Recognition Of Metal Differences Helps Lift Oil

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When a well servicing crew pulls a well, it is frequently to replace steel which has proved inadequate for the type of service. The well conditions may have been misinterpreted or under-estimated, or the engineers may simply have made a mistake.

Why should you production people look at the petroleum metallurgist's problems? A close-to-home answer is that the routines of your daily work can be efficient only as they place demands on your lifting equipment that are in balance with its mechanical and metallurgical design. You of the petroleum industry who are engaged in artificial lifting do specify equipment. If your demands exceed its abilities, unfortunately you are then involved in an expensive servicing job and replacement of equipment. We should be able to mutually agree that you, in lifting, can do your job more easily and better if you understand the nature of your equipment— its strength and its weaknesses.

The "simple" sucker rod coupling may be a homely illustration. If you run soft couplings on your rod strings, you can enjoy the luxury of loosening them with a hammmer. (Most hardened couplings that are hammered will crack and eventually fail (1). By using unhardened couplings, you can trade wear resistance for resistance to abuse.

(1) References will be found at end of paper. We will come back to our humble rod box later in the paper.

Petroleum production engineers must be interested in materials for the same reasons that petroleum metallurgists try to understand well environments. The manufacturers propose that efficient lifting results from the enlightened use of materials selected to fit a given environment.

WHAT IS ENVIRONMENT? Material-wise, environment can be defined in terms of:

1. Stress on well materials (including abrasive stresses from sand).
2. Degree of corrosive attack (the embrittlement of steels by absorbed hydrogen will be considered as a subdivision of corrosive attack).

Do you people who lift oil have control of the well environment- Yes and no! You set the strokes per minute. You add corrosion inhibitors. You maintain proper unit counterbalance. The more that you know and tell us of the environment, the more intelligently can we — the equipment suppliers—work out with you an efficient lifting installation. This reasoning applies no matter which basic lifting method—sucker rod, gas lift, subsurface hydraulic, etc. is selected. (The choice of lifting method is outside the scope of this paper. The examples apply most directly to sucker rod pumping.)

The symbolical laboratory scale of Fibure 1 is shown balanced. The pointer is centered at the mark, "Lowest Overall Lifting Costs." The symbolic "weights" hanging on both ends of the scale beam represent different factors of the lifting problem.

For a balanced toy "scale," our weights have to be of the right size. In the same idea, your well factors must be balanced if you are to actually get "Lowest Overall Lifting Costs."

FACTORS OF THE LIFTING PROBLEM

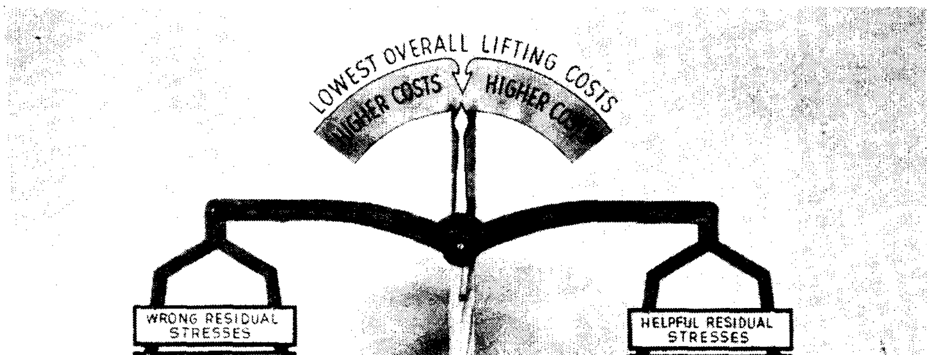

Figure 1. A Representation, from a Material Engineer's Viewpoint, of the Well and Material Factors Involved in Lifting Sour Crude. (Note: Size of "weights" is not to represent relative importance.)

Let us discuss individually the design factors and operating factors which make up the balancing weights on our symbolic laboratory scale. The "weight" marked CORROSIVE ATTACK can be first. Casing, tubing, rods, pumps, and even rod couplings can be affected. People engaged in oil lifting can benefit vitally from the work of the Technical Practices Committee "T-1" of the National Association of Corrosion Engineers. In the "T-1" committees, industry knowledge is pooled and guide posts have been erected. I am sure you know the truism—"no two wells are alike." Possibly this statement is correct—however, both you and the supplier need guide posts when a well goes on artificial life. You attempt to forecast whether the well will be initially corrosive. For efficient utilization of materials, the equipment engineer will need to know whether it is sour or sweet corrosion. "Sour" corrosion merely means corrosion where hydrogen sulfide is present. With water floods growing in importance, whether or not oxygen will appear can become of equal importance. It is well known that the corrosiveness of a well can increase with passage of time. Increasing water cut in itself can render a previously non-corrosive well commercially corrosive.

Dollars spent for effective CHEMICAL INHIBITION can determine the degree of corrosiveness which well equipment must face. The recent investigations of Koger, (2) as well as many others, emphasize that inhibitor addition practices are of great importance. Again, NACE groups permit the individual lifter to benefit from the collective experience of many. We interpret discussions among industry production engineers that 100 percent inhibition—the stoppage of all corrosion in a well—is seldom economic

ENTRY OF HYDROGEN: The evolvement of hydrogen gas is ordinarily a by-product of acid corrosion. (3). When hydrogen sulfide gas is also present on the corrosion scene, some of the hydrogen enters the steel —rather than all being dissipated in the well fluids. (As we shall see later. the entry of hydrogen into the steels used for some well eqquipment can affect their serviceability.) The factors that control the force tending to impregnate well materials with hydrogen are not clearly understood.

