon steel usually loses metal in broad, deep areas. The loss may not be as serious, in spite of its bad appearance, as pitting attack on alloy steels which is sometimes hard to see. On API Class K rods in particular, pitting occurs as pinhead-sized attack with almost pointed bottoms.

In this connection it is worth going a little deeper into the history of the Class K or nickel-moly rod. In 1935 the *Trans. of AIME* carried a report on work done by B. B. Wescott and C. N. Bowers on "Economical Selection of Sucker Rods."[3] This was followed by a later report by Wescott (in 1938).[4] These reports contained a table showing endurance limits of various metals and alloys operating in a variety of environments. The highest endurance limits in both sweet and sour oilfield brine were indicated for AISI 4615 and AISI 4820 steels, the 1.75% Ni-.25% Mo and 3.50% Ni-.25% Mo alloys. Since corrosion fatigue was a real problem, all of the rod manufacturers started manufacturing Ni-Mo rods.

However, one very important factor was not taken into consideration in interpreting the data presented by Wescott and Bowers. Their data were obtained from tests run on a conventional beam fatigue test machine at 1750 cycles per minute through the full range from compression to tension for 10 million cycles. At 1750 cpm it takes only four days to run through ten million cycles. At twenty strokes per minute a sucker rod takes 347 days to reach ten million cycles. The point of all this, of course, is that any new rod requires a finite time to start corroding; four days is hardly long enough for pitting to become a significant factor in an environmental fatigue test. Also, it is the pitting that prevents the API Class K rod from being the hoped-for cure to the corrosion fatigue problem. Wescott later acknowledged this disparity.

The manufacturers traditionally have liked the API Class K rod for several reasons. The alloy content gives them a steel whose physical properties are easily and uniformly controlled by heat treatment; a higher price can be obtained on the basis of alloy content; Wescott's original report[3] can be construed to be a recommendation. We have yet to see an authenticated, clear-cut case of meaningful rod life extension even where inhibitors are used.

Pitting corrosion brings in a factor known as stress-concentration. Fatigue cracks usually start at local stress-raisers. The sharper the radius at the bottom of a pit or nick, the higher the stress-concentration factor. With a nick into the rod surface whose root-radius is one-fifth of its depth and two percent or less of the rod diameter, the stress at the root of the nick is three and one-half times as high as on the adjacent smooth surface. Therefore, it is possible for a rod string operating under safe load to have localized areas operating far above endurance limit. Naturally, fatigue will occur first at these highly stressed points, and cracks will begin to move through the rod.

Once a crack starts, the tip of the crack is even sharper than the orginal pit bottom making the stress-concentration situation worse. Then, too, the crack opens up on the load stroke letting in well fluids which corrode the freshly exposed metal. Since any corrosion product occupies more space than the steel did, this material wedges the crack open still further when the crack closes on it during the downstroke. Usually several cracks are present in the same rod (see Fig. 5). It is just a matter of chance which crack reaches the point where the remaining sound metal in the rod is too small in cross section to support its load. The rod then parts in a tensile mode.

Looking closely at the broken cross section of the rod, it is usually possible to spot the pit responsible for the failure. (Fig. 6 is an example.) It will be at the center of an arc or half-moon area with ripple marks like an oyster shell. Often the surface

FIG. 5—CORROSION-FATIGUE CRACKING

nearest the pit will be almost polished from the peening action of the crack opening and closing; the pit itself may be worn away. Opposite the pit will be a stretched-out section where the rod parted in ductile tension.

FIG. 6—CORROSION-FATIGUE CRACKING

The cure for these corrosion fatigue failures must be double-barreled. First, the corrosion problem must be controlled by proper inhibition. Once the corrosion is stopped, the entire problem may be solved. However, pits already formed can cause additional failures. If failures continue to occur, the problem reduces to one of replacing already pitted rods or to one of fatigue which calls for review of the string design to keep the load range within safe limits.

When a rod string has experienced several failures, it is false economy to keep rerunning the rest of the string. It would be advisable to check the entire string, or at least the size rods which have been failing, and to remove damaged rods. This checking can be done by service companies, preferably one using flux-leakage magnetic equipment.

