Internal Coatings for Tubular Goods

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INTRODUCTION

Oil industry applications have been the largest single market for internal pipe coatings. In both primary and secondary recovery and in drilling operations, coatings have been widely used for corrosion control. The proper use of coatings has resulted in the solution of many common corrosion problems during the past two decades.

It has only been since the mid-Fifties that there has been a baked-on plastic coating industry serving oil and gas producers. During the years since, baked internal pipe coatings have become an accepted tool in the drilling and producing industry. These years have seen the coating industry grow to a total production volume of approximately 50 million ft of pipe per year. During this time, more than 300 million ft of oilfield pipe have been internally plastic coated.

This 300 million ft of pipe was coated because oil and gas producers had problems which coatings helped solve. These problems involve all sorts of corrosive conditions and paraffin problems. Coated pipe has been used in wells as shallow as 100 ft. There are also strings deeper than 15,000 ft. Coatings have been used all over the domestic oil industry from California through the Mid-Continent area but particularly in the southwestern United States. An extensive market out of the United States has developed in the past few years. There are considerable quantities of baked coatings in service in Canada, Latin and South America, Africa and in the Middle East. Users range from major oil companies to small independents and include drilling contractors and rental organizations.

The increasing use of baked plastic coatings is based on one primary fact: that **good** coatings can make a profit—make money—for the user with problems. But—it must be **good** coating.

HISTORY

Corrosion as an operating factor in the oil and gas producing industry was first recognized in the sour production from oilfields in the West Texas and Mid-Continent areas. In the late 1930's some efforts were made to combat corrosion in oilfield storage vessels with air-cured plastics and the first crude attempts to use baking resins on oilfield pipe were made. It was not until the 1940's, actually after the war, that plastic coatings were used in any significant quantity for oilfield work.

The substantial majority of the materials used in the late 1940's were air-drying vinyls. Most of these materials, and there were many brands and many applicators, were applied without any great amount of engineering effort in regard to application of the coatings. Also, coated materials were not used in an engineering manner. Accordingly, as might be expected, in a few instances the results were good, but in many others, were unsuccessful. During the latter part of the 1940's more experimental work with phenolic and other thermosetting materials was conducted because experience in the field indicated that plant-applied coatings of this type more nearly fulfilled the needs of the industry.

Phenolic coatings enjoyed considerable success during the early 1950's and almost completely dominated the field of tubular coatings, until newer formulations based on epoxy resins appeared on the scene. Since this time, coating formulations have been subject to wide variation aimed at obtaining specific combinations of chemical and mechanical properties for the ever-increasing requirements of oil and gas producers. Other materials have appeared on the scene since the epoxy modifications were introduced. Among these are exotic material modifications of the phenolics and totally new systems for special service requirements.

At the present time, the old tried and true phenol-formaldehyde material, the phenolic coating, in perhaps a somewhat more sophisticated form, is still the mainstay of the coating industry. It is still the "work-horse" for corrosion and paraffin service.

Along with changes in materials have come new approaches to application, including airless spray and centrifugal application methods. Improvements in coating materials have been paralleled by engineered improvements of coating application equipment and procedures. We have seen the coating industry evolve from primitive beginnings to its present point, where work is done in modern, semi-automated plants scattered throughout the oil producing regions. The coating process has progressed from an outdoor operation when the outcome depended primarily on the experience or conscientiousness of the foreman on the job, to a highly developed art in an engineered plant.

THE PRESENT ART

A protective coating functions as a barrier to prevent contact between the substrate to which the coating is applied and the corrosive fluids being handled. It follows that the applied coating, to be effective, must be adherent to the metal, and resistant to both the chemical environment and the physical stresses encountered in that environment.

Because of the rapid growth of the coating industry and the abundance of applicators, generic types of coatings, brand names, etc., some confusion exists in the selection of a material for a specific service. Committees in T-1 and T-6 of the National Association of Corrosion Engineers have attempted to clarifly this situation. Some of their recommendations have been published.[1] There is a marked trend in the coating industry today to develop and market coatings for specific types of corrosion problems.

There are a great many different environments in which corrosion problems can occur. For any specific problem, the **good** coating is one which will function in that specific environment. The selection of a specific coating should depend on what purpose the coating is expected to serve. There is no panacea, no all-purpose coating system; no single coating or system yet invented will do everything.

Any consistently good coating, however, incorporates three features. These are (1) good coating material, (2) application with equipment engineered to do the job properly, and (3) proper procedures, including an established quality control program, which insures effective utilization of the equipment and material.