The corrosion process furnishes the hydrogen and the current flow to charge it into steel. Severe corrosion with heavy metal loss is not required (4) for the introduction of what can sometimes be significant amounts of hydrogen. However, a "promoter" ion does seem necessary for significant impregnation to occur in oil well fluids. The "promoter" known to be important to the oil industry is the sulfide ion. Sulfide results when hydrogen sulfide gas dissolves in water. Some recent laboratory work has shown that even a tiny amount of sulfide ion can increase the hydrogen impregnating force by a factor of ten! Other "promoters" also exist: Arsenate ion, cyanide, (5) plus rarer selenium and tellurium have been mentioned, (6, 7, 8). The 1956 N.A.C.E. meeting heard a suggestion that hitherto unrecognized "promoters" and hydrogen might even be involved in recent brittle failures in high pressure sweet wells.

Chlorides, organic acids, and lower temperature have been reported as favoring hydrogen-induced steel failures, (9). Probably these factors aid hydrogen impregnation. Tension stresses in steel are reported to markedly increase the entry rate of hydrogen, (10).

There is evidence that chemical corrosion inhibitors can minimize the entry of hydrogen at least as judged by the mimimizing of tubing breaks in critical wells, (11). However, the writer is not aware of any that proves impregnation can not occur under long continued immersion in corrosive sour fluids that are only partially—say 80 percent—inhibited.

You have seen that our illustrative "weight" marked SERVICE STRESSES is divided into halves marked "Tension" and "Abrasion." The subject of stressing sucker rods has a sizeable literature all its own. We all know they last longer at lower stresses. Yet, the rod string must be loaded high enough to get up the barrels you need. Can we all agree that "wasted" stresses should be kept low as possible by good field practices. Pounding fluid is an example of "wasting" rod stresses.

It is worth emphasizing that repeated applications of stress—that is, fatigue loading—becomes more severe as stress range increases. For example, a rod string might work satisfactorily with a peak polish rod load of 30,000 lbs. if the minimum polish rod was 20,000 lbs. The same string might fail if conditions changed so that—for the same peak load—minimum polish rod load fell to 5000 lbs. (See footnote.)

There are many articles containing formulas for calculating maximum (and minimum) sucker rod loads. All formulas can be seriously wrong on occasion. A petroleum production engineer, who is an expert in oil lifting, had this one specific item of advice: "Keep the wells weighed!" The mechanical engineers of all manufacturers would add, I am sure, "Keep your pumping units counterbalanced!"

ABRASIVE WEAR — such as the wearing away of a bottom hole pump plunger handling sand—is also a form of stress damage. Mother nature determined which producing formations were to be worst from the sand standpoint. Sweet production finds abrasive wear on pump parts more acute. Keeping wells cleaned out eases abrasion problems on pumps. The use of fracturing procedures makes the field man's role more important in controlling abrasive materials.

On the left hand scale pan, the "weight" labeled WRONG RESIDUAL STRESSES can be kept small through the cooperation of supplier and user.

Note: That higher peak polish rod loads can be used if stress range is held close has been recognized by practical oil field men. There is one known item of laboratory research work on corrosion fatigue that says, "The severity of corrosion fatigue in sea water under reversed stress with superimposed tensile stress depends on the stress range, but is found to be almost independent of the mean stress of a cycle, provided that this is not excessive." (12) Of further interest to research people is a second point from this article, "The endurance as measured on a push-pull machine is roughly five times as great as that measured on a rotating-beam machine for the same materials and stresses." ("Residual stresses" are those stresses contained within the item of material.) A sucker rod run over by a truck, even if straightened, possesses built-in tension stresses on one side. (13, 14) (Also see footnote.) (Residual stresses—of the right kind—can be of great economic help. An example of utilizing residual stresses to lift more oil per dollar is discussed next.)

HELPFUL RESIDUAL STRESSES strengthen materials just as the wrong kind are hurtful. Normally, service stresses are tension. Therefore, if residual compressive stresses can be built at least into the surface of a part, then there is no effective tension until tension forces from well loads build up beyond the built-in compressive stresses. We design engineers have some things left to learn about residual stresses as a class. On the credit side, however, they can be very potent tools and can sometimes be bought cheaply. The illustration following is one in which an actual increase in lifting serviceability was secured. We believe the improvement in the well is most logically explained in terms of favorable residual stresses —successfully captured to counteract lifting stresses. The sketches of Figure 2 illustrates the "before" and "after" conditions.

Note: The literature on internal stresses from bending and straightening of bars has been reviewed by Richards, (15) Nachtman, (16) Forrest, (17) and others. Residual stresses after cold bending approaching the yield point of the material were estimated by Norton, (18) Brewer, (19) and Forrest. Reduction in surface stress intensity by further bending, as to straighten, is predicted by Forrest. For sucker rods, theoretical understanding is particularly complex. Sucker rod outer surfaces are critical as the origin of both stress induced fatigue cracks and corrosion induced pits. Many sucker rods are, in a sense, composite bars from their decarburized skin of lower hardness than the bulk of the steel cross section. This skin has been claimed both harmful (20) and protective. (21)

Our illustration results from experience with "slim hole" couplings. So-called "slim hole" couplings are used to connect 7/8" API sucker rods within 2" tubing. (The decrease in coupling outside diameter from 1-13/16" (7/8" API standard) to 1-5/8" has been proved critical to us the hard way.) Our field experience seems to demonstrate that properly made carburized and hardened standard-wall couplings are essentially "complaint proof." It is known that breakage of standard boxes can result from hammering. (1) Suffice it to say, however, that the author's laboratory has been requested to investigate, in five years, only two occurrences of breakage of standard rod boxes. By contrast, certain wells — and not ones

