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PROTECTIVE COATINGS FOR UNDERGROUND PIPING SYSTEMS.

The following abstracts and summaries have been prepared from articles and reports relating to protective coatings for underground piping systems and are intended to give a fairly complete outline of recent investigations and developments in this field. Where more detailed information is desired the unabridged articles should be consulted.

1. Scott, G.N., The use and behavior of protective coatings on underground pipes, Oil and Gas J., 27, 195 (1928), and Bul. Am. Pet. Inst., 10, 78 (1929).

Scott discusses a few of the important aspects of care in the application of protective coatings, the types of failure which have been found to occur in service, and the manner in which false conclusions may be drawn from tests on specimens buried in selected soils. One of the objections to mill-coated pipe is the ease of rupture of the coating by rough handling before use. Continuity of the coating is essential so as to prevent localized corrosion; hence patch work, unless done very carefully, should be avoided. Since oil-soaked earth will readily dissolve the coating, it is necessary that all collars be properly caulked to prevent leaks. Air entrapped in the coating will cause rupture of the fabric. The added life that may be realized from the application of a particular coating is a function of the conditions of service to which the coating will be subjected.

Generally, the destruction of a protective coating in service may be either chemical or physical or a combination. A soil which expands or contracts with a change of moisture content and which has the ability to adhere to the coating causes considerable damage to certain classes of protective coatings; this may be called the "soil stress effect." Chemical changes may involve oxidation, loss of volatile constituents, and solution of bitumens in oil. Physical changes may be due to loss of bond between asphalt and metal, softening and flowing of the coating, distortion of the coating by movement of the earth caused by uneven trench bottoms and settling of the backfill earth. Temperature changes cause considerable distortion, cracking, and checking of coatings. Laboratory tests show that soils which give surface or subsurface checking may be expected to have a distorting effect upon coatings. Such soils are usually high colloidal. No direct relation between soils which are corrosive to bare pipe and those which are highly destructive to coatings was noted.

2. Fitzgerald, C., The Pure Oil Pipe Line Co. of Texas, Corrosion and pipe line coatings, Am. Pet. Inst. Production Bul. no. 204 126, (January 2, 1930).

Only a small part of any Mid-Continent pipe line system traverses what may be termed highly corrosive soil or hot spots. At present these spots cannot be located accurately or economically until the pipe within their limits approaches destruction. When such spots are located and the pipe replaced, or additional lines laid, it then becomes advisable to apply the very best type of protection available, almost regardless of cost, as such places are usually of very short length. When the expense of replacing a few joints in an isolated spot and the probable loss of oil are considered, it would be cheap to spend one dollar per foot or even more on protection of this type; but it manifestly would be folly to put such a covering on an entire line before locating points of trouble.

There appears to be little doubt that simple coatings are in the development state, and, therefore, the application of such a coating at the present time must be considered an experiment. It is suggested in the interest of economy that such experiments be limited to short lengths of line and as a further economy that the application be made on a new line whenever possible rather than later as a reconditioning job, in which case the experiment becomes about three times as expensive. During construction of a line, it is a good precaution to place the very best type of protection on short lengths of line through very deep ditches, and in places where gypsum or some other known corrosive substance is apparent in the soil. The proposed three-cornered tests provide an economical means for obtaining information on new or improved materials and methods.

It is apparent that many of the simple coatings in common use are practically immune to the chemical attack of the corrosive agents in the soil, but they do not remain on the line to provide the protection which, from a chemical viewpoint, they possess.

The damage caused to simple coatings by soil stress effect may be reduced materially by the use of one or more layers of a protective coating, chosen more for resistance to mechanical penetration than for chemical inactivity. It is indicated that the useful life of a simple coating is materially increased by an added protection of this type, which may consist of pipe line felt, wood veneer, thin sheet iron, aluminum foil, or other similar substance (fig. 6). The extent to which the life of a coating is lengthened depends upon the nature of the soil and the quality and quantity of the wrapping. However, it should not be inferred that an indefinite life of coating is thus obtained, as there have been many cases of direct penetration through wrapped coatings, in from two to five years, under severe corrosive conditions.