The importance of selecting the proper coating material to do a given job—to perform in a specific environment—cannot be over-emphasized. The unfamiliarity of some laymen with the basic characteristics of the various commercial plastic coatings has led to many instances of misuse and subsequent poor performance. Each generic type of plastic has strong, perhaps outstanding, qualities, along with compensating weaknesses. Every commercial coating system might be considered a compromise. One, perhaps, will balance excellent acid resistance against poor caustic resistance, with adequate but not good mechanical properties. Another will exhibit toughness and abrasion resistance, but lack resistance to mineral acids. A third type may have limited chemical resistance but exhibit tremendous adhesion and flexibility. And within each generic type there exists a wide range of performance characteristics. For example, all commercial "phenolics" are not alike—not nearly. Some will resist 12.5 pH mud at 300°F. Others fail after a short time in 11.0 pH mud at 250°F. Often, before the introduction of a new commercial coating, upwards of a hundred variations of a minor nature are made in a formulation based on a particular pigment-resin system before optimum performance is achieved.

Plastics as a class might well be compared to metals; at least as wide a range of resins is available as there are metals. Today coatings based on many resin systems are available. The most popular ones are phenolics, epoxies, and vinyls. We could compare carbon steels with phenolic resin systems. There is practically an unlimited number of combinations of chemistry, heat treatment, etc. available to the metallurgist to obtain a desired end product. The same circumstances are true for the coating chemist who formulates a coating within a given resin system. His sphere is still more one of art than science—although science is playing a larger and larger part.

We in the coating industry today know our materials, regardless of type, are good. We know this based on good field experience, backed up by countless hours of laboratory test work and thousands upon thousands of samples tested in modern equipment such as high-pressure, high-temperature autoclaves,[2] (shown in Fig. 1), capacitance cells, tensile machines, impact and abrasion testers, salt water flow testers, etc. Most of these testing techniques have been developed during the past few years, and are being expanded and refined daily in the research and testing laboratories in the coating industry.

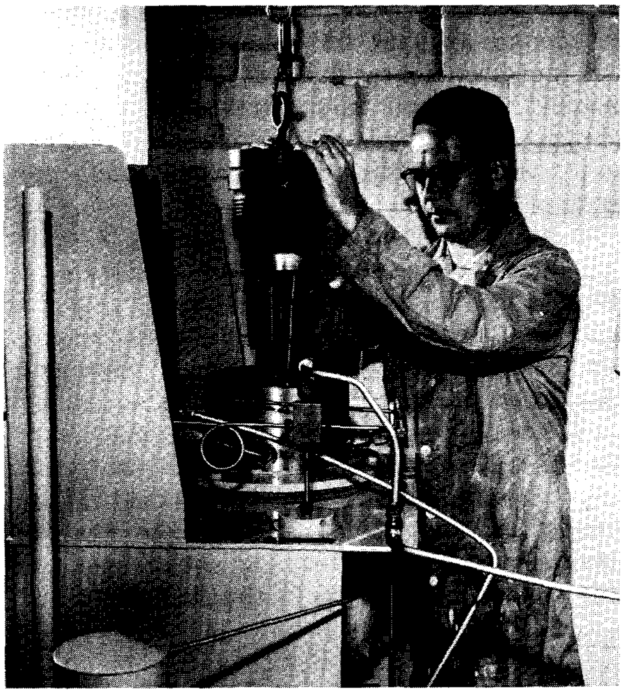

FIGURE 1

Modern coatings are researched and quality-control tested using equipment such as this high-pressure, high-temperature autoclave to stimulate down-hole environments.

In keeping with the newness of the industry, the testing of coating materials is a relatively new art, one which is not now standardized. As a result, many coating users have found it desirable to establish test programs within their own companies. These have been used to assist in selecting materials for particular services or specific problems, as well as to distinguish between the good and poor competitive coating materials of a given generic type. Needless to say, any reputable coating applicator should be able to furnish his prospective customer with legitimate test data for his own commercial products.

Good coatings are applied in engineered plants, Fig. 2, with engineered equipment and methods. Technology in the industry has advanced to the point that good operating procedures have been established. They are followed. All good coatings require excellent surface preparation, application of the coating by means adaptable to the selected material, good quality control in all phases of the operation, and final inspection of the finished product.

FIGURE 2

Engineered application equipment is used in modern coating plants.

Surface preparation prior to coating of oil-field tubular goods requires a pre-cleaning step to remove surface contaminants, such as oil, grease, varnish, wax, etc. This is commonly accomplished by either chemical cleaning with degreasers and pickling acids, or by thermal methods involving a high temperature soaking oven to char organic materials inside the tube. Either of these methods, assuming suitable controls to prevent damage to the tube or connection, can be satisfactorily used. Each has its place in an efficient plant operation. The choice is dictated by the job to be done.