THE "BEFORE" AND "AFTER" CONDITIONS

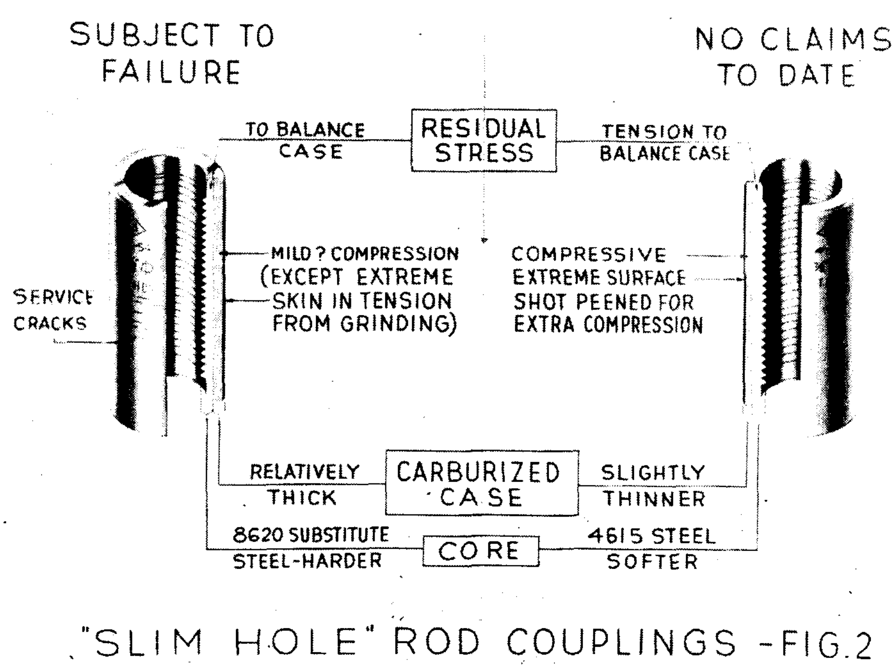

Figure 2. Alternative Designs for "Slim Hole" Sucker Rod Couplings.

heavily loaded—suffered "slim hole" coupling failure with disturbing regularity. Our hypothesis is that these problem wells suffered cork screwing of the rods on the down stroke. Fatigue cracks in the carburized case from bending seems the best suggested explanation for spontaneous failures originating at the coupling outside diameter. (Rest assured that hammering was eliminated as a cause of cracking before we became concerned about these "slim hole" failures.)

The following steps were taken and service improved: Analysis and heat treatment of the boxes were modified to minimize brittleness of the carburized case. Aim case depth was decreased slightly. Most important, in our judgment, shot peening after grinding was instituted as standard manufacturing practice for "slim hole" couplings. No failures have been reported to the plant since the modified manufacturing sequences were adopted.

The third "weight" hanging on the right hand scale arm is labeled TOLERATION OF STRESSES. It is admittedly hard to separate material damage in an oil well that occurs from stress from the concurrent damage resulting from corrosive attack. Both the metallurgists and the mechanical engineers could use enlightenment here. For maximum understanding, we like to look at the demons of stress and corrosion damage at first separately—and then as a package.

Suppose we now look at the ability of a well part to withstand mechanical loads. (We will defer the complications that come from simultaneous corrosive attack.) The metal property most usually measured is hardnesss —the resistance to indentation as by a Brinell ball. A step further is to "pull a tensile." In sucker rod manufacture, it is common to stretch a two foot length of rod. On low strength 3/4" rods, an applied load of 25—30,000 lbs. results in a detectable permanent stretch. The stress at which the obvious lengthening occurs is referred to as "Yield Point" or "Yield Stress." To complete the test, the test machine load is increased further, and the sample starts to "neck" down. It finally snaps at the smallest diameter of the "neck." The maximum load sustained during the test, divided by the original cross section area—.442 sq. inches for a 3/4" rod—is called the "Tensile Strength." The amounts of stretch and reduction in diameter are calculated as measures of "Tensile Ductility."

The above is fine—except well materials do not fail by stretching and finally parting as did our sucker rod laboratory tensile specimen. For practical purposes, all mechanical breakage in a pumping well occurs from "Fatigue."

"Fatigue" failures result from repeated applications of a load. (In the case of sucker rods and pump parts, it is more precise to think in terms of repeated variation between a lower tensile load and a higher tensile load.) Loads that can cause breakage by fatigue are much less than the tensile yield loads. Fatigue failures are brittle failures — they start without stretching and contraction of the metal. Actually, a property which we can label "toughness" is also needed for a part to withstand service stresses. The minimum amount of "toughness" needed varies for different parts—this we've found out the hard way. Compare a valve ball in a bottom hole pump and its cage. The ball has much more "strength" or hardness. A cage made the same way breaks easily. To pass over our basic ignorance, we say, from experience, that steels for cages need more "toughness."

If I may attempt to express a thumbnail philosophy of metallurgical design, it is to obtain the greatest elastic strength, (that is—ability to resist plastic deformation) that is consistent with the "minimum toughness" required. "Minimum toughness" is that amount required, by field experience, to avoid premature fracture. Normally these objectives (for steels) automatically point to heat treatment by quenching and tempering. For the last ounce of toughness, we like to quench and temper low carbon steels. (Also see discussion in footnote.)