It seems logical to decide, without the necessity of much computation, that no coating should be used where the soil is non-corrosive; and it is equally apparent that no mathematics is required to demonstrate the futility of applying, at any price, a coating that is not likely to provide protection for more than a few months.

3. Scott, G.N., Field inspection of protective coatings applied to oil and gas lines, Am. Pet. Inst. Production Bul., no. 204 p.136 (January 2, 1930); also the Oil and Gas J., 28, 96 (December 12, 1929).

The causes of failure of coatings are numerous, but most important are soil action, faulty application and careless handling, and such miscellaneous factors as loss of bond between the coating and the pipe, material disintegrations, etc. By far the greater percentage of the inspections where the coating was unable to maintain the pipe corrosion-free showed some form of mechanical disruption of the coating.

So far as the data presented are concerned, the coating types may be considered in two large divisions. Division I, - which includes all coatings composed of paints, primers, bituminous materials applied hot, cutback bituminous materials, greases, enamels, emulsions with and without cement, and some of the above wrapped with thin woven fabrics-- is less able, as a whole to prevent corrosion from occurring on the pipe than division II, which includes coatings employing one or more plies of saturated fabrics of the roofing felt type, cemented together with hot or cold-applied bituminous materials or greases.

Coatings in division I break down so quickly to a point where corrosion starts that their use cannot be expected to eliminate repairs and replacements in highly corrosive soils. The use of these coatings may postpone the time and extent of repairs and replacements more than sufficiently to justify economically the application of the coating, but prolonged freedom from trouble on the line cannot be anticipated.

The combined experience of operating companies has shown that a very small portion of all pipe lines lies in highly corrosive soil.

It is not feasible to determine from field inspections what prolongation of pipe life may be expected from any particular treatment.

4. Logan, K.H., Why not call for quotations on pipe line protection, Western Gas, 7, 37 (Oct., 1931).

The purpose of this paper is to point out the distinction between good protective coating materials and pipe line protection.

Materials suitable for some soil conditions may be unsatisfactory in other soils. A large percentage of failures of coatings is attributable to improper application of inherently good materials. Since the failure of a coating may result from poor or unsuitable materials or from improper application or handling of the coating, the pipe line owner is seldom able to fix the responsibility for the failure. Since the pipe line operator is not a specialist in the identification of corrosive soils and is usually not versed in the details of combatting corrosion it would be to his advantage to purchase protection for his line rather than to purchase materials the effectiveness of which is not guaranteed.

If an operator received a quotation for the protection of a line for a specified period he could calculate from the cost of this protection the monetary advantage if any which he would receive by accepting the bid.

The necessary steps in securing bids for the guaranteed protection of a pipe line are outlined and the advantages and disadvantages of purchasing protection as distinguished from pipe coatings or coating materials are discussed.

5. Scott, G.N., A.P.I. coating tests. Progress report to the Am. Pet. Inst. committee on corrosion of oil field equipment, Production Bul. no. 208, 55 (Nov., 1931).

In the following paragraphs are summarized the more important results, deductions and conclusions of the first inspection of the A.P.I. line pipe coating tests. The statements are tentative only and subject to revision after subsequent inspections of like coating samples. Four more inspections of each coating in each locality are planned.

(1) Two practicable tests for the field examination of protective coatings for underground pipe lines have been developed and described in detail.

(2) Conductance measurements have been shown to be of considerable value in the study of protective coatings in the field.

Note: As a guide for operators desiring to apply conductance measurements on coatings in service the following interpretation is suggested. If the conductance of a coating under investigation is less than ten micromhos per square foot the coating may be considered to be giving perfect protection. If the coating has a conductance of ten micromhos per square foot or over but less than forty micromhos per square foot the coating may be described as possibly faulty, but need not be removed for further inspection. If the conductance is greater than forty micromhos per square foot the coating should be removed and the underlying pipe inspected for corrosion.

(3) The pattern test which consists of obtaining a pattern of pinholes by the use of a potassium ferricyanide indicator has been shown to be a useful tool for the examination of protective coatings. At the present stage of development of the test the patterns should be considered as a tool only, a) to record the condition of the coating, b) to show the quantity distribution of the breakdown, and c) to locate the actual points of rupture on the coating.