Cleaning is the foundation of a successful coating job. The best material applied over a poorly prepared surface will likely be a poor performer. A mediocre material which is properly applied may give good service. As a general rule, though, applicators with mediocre materials do not have excellent facilities or techniques. It is well established that the best performing coating **must** be applied to surfaces which have been blast-cleaned to the parent metal. A "white-steel" surface, with an anchor pattern suited to the applied coatings, is an absolute necessity to obtain a serviceable product.

Conventional during past years have been the thin-film materials which were air-sprayed, multi-coat multi-bake systems. Present technology has led to the development of specialized materials including thick-film coatings, which lend themselves to more automated plant application facilities. Regardless of method, an applicator supplying good coating will have suitable equipment in good operating condition, people with "know-how" to use this equipment properly, and procedures designed to insure doing the required job in the proper way. Some consumers write detailed specifications regarding the application techniques to be used for their work. In the absence of these, any reputable coating applicator has available to a prospective customer the written procedures applicable to each of his particular coatings. In many cases, these result in a better end product than a customer specification might require.

Final inspection of all coated tubes is perhaps an obvious requirement for good coating. One of the tools most useful for this is the semiautomatic electronic holiday detector shown in Fig. 3.

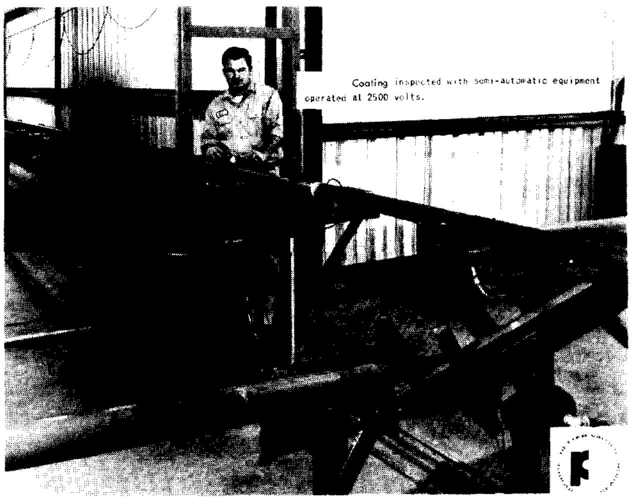

FIGURE 3

Good coating systems require modern production testing equipment, such as this holiday detector.

A holiday is an electrical discontinuity of less than 80,000 ohms equivalent resistance, sensed with a wet sponge moved at 60 ft per minute and measured with an appropriate low voltage DC instrument. Based on satisfactory field experience, this criterion has been generally accepted in the petroleum producing industry. It is applicable and meaningful for thin film coatings, such as baked-on phenolics which are usually 8 mils maximum thickness. Holidays in thick film systems, however, show a much slower response to wet sponge testing because of the additional film thickness. Mass production requirements, therefore, have led to the adoption of high voltage "hot spark" testing techniques.

Application of higher voltages, such as 2500-volt AC potential across a PVC coating, with a wet sponge will not only detect coating voids with reproducible results, but will also "break through" thin spots in the coating. Use of this technique, then, gives even greater assurance of quality workmanship and superior coating performance.

A formal established quality control program is the key to successfullly producing **good** coatings on a routine basis. Modern coating industry management thinking is that the quality control function should be invested in well equipped, experienced personnel who are responsible not to a production supervisor, but to management. This concept became well established in the industry about six years ago. It has enabled the industry to turn out coatings which have become progressively better, and which are now doing a very reliable job in the field.

COATING USES

The primary use of coatings in oilfield operations is for corrosion control. Coatings also are widely used for control of paraffin deposition in producing equipment. Proper use of coatings has resulted in solution of many common problems, often with excellent payout and profitability. This is the basis on which a coating should be judged.

PRODUCING WELLS

Control of corrosion problems in producing oil and gas wells is undoubtedly the major historical use for plastic coatings. Coatings are a recognized approach to the severe corrosion problems caused by water, organic acids and acid gases, and which are sometimes magnified by turbulence found in high-volume gas condensate and high-volume, sand-producing, gas-lifted wells. More than 10 years ago, NACE's Unit Committee T1-C concluded that " . . . coated tubing is an effective and economical way to combat corrosion in sweet oil wells . . . "[3] A recent paper[4] surveys the 10-year result of a fieldwide coating program for about 200 wells in the Hastings field. The study shows excellent coating performance and good economics in this program. Corrosion and corrosion control costs were summarized as follows:

No mitigation:

Cost in \$/well/year, \$1,014

Coated tubing:

Cost in \$/well/year (3-1/2 year coating life), \$1,127

Cost in \$/well/year (9 year coating life), \$456

Chemical treatment:

Cost in \$/well/year, \$1,481

Similar case histories showing payouts of less than one year and profitabilities even greater than above are common.