TOLERATION OF HYDROGEN: Above I have tried to point out that improved toleration of service stresses can be built into steels by thoughtful selection of heat treat procedures and chemical analyses. The extra margins of toughness, or strength so secured, were discussesd as if the well parts were running in air, or at leasst in non-corrosive pipe line oil. Now let us consider an environment like a sour well where hydrogen can enter the steel. Now, those extra margins of toughness we can obtain are still important—except more so! We have shown that even minor amounts of corrosion in sulfide environments acts to charge embrittling hydrogen into steel parts. Dead soft steels are relatively insensitive to hydrogen embrittlement.

Note: Many years ago, Wescott, Bayless and other pioneer petroleum metallurgists endorsed the usage of low carbon alloy steels for sucker rods. Corrosion aside, it seems that accepted theory now confirms that low carbon content favors maximum relative toughness. (22) Now to speak specifically of laboratory air endurance testing using rotating beam techniques. The classic view does not accept carbon content as a variable important to endurance ratio. Accumulated test results of the authors Division show endurance ratios 10 percent better at the 90 - 100,000 psi tensile range for low carbon alloy steels than for medium carbon steels. Garwood's data (24) (also see Shih - 25) is believed not contradictory regarding the effect of carbon though he did not treat the low carbon contents (XX20 down to XX05) which have been used for sucker rods.

Extremely hard steels lose their toughness to a spectacular degree. A classic illustration is the explosion of a hardened, high carbon ball bearing when dropped in acid that is "poisoned" with hydrogen sulfide. The energy for the explosion likely comes from residual hardening stresses in the ball. The absorbed hydrogen decreases the ability of the ball to withstand the imposed stresses — residual stresses in this case. A legend of artificial lifting in early times is the fracture of freshly pulled sucker rods when accidentally dropped on derrick floors. (23) The old timers discovered by trial and error that heating of used rods in open fires or with hot oil restored some toughness. Our explanation today is that the heating drove off much of the absorbed hydrogen. In recent times, there have been two cases documented in NACE Subcommittee T-1D, "Corrosion in Sour Oil Wells," where rod strings were suffering frequent breaks and consequently were retired from use. When picked up and re-run after long atmospheric exposure, failures from pumping loads no longer occurred. This can make sense if interpreted as a result of the loss of absorbed hydrogen during the aging period in the atmosphere. An understanding of the increased fracture susceptibility of steels that have absorbed hydrogen goes deep into the fundamental physics of metals. University research conducted under NACE's sponsorship demonstrates that the embrittling trend is common to all constructional type steels. (5) Some work in our own laboratories (see Fig. 3) gives us the opinion that the maximum safe hardness for steels in a given hydrogenizing atmosphere (and under a given stress) is obtainable by specification of quenched and tempered, low carbon alloy steels.

(Mentioned previously was our company's experience that low carbon, quenched and tempered steels show a relatively favorable toleration of mechanical service stresses.)

Designing materials to withstand ABRASION. Like designing for fatigue stress, the behavior of a steel subjected to abrasion is most markedly affected by concurrent corrosive attack. Again, we believe some order can be best obtained by looking at abrasion resistance, first by itself, and then secondly, under corrosive conditions. Hardness is usually considered an index to abrasion resistance. Other things being equal, it is. Among commercial materials, the "other things" can be so unequal that hardness may be a poor guide indeed. Particularly where corrosion is present, (average, i. e. Brinell) hardness in the ordinary sense is a most unreliable guide post. Because abrasion, and abrasion-corrosion resistance is so important in the service performance of, for example, bottom hole pumps, our company has attempted to correlate observed material performance with metallurgical fundamentals. A modern metallurgical technique which has eased many of the apparent contradictions is that of micro-hardness examination. Using the metallurgical microscope, extreme small hardness indentations—(the width of the impression can be less than 0.001")— are made in the individual micro-constituents of the metal. For example, two materials of high "average hardness" in the ordinary sense have been observed to give consistently different lives when used as bottom hole pump plungers or pump barrel liners. Examination in the metallurgical laboratory brings out that the longer wearing material is made up of more than 50 percent of superhard, alloy carbides (see Fig 4) that are actually harder than sand or quartz. By contract, the inferior field material has no constituents that are as hard as sand. Remember, both materials show the same Rockwell "C" hardnesss!

Bottom hole pumps with both plungers and barrels made of the material shown in Fig. 4 have performed creditably against the "flour" sand of California. Coming closer to home, one major company uses 200 of these in corrosive sulfide wells near Big Spring, Texas. Average life between overhauls is five years.