Corrosion-Wear - Wear and corrosion have been discussed separately. These two basic failure causes are often combined. Frictional wear continuously removes the layer of material deposited by surface corrosion. This exposes a fresh metal surface which corrodes rapidly, only to have its layer of corrosion product removed the same way. Centralizing the rods and inhibition is indicated if this is the source of failures.

Stress-Corrosion Cracking - Stress-corrosion cracking is a type of failure which is most common in areas where produced fluids contain hydrogen sulfide or carbon dioxide. As the name implies, both stress and corrosion are involved; and the metal itself, because of its high hardness, must be susceptible to this type of attack. In our experience, materials exhibiting Rockwell hardness below 24 can be considered safe from this type of failure.

It is generally accepted that none of the Class C or Class K rods currently made are susceptible since hardness level is controlled during manufacture to a level low enough for safety.

Couplings made to present API Standards as Class T are likewise safe. However, the surface-hardened Class S coupling should not be used where acid gases are present or expected. The hard surface case, particularly at wrench-flat areas, is definitely subject to stress-corrosion cracking. The use of Class S couplings is not recommended for any service; if hard couplings are absolutely necessary, the Class T with hard-facing bands should be used.

Mishandling - Along with corrosion-fatigue, mishandling is a big factor in the great majority of rod and coupling failures.

"Mishandling" is any practice, other than well conditions and normal operations, which causes damage to the rod string. Improper makeup, makeup of dirty threads, bending or kinking, hammering on boxes, nicks on rod surfaces from dropped tools, gashes on the rod from removing shipping restraints are all examples of mishandling.

Practically all box or pin failures are the result of improper makeup. In a few rare cases a manufacturing defect such as lack of parallelism on box and pin shoulder may be responsible for the failure. In a few other cases corrosion or wear may be the chief cause. But, in general a properly torqued joint will not fail. Also, in general, the failures that occur are due to insufficient torque rather than to too much torque.

For proper makeup, the API sucker rod joint is designed so that the pin is in tension. The tension should be high enough to compress the pin shoulder against the rim of the coupling. This compressive preloading is designed to be high enough so that when the rod string is under its maximum tensile load there is enough remaining compressive load to keep the pin and box shouldered up tight.

If the pin tension is too low, compressive load is lost on the upstroke. Several things can then start happening to cause failures.

First, sideplay and free stretch occur in the necked-down portion of the pin resulting in fatigue failure of the pin. In the old-style tapered pin thread, failures almost always occurred at the last engaged thread of the pin at the first notch not fully supported by the coupling thread.

Second, the mating surfaces of box and shoulder will separate slightly on every stroke. This permits well fluids to enter the box and corrosion to start. Corrosion under these conditions becomes corrosion-fatigue.

A third thing that can happen when pin and box are not shouldered is unscrewing. Without the drag of friction on the mating surfaces and with the smooth finish of rolled threads, each stroke permits a little rotation until eventually the rod string separates with no apparent damage to either pin or coupling.

On couplings with wrench flats, the weakest point is opposite the last engaged thread in the box so that fatigue or corrosion-fatigue will occur here. Proper torque will minimize load range in this portion of the box and cut down on box failures.

Anything that prevents full shoulder contact with adequate pin tension has the same effect. A grain of sand or metal shaving on either face or in the threads can be enough to permit insufficient makeup pressure between pin and box. This means that all surfaces must be clean before stabbing.

Just because new rods come from the supplier with a coupling on one end is no reason to assume the makeup is correct. Boxes may be barely more than hand-tight to prevent separation in transit. It is good practice to remove mill-applied couplings to make sure everything is clean and to then use proper torque for maekup. It is also recommended that both pin and box be doped with an inhibited lubricant. This action provides lubrication for smooth makeup and protection against corrosion.

One final word about torque: Overtorquing brings the stress in the pin up to a level where the safe range of stress is severely restricted. Even if the maximum stress is below the elastic limit and pin threads have not been permanently stretched, fatigue can occur in this load range. In addition, it is possible to damage the shoulder of the pin or the rim of the coupling so that the joint cannot be reused.