(4) The conductance and pattern tests are not completely applicable to all types of coatings, but when applied with intelligence one or the other, or both, will give satisfactory results for all types of coatings under test in this investigation.

(5) It is not particularly difficult to select from any given series of coatings tested those which are of little value and those which are quite effective, but it is an extremely difficult problem to determine what actual added pipe life is afforded in any particular case. This fact itself is of the greatest moment since the data are absolutely essential for the application of any economic rule of coating selection.

(6) The measurement and visual inspection of the pipe underlying protective coatings constitute the most satisfactory method of studying all types of coatings. The visual inspection is less certain for short service periods and for mildly corrosive environments, but when supported by the conductance and pattern tests becomes much more definite and reliable.

(7) The presence of pits on a coated pipe constitutes the most satisfactory criterion for judgment upon the protective value of coatings. The presence of rust (no development of pits) may have different significances depending upon the type of coating under consideration. The pitting criterion may be too liberal with respect to the coating for short periods of service or for mildly corrosive environments.

(8) The importance of knowing the corrosive environment of a coating inspected is emphasized.

(9) To take account of the corrosive environment of the coating, minimize the injustice of the percent-pitted figure in mildly corrosive environments and to assign a value to the various coatings whereby they may be compared quantitatively, a "degree of effectiveness" has been calculated for each coating. A justification for the use of this criterion lies in the agreement of the results with those obtained from the pitting criterion.

(10) The percentage of coated pipe showing pits is related to the thickness of the coating. The data indicate that the effectiveness of the coating increases very rapidly with the thickness up to about 0.20 inch.

(11) The data indicate that the rate of development of the deeper pit on a pipe beneath a ruptured coating as compared with a similar unprotected pipe is not related to the exposed area of the coated pipe.

(12) Only the heaviest coatings showed the development of no pits.

(13) For the period of test covered by this report the calculated degrees of effectiveness indicate that the soft coatings are of no value in preventing pits. These coatings are entirely too soft to resist soil stresses.

(14) Enamel coatings without shields or reinforcements reduce the anticipated average pitting by roughly fifty percent or less.

(15) All of the fabric-reinforced treatments, excepting the reinforced grease coating, reduce the anticipated average pitting by eighty percent or more.

(16) Shields are effective in general but wood veneer is less effective than strip steel or pipe line felts.

(17) The problem of perfect protection is still largely one of minimizing the effect of soil stress.

6. Davidson, J.H. et al, Study of protective coatings for interior of steel tanks and underground pipe lines, Am. Rway Eng. Assn. Proc., 30, 143 (1929); Rwy. Eng. and Maintenance 25, 244 (1929).

A coating of portland cement grout, preparation of a petroleum base into which rust-inhibiting chemicals have been compounded, or asphaltic liquid paints appear to have given better results for protection on the interior of steel water tanks than red lead and linseed oil customarily used. In underground pipe lines, records indicate that portland cement is much the best, bituminous coatings wrapped are next and paint coatings give the lowest increase in life.

7. Stokes, Albert, et al., First report of the corrosion of pipes sub-committee, Inst. Gas. Eng., Communication no. 20 (1930).

The effects of various coatings on wrought iron and steel were determined in two types of tests. (a) The coated metal was placed in soil and made the anode of a closed electrical system. The source of current was a 6-volt battery. The current was measured at different intervals of time and the resistance of the coating calculated. (b) The voltage differences between a coated and uncoated specimen were measured at various times. The resistance of the coating decreased with increasing water content while the voltage measurements showed increasing values. Painted pipes showed much greater resistance to the flow of current than bare pipe. Pipes covered with paper wrappings and paints were about 50 times as resistant to the flow of current as paint coatings. Deep pits occurred in the metal surfaces where the coatings were broken. Cement coatings were found temporarily resistant to stray current electrolysis.

Also in Gas J., 192, 725 (1930).

8. Shepard, E.R., Bureau of Standards, Measurement of the electrical conductance of non-metallic pipe coatings, Am. Gas J. 136, 22 (June, 1932).