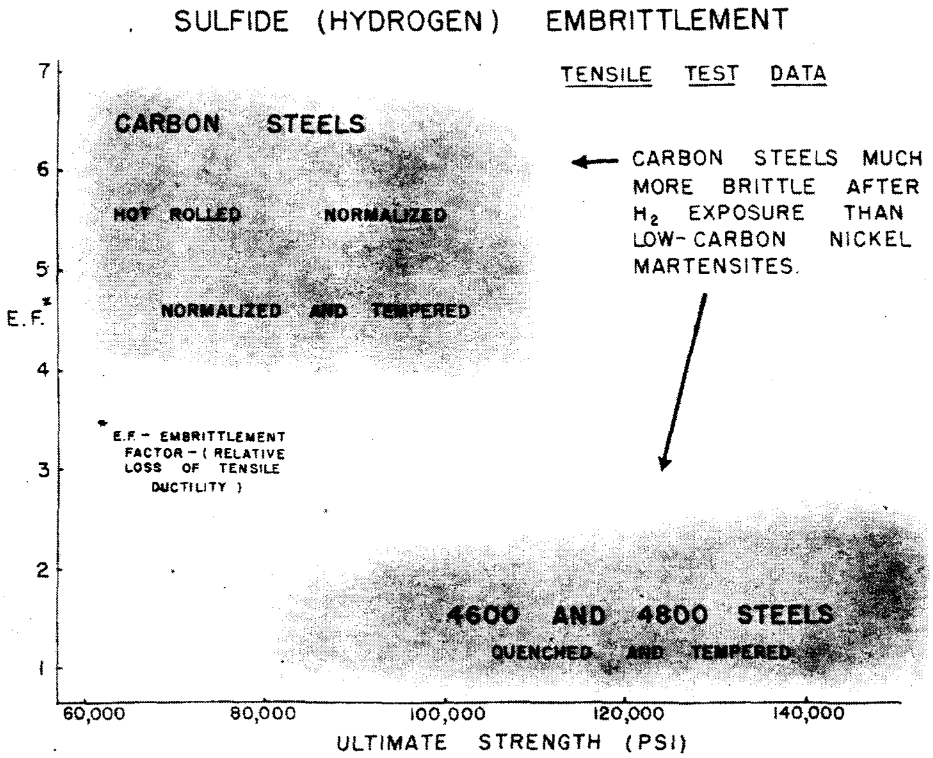

Figure 3. Two Groups of Steels Freqquently Used for Sucker Rods and Surface Fittings. Note Differing Responses When Cathodically Charged with Hydrogen.

SHOW THE SAME ROCKWELL "C" HARDNESS

Figure 4. Photo Micrograph of Nickel Boron Martensitic White Iron Pump Liner. 500X Nital Etch.
"Stars" are micro-hardness impressions. White carbide hardness is 900-1200 Vickers. The "Steel Phase" (streaked Austenite-Martensite) is 400-700 Vickers hardness. To appreciate the micro-hardness measurements, note that a 60 Rockwell "C" hardness indentation at this point, similarly magnified, would fill a twelve inch diameter circle.

A second idea that has helped us in designing abrasion-resistant materials is the one simplified into the term "Modell." I am sure a great many lifters know first-hand the superior wear performance of either hard chrome plate or hardened cast iron— as compared to ordinary quench-hardened steel. Bottom hole pump plungers are one part on which numerous service comparisons have been made. The Rockwell "C" hardness of both of the longer lived materials is inferior to that of fully quench-hardened steel. Yet the "softer" ones wear better! Mr. Oberle's concept of "Modell" explains the superior materials by their lower (than steel) modulus of elasticity. (26) Modulus can be described as the relative load required to elastically stretch a given bar of material a constant small amount. The "modulus" of steel is higher than for cast iron and other common metals. Under the concentrated load of a grain of sand, the good wearing materials are pictured as deforming elastically and the sand particle rolls along till it escapes. Under similar conditions, with a steel plunger, the sand particle makes a permanent indentation which further rubbing turns into a disabling "score." Figure 5 is reproduced to illustrate this useful concept of metallurgical design.

To discuss the last "weight" on our symbolic scale is to summarize what we know of the inherent CORROSION RESISTANCE of materials. However, there could be two viewpoints which would see the issue as already settled. From a narrow view, there are materials—monel, 18-8 chrome nickel stainless steel, certain bronzes, the stellites, which are essentially resistant to known oil well environments. Actually, we do use these materials. The qualification is that experience of the petroleum industry has shown them to be too expensive to be economic for most equipment items. For example, casing a well with 18-8 stainless steel would be very costly. On the other hand, balls and seats in some pumps employ sintered carbides which cost in the range of "dollars per pound."

At the other pole, the second viewpoint would say "today's chemical inhibition renders corrosion resistant materials unnecessary." Naturally, as equipment engineers and manufacturers, we have given much thought to the proposition that "steel is steel in an inhibited well." We try to follow at the NACE and API meetings, the deliberations of your engineers on this matter. We do market one grade of sucker rod specifically created and engineered for heavily loaded, but effectively inhibited, wells.

In the partnership of inhibition and materials, we size up the existing status about as follows:

A. Inhibition costs mount at concentrations of chemicals giving more than 90 percent protection.

B. Relatively more is known about inhibitors for sour wells than for sweet corrosive oil wells. (27)

C. Inhibition practices that may give reasonably good corrosion control for rods and tubing in pumping wells do not, in many fields, reduce pump troubles correspondingly.

D. Inhibition is apparently not economically feasible for salt water disposal systems or for water floods.

E. Even under conditions where a carefully supervised inhibition program can be effective, actual operating conditions can result in appreciable corrosive attack.

We would say, then, that rods, couplings, bottom hole pumps and water flood pump trim are preferably specified with material corrosion resistance fully in mind. To say it another way, there are believed to be differences of dollar significance in the resistivity of commercial steels (and bronzes). We can cite a few cold turkey examples where a cheaper material definitely lasts longer. For the customer to obtain this performance bonus, plus sometimes a first cost savings, the environmental conditions must be known. Hence the emphasis earlier in the paper on knowing the severity and the nature of the corrodant.

The following illustrations are from commercial experience where differences in performance of "common" materials frequently are reported to outweigh any moderate differences in first cost.

Figure 6 illustrates particularly the increased corrosion sensitivity of resulfurized screw stock steels (parts A-1, A-2, and B-1). Valve rod guide B-4 of wartime 4140 analysis shows severe attack after only a month's service. Two of the three 3-1/2 percent nickel fittings (B-2 and B-5) are unattacked, whereas closed cage B-3 has some corrosion. Some localization of attack by fluid velocities is apparent. (The most striking velocity effects on corrosion in our experiences have been in sweet wells.)