The American Petroleum Institute has issued a bulletin, "Recommended Practice for Care and Handling of Sucker Rods,"[2] (RP11BR). This bulletin is the product of a cooperative effort by practically every rod manufacturer and oil company. It is intended to point out some practices to observe and others to avoid in order to get the most service out of sucker rod installations. It would be an excellent idea for everyone involved with running, using, or pulling rods to become thoroughly familiar with its content and to make a habit of following its recommendations.

This bulletin will be covered item by item. Special emphasis will be placed on certain items as follows:

1. The use of power tongs is recommended.
2. Pulling rods in singles rather than doubles and hanging rods rather than laying them down is recommended.
3. The use of the circumferential displacement method is recommended for proper joint makeup.

It is realized that following the above recommendations can result in increased pulling time and cost. It should be remembered, however, that not following them will likely result in rod failures.

Corrosion and Corrosion Control

Corrosion can be defined as the destruction of a metal by a chemical or electrochemical reaction with its environment. Corrosion is destruction. It is the natural act of the metal trying to return to its lowest level of energy—iron ore.

The Corrosion Reaction - In oil-producing operations corrosion exists as chemical corrosion due to the fluids handled, electrochemical corrosion due to soils, dissimilar metals, and various types of "cell" action.

The term "electrochemical" is used because it describes the corrosion reaction. For corrosion to occur, electric currents must flow. Electrons move through the metal, and the metal is converted to ions that go into solution to form corrosion products. Often the flow of current is quite small, and the distances are very short (from one point on a pipe to another only a fraction of an inch away). This is particularly true for internal or fluid side corrosion. External corrosion in soils may on the other hand involve long line currents.

A very common example of an electrochemical cell is a battery. A battery has an anode and a cathode in an electrolyte. When the anode and cathode are connected by a metallic path, current flows. In oilfield corrosion cells the anode and cathode can be on the same surface and thus connected. The electrolyte is moisture in some form. It does not take much moisture, just a drop or a film. Since some water is usually present in our operations, a corrosive environment usually exists.

When talking about a corrosive environment, we are referring to the word in its broadest sense. This includes the physical characteristics of a system (temperature, pressure, flow rates, ratios, sizes and dimension, times, schedules, etc.) as well as the chemical and physical properties of the metals and fluids being handled. It has been stated that for corrosion to take place an electrolyte (water) must be present. There are many things that will dissolve in the water that will affect corrosion rates. Acid gases such as H_2S and CO_2 are quite common; and, of course, the greatest accelerator of corrosion in any system is oxygen.

If the metal is always trying to corrode and we usually have a corrosive environment, why is corrosion not present all the time, everywhere, and in all equipment? Actually it is to varying degrees, but corrosion presents a problem only when costs due to corrosion are excessive and when safety is involved. Then corrosion control is needed.

In the early life of most producing oil wells the steel is preferentially oil-wet, and the little water that is produced does not contact the metal. In most cases as the produced water increases, there is a time when the steel becomes water-wet. It is at this point when problems usually start. Unfortunately, there is no predictive technique to indicate just when this will occur in any particular well or field. Experience usually is the best and often the only guide.

For example, several years ago it was found in East Texas that the first in-hole corrosion failures were occurring at about an 80% water-cut. That water ratio was picked to start wells in an inhibitor program. Sometime later it was discovered that failures were beginning to occur earlier and earlier in the life of a well. It was discovered that with changes in producing days, optimization of schedules, etc., those prorated wells were staying shut-in most of the month. Water was separating and settling inside the tubing so that the bottom part contained 100% water, the pipe and rods were water-wet, and corrosion was occurring.

The point is: Even changes in producing schedules can affect the corrosive environment.

Control Methods - There are four basic methods of corrosion control:

1. Protective barriers such as pipe coatings (internal and external), paints and plastic films, and inhibitors (which are but temporary coatings)
2. Electrical circuit control as illustrated by cathodic protection of flowlines, well casing, and vessels
3. Material control as when corrosion-resistant metals or plastics are used
4. Environmental control as achieved by changing the properties of the fluids handled by neutralizing acids, removing dissolved gases, or preventing oxygen entry.