The electrical conductance of pipe coatings is recognized as an important factor in the study of protective coatings. Because of the very wide range in conductances encountered, it is difficult to find a simple and universally applicable method of test suitable for field use. Resistances of the order of megohms are frequently encountered, which precludes the use of the a-c bridge with induction coil and telephone receiver. On thin coatings, capacity effects are noticeable when using a periodically reversed current, and where the resistance is very high, the error introduced by this effect may be large.

Errors involved in the measurement of conductance by the use of direct-current apparatus include: (1) polarization; (2) galvanic potentials between the pipe and the auxiliary electrode, called the saddle; and (3) endosmose, or the movement of moisture within the capillary pores of the coating. Polarization errors are found to be relatively small if the pipe is made anodic during the measurement. Galvanic potentials between the pipe and the saddle may be as high as 0.3 volt, even though an iron saddle is used. Errors from this effect may be kept within limits considered aatisfactory for this class of work, if a potential difference of at least 3 volts is applied across the coating under test. A potential difference of 30 volts is sometimes found to give variable and erratic results when testing coating conductances. This is attributed to endosmose or the movement of the liquid in the direction of current flow, within the pores of the coating.

With these various difficulties in mind, a simple and portable direct-current test-set has been assembled which measures coating conductances with an accuracy considered satisfactory for that class of work. It includes two current indicating instruments in series with a 3-volt dry battery. A number of ranges corresponding to currents of 4.5 microamperes to 0.45 ampere are obtained by a combination of shunts. For the lower resistances a Weston milliammeter is used which can be read immediately after closing the circuit and before polarization appreciably diminishes the deflection. For the higher resistances a microammeter is employed, the relatively long period of which is not objectionable, as polarization effects are not serious at low current densities. For extremely high resistances, a 30-volt battery is provided.

Comparative tests on a large number of sample pipe coatings in soil boxes indicate that this d-c test-set, when properly used, can be relied upon to give results within about 15 percent of those obtained with an a-c bridge. Because of the variable and unstable character of coating resistances, this accuracy is considered satisfactory.

Summary of Test Procedure.

The following procedure should be employed in measuring pipe coating conductances in the field with direct-current apparatus:

(1) Make measurement soon after uncovering pipe.

(2) Provide a suitable conducting medium between the coating and the metal saddle, which makes intimate contact with the coating at all points.

(3) Prevent surface leakage along the coating by either cutting the coating away on both sides of the saddle or by thoroughly drying the coating surface. Only on very high-resistance coatings will the surface leakage introduce a serious error.

(4) Use a voltage of not less than three volts and not more than six volts, except for coatings of very high resistance. Avoid the application of sustained high voltages when making tests.

(5) Connect the positive terminal of the test set to the pipe and the negative terminal to the saddle to insure a flow of current through the pad from the pipe to the saddle.

(6) Read the indicating meter as quickly as possible after closing the circuit to eliminate, as far as possible, the effects of polarization and endosmose.

9. Rogers, W.F., Influence of oil in soil corrosion, Proc. Am. Pet. Inst. 13, 131 (1932).

The paper describes the results of the examinations of oil lines in various parts of Texas, carrying widely different crude oils. The findings have been so consistently the same that it is now regarded that the presence of oil can accelerate soil corrosion. It seems that regardless of the type of oil, as long as a sufficient quantity is present, accelerated corrosion will occur. The soil texture does not play a direct part in promoting the rate of corrosion in the presence of oil. Soil texture is important only when it controls the rate at which oil may be washed away. The type of pitting which has been discussed is that of sharp-featured direct pits filled with black-green and white corrosive products. It has been found that this type is almost universally confined to oil bearing soils.

The corrosion appears to be the result of a difference of potential originating in the exclusion of oxygen from a limited area on the pipe surface by the oil.

10. Gill, Stanley, Pipe line protection, Ind. Eng. Chem. 25, 49 (1933).

This paper describes briefly the different types of pipe line protection now in use pointing out the virtues and weaknesses of each. The following are excerpts: "Generally speaking this class (bituminous cutbacks) are of little or no value for the protection of pipe which is exposed to destructive soil corrosion. The asphalt emulsion coatings have not been at all successful on buried pipe lines. The greases possess in comparison with bituminous materials, the advantage of a far greater inherent impermeability.