Figure 7 below pictures a corroded pump barrel made of the most discriminating material as between sour versus sweet corrosion—in our experience. The pitting pictured is corrosion without much abrasion since sample was just beyond plunger stroke. Barrel fittings were badly attacked. Was definitely sweet corrosion from carbonate deposit and absence of iron sulfide.

The point of interest is that the nitrided surface of this nickel nitriding steel is extremely resistant to corrosion (and abrasion) even in strongly corrosive wells provided that hydrogen sulfide is present. So long as the wells are sour, they can be so corrosive that monel and 18-8 stainless pump fittings are required—and yet this nitrided surface of the barrel interior resists attack. (Also see footnote*) (Service records show that some of these corrosive sour wells of specific West Texas problem fields can be reasonably well inhibited as regards rods and tubing but can yet ruin a pump of non-resistant materials in a week's time.)

Somewhat analogous to the preceding, Figure 8 illustrates two widely used sucker rod steels and their wide-

USEFUL CONCEPT OF METALLURGICAL DESIGN

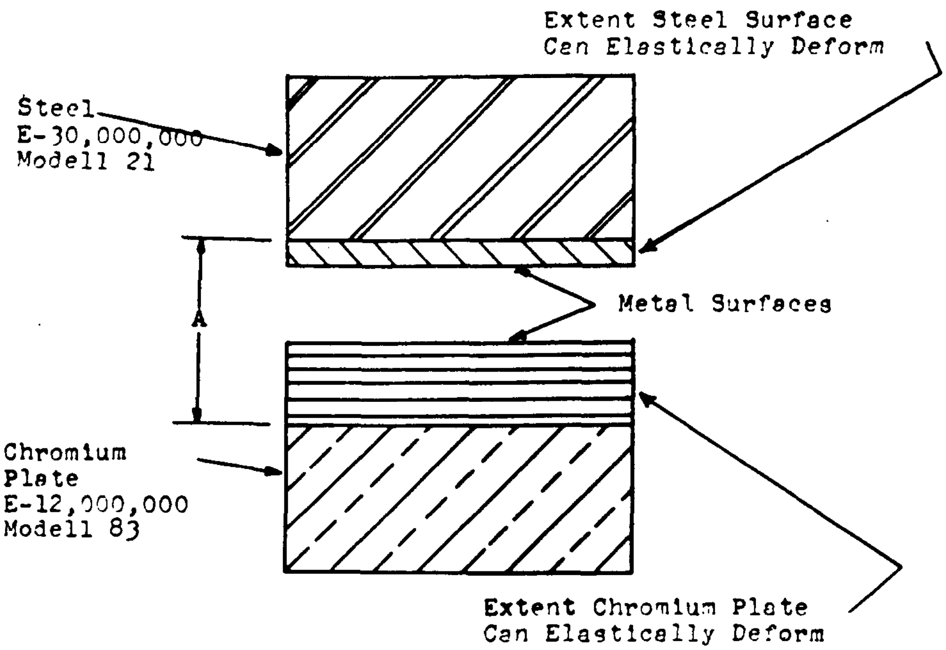

Figure 5. This illustration is from Mr. Oberle's 1951 paper. It is to show the amount of deformation from a trapped grit particle of size "A" that can be endured without marking the surfaces. In other words, the distances the metal plates can indent without exceeding their respective yield points. The E's of the figure are Moduli of Elasticity for the materials. His Modell value is calculated from the formula:

$$\text{Modell equals } \frac{\text{Brinell} \times 10 \text{ Million}}{\text{Modulus of Elasticity}}$$

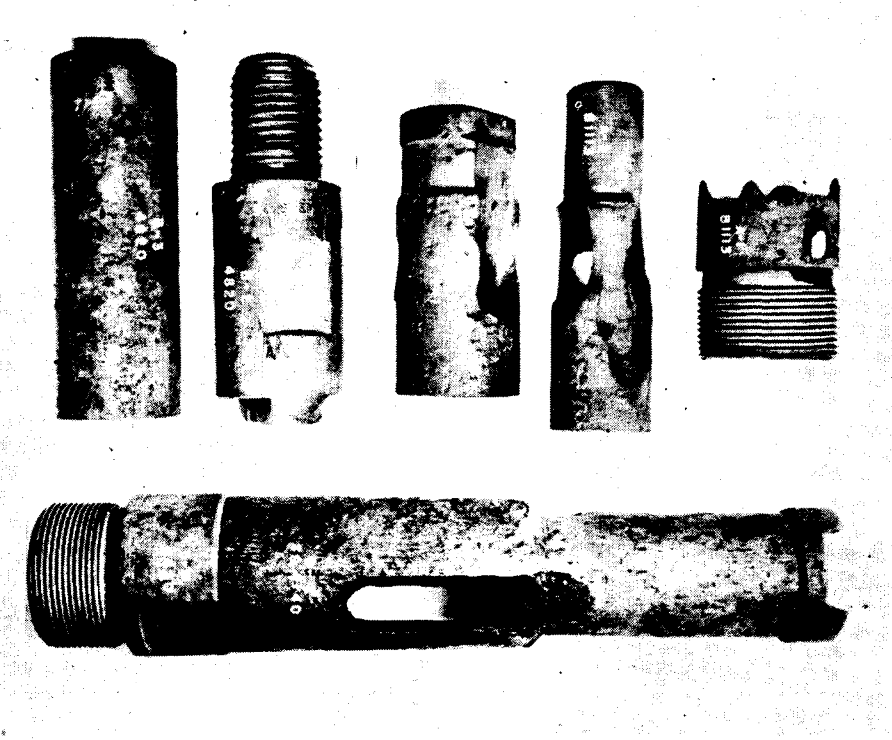

Figure 6. Approx. 1/2 size. Bottom Hole Pump Parts of three Steels Used in Two Corrosive Sour Wells. "A" Series parts 187 days, Utex Lease near Odessa, Texas. "B" Series parts 26 to 42 days, Walker Lease near Odessa, Texas. Steel compositions shown by AISI numbers on parts.