This discussion will concentrate on the use of inhibitors and to a much lower degree on the use of protective coatings and/or paint systems. As a matter of fact, on the subject of coatings it is sufficient to state that a list of approved coatings and paint systems is available which describes approved materials and furnishes pertinent information concerning these materials (maximum and minimum temperatures and pressure, required application method, film thickness and anchor pattern required, and other applicable information) in these ways:

1. By type of environment—for example, coatings for "fresh and salt water injection systems" or for "high temperature (300°F), high pressure (above 500 psi) oil and gas systems and gas condensate wells," or "external coatings for surface lines," etc.
2. By type of installation—for example, "internal coatings for downhole tubing" or for "structures in severe corrosive environment: platform surfaces four feet above mean high water," etc.

3. Alphabetically by coating and by manufacturer's name and/or applicator's name.

Corrosion Inhibition - Corrosion inhibition is usually the most practical and profitable way to handle corrosion in rod pumping wells.

The corrosion inhibitors in common use are called "polar organic film-forming inhibitors." That simply means that due to their nature, these are surface-active materials that are attracted to and tend to cling to solids. One end of the inhibitor molecule clings to the metal and the other attracts oil, resulting in the formation of an inhibitor oil film on the surface of the metal thus establishing an oil-wet surface. Of course, this is not a permanent film, so inhibitor must be added from time to time. The ability of an inhibitor to maintain an oil film or to repair breaks or voids in the film is known as film persistency. Generally the inhibitors used in oil systems have good film persistency; on the other hand, the inhibitors used in water systems do not have good film persistency; this is why most water-system inhibitors must be continuously injected.

These organic film formers will protect equipment against the various corrodants in the oil field with the exception of oxygen. Oxygen can penetrate the inhibitor oil film and form oxygen concentration cells which cause severe pitting. This is one reason why it is so important to keep oxygen out of water systems.

But, no matter how good the chemical is or what its properties are, it will not protect from corrosion unless it is properly applied. Inhibitor application is very important. The inhibitor cannot form a film on the metal unless it gets to the metal surface, and for this reason most so-called "inhibitor failures" are actually application failures.

Section 2 of "Care and Handling of Sucker Rods,"[2] (API RP11BR) is concerned with the subject of inhibitor application. Summarizing the contents of Section 2 and on the subject of routine downhole treatment, experience has indicated that certain of the inhibitor circulation methods are the most practical and profitable to use. The inhibitor squeeze and displacement methods are excellent for gas wells and for certain special applications, but the treatment costs are usually too high for general rod pumping well applications.

Monitoring a Corrosion Inhibitor Program - How do we know whether we have the right chemical, the proper dosage, and the proper application after a treating program is under way? The failure history is, of course, the best monitoring tool. There are, however, other monitoring techniques available which can be used to troubleshoot problem wells and abnormalities that do not respond to an overall program or approach.

The most common of these monitoring techniques is iron content surveys which consist of sampling and analyzing well fluids for iron content. Changes in iron content in samples collected before and after the inhibition program is started serve as a guide to the success of the treatment. There are many limitations to this technique. Sample collection is quite critical as is the method of analysis. To be truly definitive, the iron content must be determined on samples of the total well fluid. Thus, the iron in the water, iron in the oil, and iron trapped in emulsion at the interface should be determined. Furthermore, this is a lab technique and should not be done in the field.

Iron content surveys cannot be used where there is a lot of dissolved iron in the formation water. This is the case in many waters, so iron content monitoring may have limited application in some areas.

Another monitoring technique is the use of corrosion coupons. These are specially prepared pieces of metal which are exposed to the well fluids for extended periods. Coupons are a comparative technique, and some should be exposed before the inhibition program starts and replaced once the corrosion control program is under way.

There are a number of instrumented corrosion rate measuring devices. Since the evaluation of the results of all of these requires considerable interpretation, their use has not been too great.

Economics of Corrosion Control - It is difficult to predict the exact costs which will be reduced when a corrosion control program is initiated. In fact, it is difficult to determine just which costs should be charged to corrosion. Therefore, when first analyzing a corrosion problem, all pulling costs and all benefits to be gained from the implementation of the program should be considered.

There are the benefits of controlling tubing failures due to pitting corrosion and corrosion-wear and collar leaks due to corrosion-erosion. Since proper makeup is also important with tubing, the chances of having this type of failure decreases if the frequency of tubing pulling is decreased.

