A Report on Sucker Rod Research and Development to Date

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Sucker rods, the prime purpose of which is to impart the reciprocating motion and power of the end of the walking beam to the sub-surface pump, are such a simple piece of apparatus that it might seem nothing much could be done to improve them. However, much has been and is being done to make their proper care and use better understood, to obtain a more accurate understanding of the actual loads imposed upon them, and to improve the joint design, the rod materials and the manufacturing techniques. It is the purpose of this paper to review what has been done and what is now being done along these lines with a belief that an understanding of these problems will lead to a better use and, consequently, a more economic life of this vital link in the oil well pumping mechanism.

CARE AND USE

Abuse or misapplication can be fatal to anything, even to the most modern and best materials. This is particularly true of sucker rods where our design safety factors must necessarily be so small because of the very restricted space in which we must work. With this in mind, well over twenty years ago, the A.P.I. sub-committee on sucker rods included a code on "Care and Use of Sucker Rods" in A.P.I. Standard 11B which covers their specifications. This code has not been neglected by the committee, for it has been revised several times, its last revision carrying the date of January, 1955. In the spring of 1952 the A.P.I. Division of Production, Central Committee on Training, organized a sub-committee to formulate a course and write a text on this subject. This was done and the text was completed in early 1955. Since that time, the A.P.I. and several others have conducted a number of courses on the care and proper handling of sucker rods.

Some of the manufacturers also for a number of years have conducted classes and given talks, including illustrative films, on the subject to men in the field. Many articles have been written by many authors in an endeavor to promote better care and use of these rods. All of these codes, courses, lectures, films, articles and instructions have done a great deal to better our understanding of the proper handling and correct usage and application of these rods, and have undoubtedly paid off well in more trouble-free operation and lower cost performance of the pumping well.

INVESTIGATION OF WELL LOADS

In order that we may design sucker rod strings for pumping wells where the load is not known, empirical formulae have been developed for estimating such loads. One of the earliest and best known of these was devised by Slonnegar and included in the early editions of A.P.I. Standard 11E covering pumping units. This formula applied an impulse factor to the combined weight of the rods and fluid. Later Mills suggested a new formula which applied a larger impulse factor but to the rods only; then Carroway suggested applying the Mills impulse factor to the combined weight of the fluid and the rods, especially on faster pumping wells. In 1951 the author devised a combined form of the Slonnegar and Mills formulae which more closely approximated actual load averages in the complete speed range.

During this period many others, including oil operators and equipment suppliers, were investigating loads through the use of dynamometers, compiling data on the subject and gaining knowledge. The use of the dynamometer in analyzing well loads and attendant troubles has added much to our understanding of rod troubles. Many authors were investigating, theorizing and writing on such kindred subjects as rod and tubing stretch, plunger over-travel and synchronous speeds and their effect on polished rod loads.

Even with this great accumulation of knowledge and experience, results of the various formulae are widely divergent from each other and from actual values. With this realization in mind, a number of companies, including both oil operators and manufacturing concerns, met in late 1951 to review the possibilities of a cooperative research organization to study the sucker rod pumping system. In early 1954, with a membership of about 28 oil producers and manufacturers, "Sucker Rod Pumping Research, Inc.," was organized for the purpose of developing and building a sucker rod pumping system simulator. This simulator or "mechanical brain" is now almost complete and from it we expect to learn a great deal about the behavior of sucker rods which is now just conjecture and theoretical reasoning. It will enable us, we hope, to design new sucker rod strings based on proved facts rather than empirical formulae developed from average conditions which may or may not apply to a particular case. It should also enable us to diagnose well troubles and thus operate our rods and other equipment much more economically.

ROD DESIGN

In spite of the fact that a sucker rod is a very simple piece of equipment, a great deal of work has gone into investigation, research and experimentation on design, particularly on the joint. In the twenties and early thirties, many different joint designs were devised and tried with varying degrees of success. In general, though, the present design as standardized by A.P.I. has been accepted as the most practical from an economic and performance standpoint. It has, however, been improved, changed and revised from time to time in minor degrees, through the years, through the A.P.I. committee on sucker rods.