*Experience that nitrided cases possess a singular resistance to sulfide corrosion is confirmed by Houghton, (28) "they are impervious to many corrosive media including the sulfides commonly found in crude oil." Metallographic examination of the pump barrel surfaces shows an armor of interlaced spines of metal-nitrides which are cathodic to the steel matrix. Explanation of widely differing resistance to sweet and sour attack may involve differing effective anode-cathode areas in the two media—compare. (29)

ly differing resistance to carbon dioxide (sweet) corrosion.

The resistant sucker rod steel (lower rod in Fig. 8) is not an AISI standard steel. It is nominally .35 percent carbon, 1.50 percent nickel and .75 percent chromium. Heat treatment is by normalizing and tempering. An extremely fine—essentially irresolvable — "pearlite" results. The "worm-track" attack pictured on the corroded rod of Figure 8 appears to be typical—not of this 4615 rod — but of many low carbon, nickel molybdenum analyses in this environment. Similar experiences are known in which 4621, 4820, and 4805 steels have all suffered severe metal loss as against negligible corrosion on the higher carbon, nickel-chromium material.

Manuel, (30) and Prange (31, 32) have previously pointed out similar instances where differences of dollar importance in corrosion resistance appear attributable to differences in microstructure of steel. For reasons not well understood, sweet corrosion accentuates microstructural differences more than does sour environments. Frisius (33) quotes Rohrback and McCloud regarding "worm track corrosion" that, in carbon dioxide brine, the "scrubbing action of fluid flow" makes cathodic areas more cathodic.

Differences under the metallurgical microscope can be important corrosion-wise for metals other than steel. Figure 9 compares the structure of two aluminum bronze valves. For water flood and salt water disposal pumps, aluminum bronze is widely used—both for trim and for entire fluid ends. There are occasional extraordinarily corrosive brines which do attack aluminum bronzes. The valves pictured below were in different pumps—however, both fluids were capable of corroding some aluminum bronze parts in each pump. Both valves have the same nominal chemical analysis.

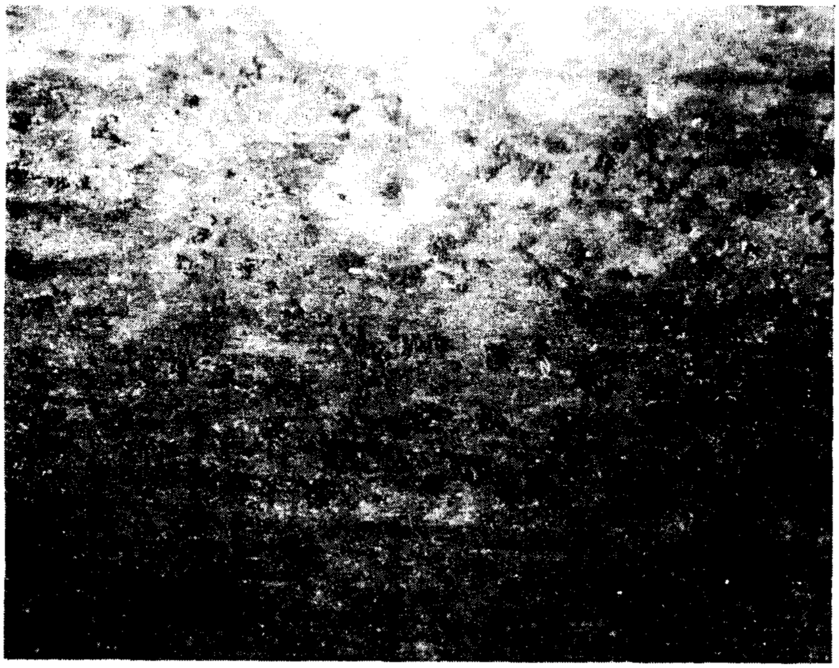

Figure 7. 5X Pitting from CO2, Interior of Nitrided 3 - 1/2 percent Nickel Barrel. 4 - 1/2 months service near Mirando City, Texas.