This advantage is more than overbalanced by the fact that the greases possess no mechanical strength and are consequently punctured by the slightest soil pressure. In combination with suitable wrapping materials grease coatings will give good protection but it is essential that the wrapping material shall itself be quite impervious as otherwise the grease may be absorbed by the soil. There have been no extensive field tests of pipe line coatings of the lacquer type. In general by properly selecting asphalt and wrapper and by exercising proper care in application, coatings of good protective value can be obtained. Certain petroleum asphalts are entirely unsuitable for pipe line protection, being subject to rapid deterioration. Others have been found to be exceedingly stable when exposed to soil action. Asphalts should never be used without the protection of a wrapper.

Coal tar enamel coatings will afford protection under some conditions without the use of wrappers. The wrapped enamel coatings which probably possess greater protective value than any currently available coatings of comparable cost fall into two classes depending upon whether the wrapper is applied while the bitumen is still molten or whether the wrapper is applied loosely for a chilled enamel layer. The most widely used, and at present the most satisfactory, wrapping materials are bitumen-saturated felts similar in general character to those which are used for roofing. Generally speaking, the asbestos felts are more satisfactory for the purpose, since rag felts have been found to deteriorate when exposed to certain soils.

Experience has shown that a properly applied cement mortar coating will afford lasting protection against soil action under almost any conditions. The objections to cement coatings are the relatively high cost of application and the fact that pipe so coated can not be economically recovered for re-use if the pipe line is abandoned.

Pipe coated with vitreous enamels has been marketed during the past few years in Germany, and a large American manufacturer of pipe is now equipped to supply a similar coated pipe. Since there have been no lines laid with this pipe and since no data on its performance in actual lines are available, no conclusion as to its merit can be drawn.

11. Peper, J.H., Use of cement in protecting underground pipe lines against corrosive action of soils, Oil and Gas J., 32 9 (1934).

The value of cement as a protective coating for metals subjected to the corrosive action of soils can hardly be questioned. It is today considered a most durable and reliable material for all structures in contact with either soils or atmosphere.

The protective value of cement in cases of electrolysis due to stray currents is questionable. Boxing and cementing lines to protect them against stray currents was tried by our companies many years ago and proved a failure. The pipe was destroyed in a short time.

As compared with coatings of bitumen, the chief objection to the general use of cement coatings has been the heavy cost.

Lately there have been developments in the application of cement coatings which bring the cost of these coatings down to a basis comparing favorably with the well-designed bituminous coatings.

As a rule, a plain sand-cement mortar will not have the high qualities that a good concrete has. The mortar costs more and ordinarily a much higher water ratio has to be used, because where a thin coating - say one-fourth inch to one-half inch - is to be applied, it is impossible to use anything but a thin mortar. The thin mortar coating, however, is sufficient in most cases to thoroughly protect the metal against soil corrosion.

Combinations of asphalt emulsion with cement and concrete have been developed and claims are made that under certain conditions the asphalt is helpful in preventing disintegration of the concrete. The combination should be effective as a protective coating, but the cost and method of application have to be such as to make it practicable.

In 1914 a cement coating was applied to 2 miles of 6-inch pipe by means of a gun. After several trials as to the best way of applying this coating the following method was developed: the pipe was laid in the bottom of the ditch on a 6-inch board and supported above the board by 1-inch concrete blocks. The mixture was show under the pipe and prevented from getting away by holding boards against the pipe and edge of board, thus forming a dam. After the bottom was filled up, the nozzle was applied to the top and sides until about three-fourths inch of coating was built up. The job of coating cost about 31 cents per foot and has never to this date given any trouble.