For many years the aircraft industry has employed what is called an undercut thread for studs and bolts in stress applications similar to those in the sucker rod joint, thereby practically eliminating fatigue failures in such components which had been disastrously troublesome. The undercut thread consists of turning down the body of the male threaded member for a distance equal to one or two diameters between the last full thread and the seating shoulder to a cylindrical section slightly less in diameter than the minor diameter of the threads. This principle is not new, having been applied to sucker rods in a modified form as early as 1932; but it is now universally recognized as the preferred design for threaded components subjected to reversals of stress. In 1949 this fact was pointed out to the A.P.I. Engineers' sub-committee, and in 1950 to the Sucker Rod Committee. Three strings of rods with undercut pins were run in Seminole wells in December of 1956. They were still in operation as of last December and the well records show that their performance is much superior to the A.P.I. standard pin.

At the 1956 meeting of the A.P.I. Standardization Committee on sucker rods, a new thread fit was proposed. Our present fit according to Unified and American Screw Thread Standards for all industries is obsolete. The class now recommended for sucker rod fits is known as the Class 2A-2B fit. Its main feature is greater clearance between the box and pin threads, whereas the present A.P.I. standard requires unnecessarily close fits. The more realistic class 2A-2B fit has greater tolerance for sand and grit, as well as permitting some slight angularity between the shoulder faces. Many broken pins can be traced to the lack of these two features in our present joint. Adoption of the new Class 2A-2B, now under consideration, will be a big step forward in the effort to minimize such rod joint failures.

Considerable research work has been done to determine the proper torque to apply to the various size rod joints in making them up to prevent pin and coupling breakage. Theoretical considerations indicate that pins cannot break if they are pre-loaded by proper make-up torque to a load at the shoulder faces greater than the maximum working load on the string. Power torque wrenches are available for this purpose and many operators have discovered that pin breakage can be practically eliminated by their consistent and proper use.

Another new design development of the past few years is the hollow sucker rod. While its principle use today is in paraffin control, wherein heated oil is pumped down through the rods and circulated up with the produced oil to melt the paraffin, it has other valuable possibilities. It can be used to inject corrosion inhibitors at the pump; to produce dual zones both through and around the rods; to produce oil through the rods, thus eliminating tubing; and, if joints could be effectively sealed, to give a buoyancy effect to lighten the polished rod load. Hollow sucker rods are appreciably more expensive than solid rods and their use in some of the above suggested applications often cannot be justified economically at the present time.

ROD MATERIALS

Well over fifty different type of carbon and alloy steels have been tried for sucker rod applications over the past several years. These steels include at least fifteen standard A.I.S.I. steels with the balance of them being "specials". These "specials" usually consist of some standard alloy as a base, with additions including such elements as copper, vanadium, boron, molybdenum, chromium, silicon, and nickel, in addition to the usual manganese. Many of these have been tried and discarded as being unsatisfactory although over twenty different steels are still available today from the eight manufacturers of sucker rods, and new ones appear every year. Quite frequently we find an alloy that apparently gives exceptionally good service in some particular well environment where others had failed, but then it too fails in a most disappointing manner under slightly different conditions. No panacea has yet been found among the alloys, although three or four old stand-bys have been adopted as standard by all manufacturers.

Besides the alloy steels, several non-ferous alloys have been tried including monel, K-monel, Ampcoloy, duronze, and aluminum. Monel has excellent corrosion resistance but does not have the required strength for deep or heavy wells and is very expensive. K-monel has the necessary strength, excellent corrosion resistance and comes as near being the panacea for sucker rods as any metal yet tried, but has a cost ratio of six or seven to one over steel rods, which just about rules it out economically. Ampcoloy has excellent strength and good corrosion resistance but has a fairly low fatigue endurance limit and high notch sensitivity. Duronze is in much the same category without the higher strength of Ampcoloy. Aluminum's main claim to fame in some alloys is its light weight, that is, high strength to weight ratio, and its excellent resistance to hydrogen sulfide corrosion. However, it is extremely difficult to forge without losing its built-in work hardened strength, is susceptible to salt water corrosion and has a much higher stretch factor under load than steel. It does, however, hold promise, and research is still under way on this material.

Rods have been electro-plated with chromium, nickel and zinc, galvanized, and metalized, with several metals, including zinc, monel and stainless steel. They have also been coated with plastics of several kinds, and even poreclain enamelled. All of these plating and coating trials have met with varying degrees of success, some of them proving quite beneficial. However, generally speaking, the coating is effective only so long as it continues to cover completely. As soon as it wears through or is damaged so as to expose the bare rod, even in one small area, corrosion then takes place at that small point at a greatly accelerated rate and very quickly proceeds to failure.