In most instances rod-body failures can be attributed directly to corrosion. As pointed out, the rod may appear to be corrosion-free; but small pits may be creating stress-raisers which lead to cracking and failure. As a generality, an inhibition program should be expected to eliminate most of the rod-body failures. Rod pin and box failures are not normally due to corrosion; they are usually mechanical failures. The corrosion inhibitor treatment itself does not stop the pin or box failures, but less frequent pulling and handling results in lower pin failures.

In the case of rod boxes, it is not unusual, where corrosion and corrosion-wear have caused sufficient loss of wall thickness, to affect the strength of a box and thus cause failures. In such cases an inhibitor program can be expected to minimize box failures.

Examples are often cited where pump repair costs have dropped drastically after the start of a corrosion inhibition program. This is due to at least three things. The inhibitor film on the pump parts reduces the effects of corrosion-wear; the film has a lubricating effect on the pump; and cheaper pumps can often be used with inhibitors.

It is for these various reasons that all pulling costs need to be considered when trying to decide on the economics of a corrosion inhibition program.

The Economics of Failure Control

The availability of a failure history on a well-by-well basis makes it possible to predict the rate at which subsurface failures will occur in the immediate future. These predictions have been found to be accurate within the limitations brought about by the assumption that operations will continue as they were without improvement and without deterioration. Since information is available as to the number, type, and cost of expected failures, these predictions are both a goal and a base line to measure progress in controlling failures.

Summarizing what has been said on the subject of subsurface failure control, possible progress in controlling subsurface failures can be made by following these guidelines:

1. The overwhelming majority of rod pin and box failures are avoidable by following proper equipment handling practices.
2. The majority of rod-body failures are caused by corrosion, corrosion-fatigue, mishandling, and corrosion-wear. These failures are also overwhelmingly avoidable.
3. Many tubing failures are due to pitting and to corrosion-wear situations. These failures are controllable by corrosion inhibition.
4. The frequency of tubing handling affects the frequency of collar leaks. This is generally due to improper makeup.
5. The handling of in-hole equipment associated with pulling can lead to both pump and rod failures. A good corrosion inhibition program will decrease the frequency of pulling jobs.

Items 1 through 5 describe guidelines for possible progress toward controlling subsurface failures. As failures are reduced, the need to handle subsurface equipment is reduced. Therefore, less handling-caused failures will occur. Also, a corrosion inhibitor program designed to reduce corrosion-caused rod failures will benefit all other items of subsurface equipment.

It is recommended that we consider any well which fails more often than once per year a problem well and to act accordingly.

In any attempt to control failures, the cost of remedial measures must be estimated. The decision on whether to proceed with a failure control program would then depend on the comparison of failure costs versus remedial costs. Whether or not to apply control measures must depend not on how much hydrocarbon the well produces but on the cost of corrosion-caused failures. In estimating this cost, any lost time or lost production due to the well being down should be considered.

REPORT ON THE FAILURE SHORT COURSE MEETINGS TO DATE

The failure control short course has been given in the West Coast area (4 meetings), the Permian area (5 meetings), the Rocky Mountain area (4 meetings), the Gulf Coast area (2 meetings), the East Texas-Arkansas area (2 meetings), and in the Mid-Continent area (11 meetings) at two different times one year apart.

Results of data failure analysis for various periods of time have been prepared.[1] The following summarizes results obtained from these analyses. These results are pertinent to the Company's performance prior to, during, and after the 26 downhole failure short courses were presented.

Data comparing the Company-wide performance during 1970 to that of the first nine months of 1971 show that:

1. Average pump failures per month for the first nine months of 1971 were 20% lower than the 1970 average.
2. Rod failures were 27% lower in 1971.
3. Tubing failures were 9% lower in 1971.
4. Corrosion and handling-caused failures were 17% lower in 1971 than in 1970.

As a result of the above reductions, the expenditures to repair, clean, and maintain rod pumps were 30% lower in 1971 than they were in 1970.

CONCLUSION

The downhole failure control short course was designed as a means to supply production and engineering personnel with the know-how necessary to act to reduce subsurface corrosion and handling-caused failures.

A study of equipment performance data for the periods prior to and following the presentation of the short course indicates significant reductions in corrosion and handling-caused failures. It is likely that the presentation of the short course is related to the achieved failure reductions.

REFERENCES

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