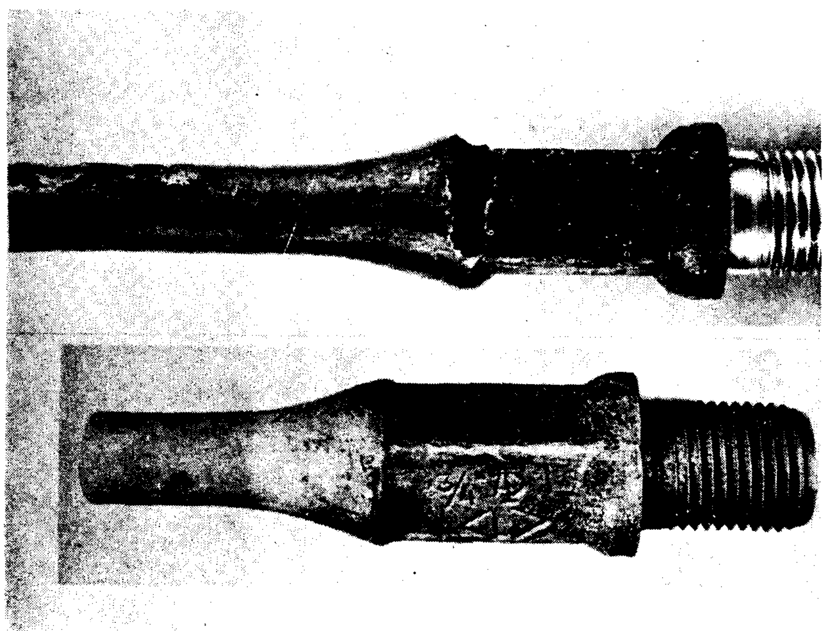

Figure 8. Approx. 1/2 size. Compare Metal Losses in Sweet Corrosive Well (near Brookhaven, Mississippi) Upper Rod—AISI 4615 steel—5 Months Service. Lower Rod—Special "3235" steel—23 Months Service.

Summary

It would be nice to offer an explanation that could precisely relate the microstructural and environmental differences of Figures 6 - 9 to the observed diffferences in service to the customer. We try to make use of these differences even though we cannot yet understand them in a fundamental scientific way. Workers at the fundamental level (in both chemistry and metallurgy) may be beginning to knock at the door of understanding.

In any case though, we submit that differences in corrosion resistance—and in "strength"—do exist. When the supplier and the lifter are closely enough coordinated, these differences can put extra dollars in the lifters' pockets.

Acknowledgement

Thanks are due members of the Oil Well Supply Field Organization for reporting their observations of material performance in the wells. I acknowledge my appreciation to many co-workers and also to the Oil Well Supply Division for permission to publish these opinions.

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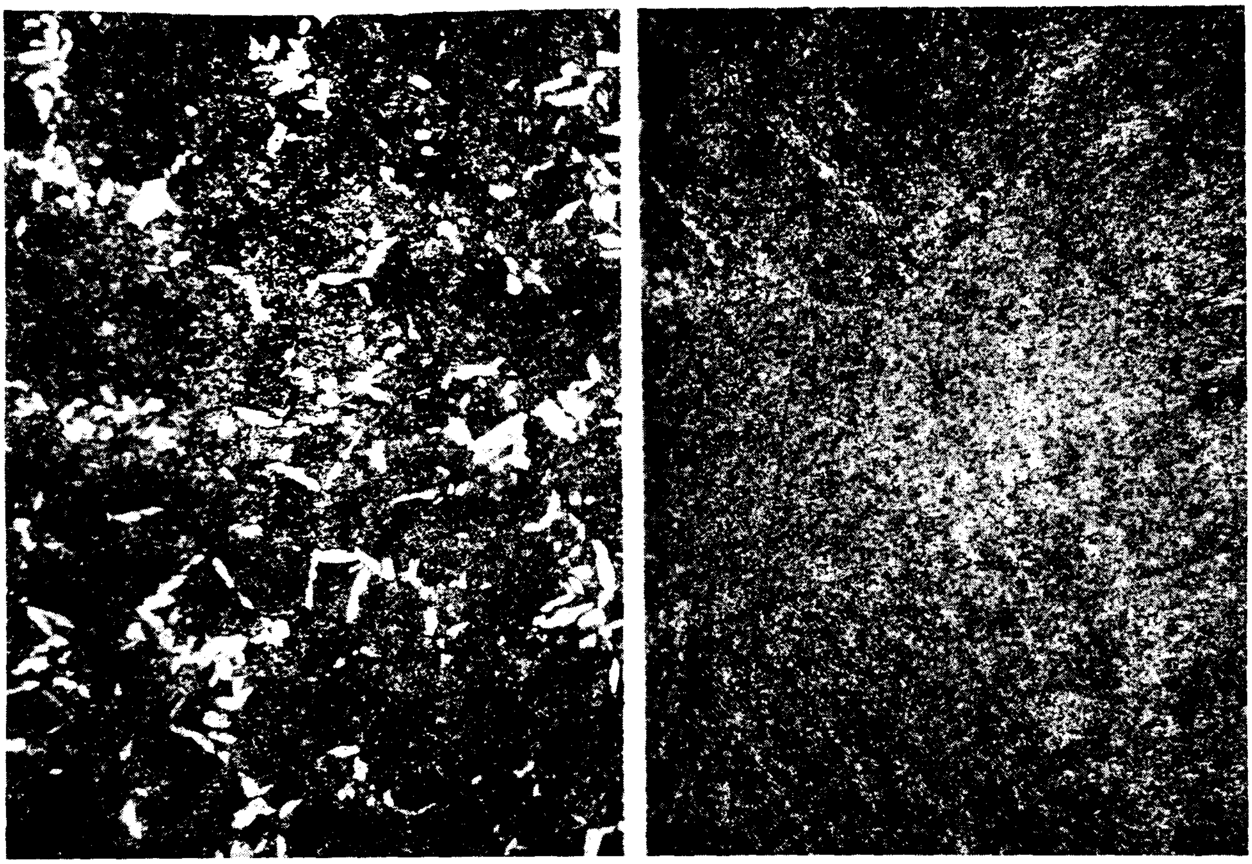

Figure 9 100X Etchant— 1st: Ammonia hydroxide-hydrogen peroxide 2nd: Ferric chloride-hydrochloric acid

Photomicrographs of Aluminum Bronze Valves of Known Service Performance. (Both valves heat treated for wear resistance.) Left: Prominent alpha phase (white) in beta matrix - resistant. Right: Largely beta phase —was severely corroded.

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