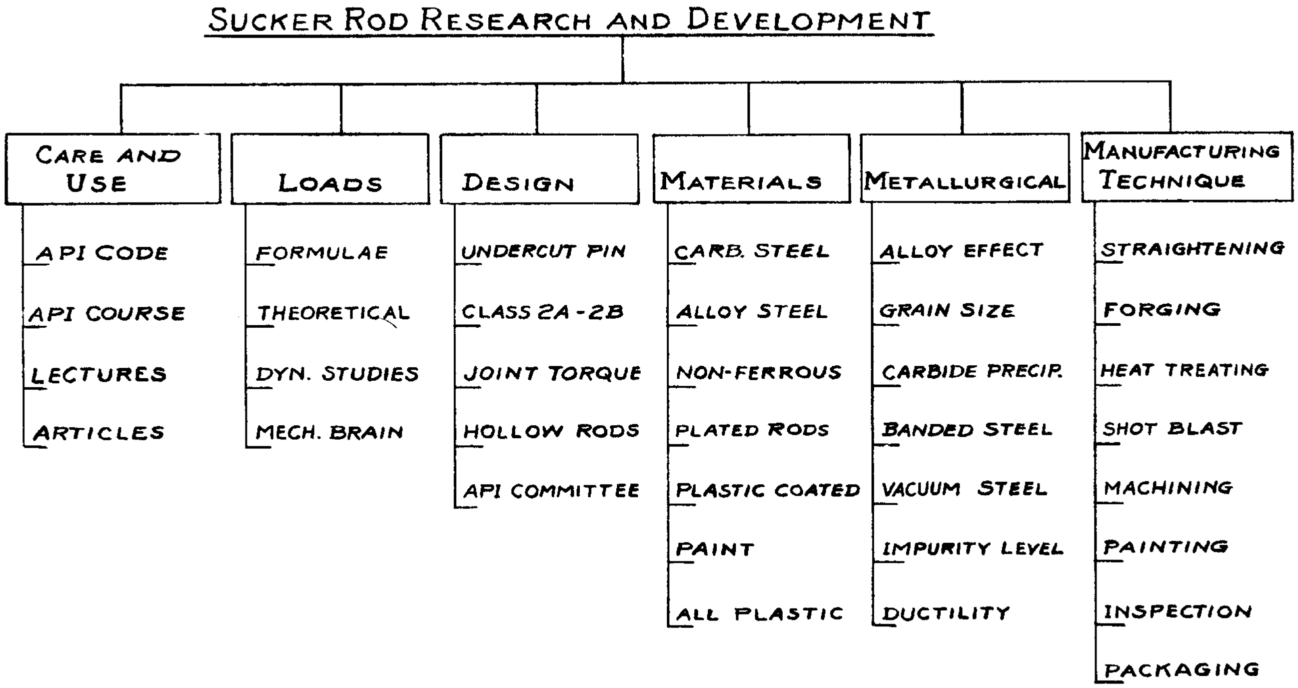
With this fact in mind there is a growing feeling, particularly on the west coast, that rods should be painted with an oil soluble paint. The thinking behind this is that the paint will protect from rust and corrosion until the rods are run in the well. The paint would then dissolve, exposing the rods' total surface to the corrosive fluids, thus spreading the effect over a much greater area and thereby minimizing its severity at any one point, consequently greatly increasing the life of the string. This theory may have some merit, but the merit is questionable. Some manufacturers have been furnishing oil soluble paint for a number of years, while others have not. Those who have furnished it have not seemed to gain any appreciable sales advantage.

With the advent of modern plastics it has been suggested that this miracle material might be an ideal sucker rod stock. Unfortunately, the phenolic and polyester resins are bad actors when it comes to failure by fatigue on repeated stresses. Their application to sucker rods, therefore, is not attractive. The new epoxy resins, however, are much superior in this respect and offer more promise. The main difficulty here, though, is the problem of a satisfactory joint, the low modulus of elasticity and the possible problem of buoyancy. The main advantages are practically complete corrosion resistance and light weight, being less than a quarter that of steel. All of this is now under investigation.