At the present time our companies are using a method involving a form which applies a 1:3 cement mortar one-half inch to five-eighths inch thick. This method consists of an 8-foot hinged metal form suspended from the pipe by hangers which give the proper clearance all around. Slaters felt is used inside the forms to prevent the mortar from sticking to the forms and at the same time prevent leakage at the joints. The felt also sticks to the mortar and prevents rapid drying out of the mixture. The form can be removed the next day following the application. The pipe is supported on skids over the ditch while coating is applied and lowered into the ditch a day or so after forms are removed. This method is now in use for reconditioning jobs at the rate of approximately 20 miles per year and the average cost is not in excess of 15 cents per foot. Details as to the construction and use of the forms are given in the Oil and Gas J., Feb. 1, 1934.

Information in regard to the making and using of the forms has been given several different companies. Patents have been applied for on the form, largely as a measure of protection to ourselves, and we are glad to allow other companies to use them when they express a desire to do so.

There are several distinct advantages in using cement:

(1) There is no time lost in its application while waiting for proper weather conditions. This applies most generally to field applications, which in the majority of cases, call for careful cleaning of the pipe, application of primer, followed by the main coating. When using cement, the work can be done at any time that it is possible to do pipe work, except in freezing weather. It is not necessary to have the pipe warm and dry, as is the case with the hot applications. The saving in time is a cost factor of considerable importance.

(2) Reconditioning with cement can be done without taking the line out of service; in fact, with oil in the line, quick drying out of the coating is prevented and is an advantage. Combined with the use of the electric welder for spot welding, the application of a cement coating can be accomplished with a minimum loss of use of line.

(3) While it is necessary to clean a line in order to observe its condition, it is not necessary to clean as thoroughly when using cement coating as when a primer is to be applied.

(4) Cement has high corrosive inhibitive qualities and acts toward the arresting of corrosive action. A close observation of the depth of pits in a line to be reconditioned will show that a majority of the pits are not deep enough to weaken the pipe materially, provided corrosion goes no further in them. Cement will stop the action and thereby make it possible to cut down the amount of welding.

(5) There is less danger of injury to men when using cement than when using hot bitumens. It is also easier to get men to work with cement than to work with hot tars.

(6). The corrosive effect of oil-soaked soils on pipe has been clearly demonstrated. Under such conditions it is unsafe to apply any coating which is affected by crude oil. Cement coatings will be found effective under these conditions.

12. Scott, G.N., A.P.I. coating tests, Progress report no. 4, Proc. Am. Pet. Inst., 15 (1934).

This is a report on the conditions of 19 kinds of bituminous pipe coatings applied to working lines in approximately ten widely separated localities and 46 coatings applied to short lengths of pipe exposed in 15 locations. The time of exposure was approximately four years. The tests were conducted jointly by coating manufacturers, the American Petroleum Institute, and the National Bureau of Standards. Tables are given showing the structure and performance of each coating.

The following conclusions are based upon the results of 1934 and previous inspections and are subject to revision after a final inspection which is planned.

(1) While complete prevention of corrosion by any of the coatings in this test has not been realized, pitting has been reduced by most coatings. A practical view of the problem is taken and suggestions offered in the choice of coating. Shielding or reinforcing is considered minimum and necessary practice in pipe protection for average conditions. Special measures depending upon circumstances will be required in severely corrosive environments.

(2) In general, soil stress is progressive and is the most important factor in coating design. Methods of eliminating soil stress are discussed.

(3) The next most important progressive factor is the absorption of moisture by the coating. Suggestions for the improvement of coatings in this respect are given.

(4) Inspection Methods. Neither of the electrical tests are entirely satisfactory for arranging all coatings in any order of preference. In a particular case the conductance may measure the amount of water absorbed and/or the area of pipe surface exposed. The amount of dissolved substance in the water will determine the particular value of conductance determined. The pattern test is efficient only when there is an actual exposed area of pipe. However, both of these tests are of value in eliminating the less desirable coatings. The best criterion for judging the behavior of a coating is the condition of the pipe.

(5) For the purpose of arranging a variety of coatings in order of relative merit, tests on short pipe sections of small diameter do not agree closely with tests on large operating lines. Reasons for this disagreement are discussed.

13. Rolfe, E.C., Reconditioning of pipe lines is fast becoming of primary importance, Oil & Gas J. 33, 97 (Oct. 25, 1934).