Coatings have also been used over the years in conjunction with chemical corrosion inhibitors to mount a double-barrelled attack against existing or potential high-cost corrosion problems such as might be encountered in offshore production. One study[5] included a detailed economic analysis of corrosion control costs of 41 offshore gas condensate wells. It was shown that wells with plastic-coated tubing consistently have been treated effectively with less inhibitor than wells completed with bare tubing. Additionally, coating payouts through inhibitor savings as short as two years were indicated.

WATER INJECTION WELLS

Most water systems are economically corrosive—corrosion is costly enough to justify spending money to control it in the initial installation. Coatings are recognized as an outstanding approach to corrosion control in water systems, and they have an impressive record in water service. Even in earlier days, thin-film coatings provided yeoman service in the field. In fact, the use of coated lines and tubing has permitted successful and profitable operation of some projects that otherwise would have been uneconomical because of the corrosion problem.

However, several years ago, it was widely recognized that thin-film materials left something to be desired, particularly in oilfield water handling service. Experience had taught that conventional thin-film coatings in aggressive waters required a holiday-free coating. Experience also taught that it was difficult, if not impossible, to obtain a holiday-free, thin-film coating inside normal waterflood pipe as it was handled in the field.

Economic requirements of some waterfloods dictate the use of existing facilities, tubular goods included, insofar as is possible. The need for coatings adapted to application inside used pitted pipe for such projects has resulted in the introduction of many thick-film coating systems during the past few years. Typically, these are applicable 100 per cent holiday-free to used pitted pipe and have mechanical properties such that they remain holiday-free with normal field handling practices. Field experience with some of these thick-film coatings has been excellent[6], with reported payouts and profitability much better than general industry guidelines.

DRILL PIPE

The most common form of drill pipe corrosion is corrosion fatigue where the fatigue life of the pipe is reduced by a combination of metal loss and stress concentration resulting from pitting of the inside surface of the pipe. Corrosion fatigue is recognized as the source of a majority of the drill pipe washouts and twist-offs being experienced.

Coating of drill pipe is a relatively new major market for coatings. There is probably more interest in coatings now than ever before because economics are more important to the typical drilling contractor than before. Corrosion control is of paramount interest to the progressive drilling contractor simply because drill pipe represents one of his largest capital investments.

It is conservatively estimated that over 6 million feet of coated steel and aluminum drill pipe are currently in active service. Coatings are effectively protecting this pipe, are becoming accepted and are considered standard practice by some operators. One study[7] showed that the use of drill pipe coatings in the Mid-Continent area reduced drill pipe expenses from 33 cents to 18 cents per foot over 100,000 ft of drilled hole. This is a savings of \$15,000 for a \$12,000 investment, with prospects of a considerable further profit as the string continues to drill. Most contractors report that a coating which lasts for 100,000 ft of drilled hole has paid for itself and is making money. Economics are even better in some places, such as the Permian Basin, where severe corrosion attack is prevalent.

A recent economic examination[8] of drill pipe coatings used field data from both the Permian Basin and Gulf Coast. Results showed excellent profitability of internal coatings in both areas.

PARAFFIN CONTROL

Use of coatings for control of paraffin deposition in oilfield pipe is one of the oldest conventional uses of coatings. Paraffin accumulation is undoubtedly one of the major nuisance problems encountered in production. On occasion, it can also be extremely expensive.

As has often been the case in the oil field, practical experience has outstripped theory and scientific knowledge. There is much yet to be learned about deposition and accumulation mechanisms themselves, as well as considerable further study due several common theories of prevention. Current thinking is that plastic coating helps prevent paraffin build-up because of one or possibly a combination of these three factors: (1) surface smoothness compared to bare steel, (2) thermal insulation, and (3) forces related to the composition of the plastic surface.

Many outstanding successes with coatings for paraffin control have been reported. One study[6] covering 116 wells in one field, including flowing, gas-lifted and pumped wells, proved the coating to be about 90 per cent effective with payouts ranging from 15 to 48 months. In the same study, plastic coated tubing was installed in wells in another field and found to be 100 per cent effective.

CONCLUSIONS

Current experience with good coatings shows them to be useful, practical tools for profitable treatment of operating problems. Good coatings are available today. If they are taken care of, properly handled and used within their limitations, they will perform, and help solve most types of oilfield corrosion problems.

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