METALLURGICAL RESEARCH

Many papers have been written on this one subject alone, so our comments here must necessarily be in outline form only. It has been known for a number of years that the alloy content of steel affects the degree to which it is susceptible to corrosion. In evidence of this we have the many tests made on the many different alloys in sucker rod service. The search has been for an ideal alloy that would stand up in oil well fluids of all kinds. Of course, none has been found, although the nickel steels such as 4621 alloy, containing 1-3/4% nickel, recommended for mildly corrosive well fluids and 4820 alloy, containing 3-1/2% nickel, recommended for highly corrosive well fluids, have been the old stand-bys of the industry for years. More recently, however, we have begun to suspect that alloy content is not the complete answer. This was underlined when we found that in certain fluids, steels with smaller amounts of alloy stood up better than the more highly alloyed steels, particularly in the sweet crude territory. This led us to believe that such things as metallurgical structure might have a bearing on the problem. Laboratory experiments have proved this to be true and a rather large field has been opened up for investigation in the field of how metallurgical composition and structure affects sucker rod preformance.

Under investigation and scheduled for investigation are such subjects as effect of grain size, banded steels, and impurity level; the difference between open hearth and electric steels and their relative nitrogen content; carbide precipitation at the grain boundaries and the related subject of normalizing vs. normalizing and tempering; the advantage



of vacuum melted steels, if any; the true significance of our old standards on reduction of area, elongation and impact values; the relative value of normalizing and tempering vs. quenching and tempering; possible beneficial effects of the rare earth metals such as cerium and thorium as additions, and even the value of improved steel mill practices. We have learned a great deal from the studies already made along these and kindred lines, but there is a very large field of basic metallurgical investigation yet remaining. This must necessarily include a vast amount of field testing which after all is the criterion, for the proof of the pudding is still in the eating. Undoubtedly, a program of cooperative research and field testing by the manufacturers and the producing companies will be evolved and will greatly hasten the realization of the large benefits to be derived.

MANUFACTURING TECHNIQUE

Much has been done to improve manufacturing technique in the past several years, all of which improves quality and assures the user of a better and longer service from his rods. This applies to both rods and couplings.

As far as rods are concerned, the first operation is straightening by what we call the cross-roll process. Work is being done on developing a new process which will leave an improved stress pattern in the rod. Heating for forging has been greatly improved. Years ago we required two heats or two times in the furnace resulting in grain growth and heavy scale to complete one forging. This has long since been cut to one heat and some manufacturers are using so called "high head" heating and even induction heating. This leads to cleaner, sounder forgings.

Originally rods were heat-treated on the ends only. Today all manufacturers heat-treat from end to end and furnaces and heat-treating techniques are being improved for closer and better control. Most manufacturers today shot blast their rods to remove mill, forging and heat-treating scale. This means a better and more adherent paint job.

Machines and machining methods have been improved, utilizing modern carbide tools, automatic machines and better threading dies, all of which means better quality control and higher quality. Work has been done on rolling threads rather than cutting them and the process holds much promise. Some manufacturers degrease the rods before painting, which permits a better paint job. Most manufacturers now bake the paint after dipping which makes it more permanent and improves the appearance, and most manufacturers are equipped to bundle the rods, giving better protection in transit and allowing easier handling.

The making of couplings has also been improved. Both carburized and induction hardened couplings are available. Here again automatic machines utilizing carbides are being used for better quality. All manufacturers now tap their couplings from end to end instead of each end separately, thus assuring better thread alignment. Also, all manufacturers have added an operation to control parallelism of the contact faces, thus assuring a tighter, more uniformly stressed joint.

For both rods and couplings, experience and research has developed a much better sequence of operation resulting in improved quality and quality control. New and more complete conveying and handling equipment protects material in process from damage and most important, improved and more complete inspection methods assure the oil producer of a much better and more uniform rod than he was getting a few years ago.

Thus we see that research and development work on sucker rods progresses on all fronts. It has been greatly accelerated in the last three or four years. We know of several processes today which would improve sucker rod performance, such as nitriding, aluminizing, chrominizing, centerless grinding and special mill practices to give sounder more impurity free billets; but all of these are at present uneconomical. The work will continue, however, and will continue to bring about better rods for the more economical production of oil.