This is a descriptive paper covering briefly recent trends in pipe line protection including the use of thicker coatings and new apparatus for locating lines, cleaning pipe, applying and testing coatings and handling the coated pipe. Soil stress is said to be appreciable in a large portion of the midcontinent and western states. For such soils an asbestos felt should be incorporated in the coating to prevent its distortion and puncture.

14. Logan, K.H., Development of specifications for protection of pipes underground. Ind. & Eng. Chem. 27, 1354, (Nov. 1935).

Eighteen factors concerning protective coatings are summarized. Most of these deal with the relative merits of coatings. A protective coating may have one or both of two purposes: (1) to eliminate potential differences along the surface of the pipe by keeping the soil and soil solutions away from the pipe, and (2) to increase the electrical resistance of the circuit of the corrosion currents either through the resistance of the coating itself or, in the case of metallic coatings, by the film which the corrosion of the coating produces.

The need for specifications is discussed. The requirements for a satisfactory coating are listed as follows:

(1) The coating should resist mechanical shock. The requisite numerical measure of this resistance is not now known but it can be determined approximately or within limits by tests of coatings known to have this property in a satisfactory degree.

(2) The coatings should not flow under moderate pressures applied over long periods. Appropriate specifications to assure this property can also be determined by a study of existing coatings, the performances of which are known.

(3) The coatings should have and maintain a relatively high electrical resistance. The required resistivity of the coating can be estimated from a study of the electrical data on pipe coatings secured by the American Petroleum Institute, the American Gas Association, and other investigators.

(4) This requirement of high electrical resistance, if applied to the coating on the pipe in the trench, will take care

of the need for freedom from pinholes, holidays and abrasions.

(5) The coating should deteriorate but slowly with age and exposure to soil conditions. This requirement probably cannot be embodied directly in a performance specification but may be covered in part at least by the exclusion of certain materials known to deteriorate, the presence of which can be determined by tests.

(6) The adhesion between the coating and the pipe should be sufficient to maintain the two in intimate contact when the coating is exposed to such shocks and strains as it will encounter; otherwise, moisture entering at a point where the coating is ruptured may spread to other sections of the pipe and rusting may follow. Methods for measuring the adhesion of a coating have been developed but no standard has been adopted.

Certain other requirements not fundamental to coating service are necessary for the satisfactory application of the coating material. Some of these will vary with the season of the year during which the coating is applied to the pipe and with the manner of application. These include the evolution of fumes, susceptibility to temperature changes, and ease of application. Such requirements can be specified quite definitely when the conditions under which the coating is to be applied are known.

The means of securing pipe line protection are so numerous and the conditions against which protection is required are so varied that it is not practicable to write a single specification suitable for all pipe line protection, nor can an engineer or technologist sit at his desk and evolve a series of satisfactory specifications. It would be quite possible, however, for an organization, through a study of existing data and a relatively few tests of materials of known performance, to evolve a series of performance specifications for pipe coatings that would, if adopted, be of definite assistance in the procurement of a protective coating offering promise of real service.

15. Ewing, S., and Scott, G.N., Deterioration of pipe line fabrics. Am. Dyestuff Reporter, 24, 699 (Dec. 16, 1935).

Twenty-six fabrics were exposed to a moist clay loam containing considerable organic matter for periods up to 300 days. The exposure caused a decrease in strength of all of the fabrics. The asbestos felts were less affected than the other materials. All organic materials showed an appreciable decrease in strength within 100 days and most of them showed a further decrease for longer periods of exposure. The use of creosote, tar and other disinfectants delayed rotting considerably but did not prevent it. There is little choice between asphalt and coal tar as a saturant for fabrics so far as strength is concerned. The asphalt-saturated fabrics appear to absorb more water and become limp which is not true of the coal-tar saturated felts.

16. Allyne, A.B., Recent trends in pipe protection and maintenance. Gas Age Record, 77, 18, p.465 (May 2, 1936).

This is a carefully prepared survey of recent developments in pipe line protection. The use of soil surveys in the selection of a pipe line route requiring a minimum of pipe protection is suggested. Shields are recommended as a protection against soil stress. The advantages of a shield as compared with a reinforcement are as follows: (1) it protects all of the bitumen from soil stress; (2) when used internally the reinforcement often results in blowholes in the outer coat from air or gases existing on the surface of the wrapper; (3) an inner reinforcement often acts as a wick to carry moisture. The use of holiday detectors is discussed. The costs of cathodic protection have been reduced by the use of apparatus designed especially for the purpose. Concrete has shown extreme life in some soils but crumbles rapidly in soils high in sulphates.

Several new field cleaning and coating machines are mentioned and shown in illustrations. Details concerning the machines are not given. The paper closes with a discussion of internal corrosion. Dehydration and the removal of hydrogen sulphide are suggested as remedies.

17. Anonymous. Effect of corrosion on coated and uncoated pipe lines. Petroleum Eng. VII, #9, p.51 (1936).

The paper gives data on the condition of lines laid in 1917 and raised in 1935 in southern Oklahoma and northern Texas. The amount of pipe in various conditions is tabulated for bare pipe and pipe coated with felt reinforced asphalt. The coating nearly doubled the percentage of pipe that did not require spot-welding.

18. Strieter, O.G., The effect of mineral fillers on the serviceability of coating asphalts. Proc. ASTM, 36, part 2, p.486 (1936).

This paper deals with fillers used with asphalt applied as a coating to felt shingles or sheet roofing. However, some of the results have a bearing on fillers used for pipe coatings. Two asphalts were prepared from the same crude petroleum, differing only in the duration of blowing and having softening points of 194°F and 225°F. These were so blended that with 15, 25 and 35% by weight of various fillers the resulting mixture had a softening point of 225°F. 57 combinations were tried. The mixtures were applied to aluminum sheet 3"x6" to a thickness of 0.025 inch. Mica, slate and talc fillers appeared to be superior to the others. Silica fillers resulted in porous coatings. The higher the fineness factor of a filler the less material is required to obtain a given effect. The fineness factor is defined as the ratio of the density less the compacting weight to the compacting weight. The finer the filler has been ground the larger is its fineness factor.

19. <u>Scott Ewing, AGA Field tests of pipe coatings. Report on specimens removed in 1935. Proc.AGA, p.627, 1936.</u>

This paper describes the results of the examination of specimens of 42 varieties of bituminous coatings exposed for approximately five years to 14 soils. The paper discusses also the 4-year results of the API coating tests. The paper contains a number of charts showing the structure and thickness of the coatings tested and their performance as indicated by pattern tests, conductance tests, and the condition of the coated pipe. The following conclusions were reached.

1. No coating in either the A.G.A. or A.P.I. tests has entirely prevented corrosion in all test sites. The thicker the coating, the more effective and the more expensive it becomes. The lower economic limit of thickness is believed to be about 1/10 inch. If any coating is justified or necessary it should be at least this thick. The upper limit of thickness is more variable, depending upon the cost of coating material, the corrosiveness of the soil, and the cost of repairing a leak, but it is probably never over 1/2 inch for bituminous coatings. With concrete the upper economic limit is probably considerably greater.

2. The coal-tar-base materials are more stable and moisture-proof, but they have a greater tendency to flow when warm and to crack when cold than the asphalt-base coating materials. The choice between these materials should depend upon relative costs. Good coatings can be designed with either type of material.

3. The coatings which were applied to the pipe line by hand in the field in the A.P.I. tests are in every case less effective than the corresponding coating, on the short pipe, which was applied under more favorable conditions. There was no essential difference in the effectiveness of the coatings on the line and on the short pipes, when both were applied by machine. Instead of continually emphasizing the necessity of care of field application, it seems more sensible to accept the fact that coatings cannot be applied properly in the field by hand. Hand field

methods of application should be avoided. Since the A.P.I. tests were installed many improvements have been made in field application methods. Machines for applying bitumen and wrappers in the field have been built and the high-voltage pinhole detector has made adequate inspection possible. With mill application, the joints, which must be coated in the field, are probably always the weakest part of the coating. Equipment and methods should be devised and used for making the coating of joints as nearly foolproof as possible.

4. Any organic reinforcement in a coating is a weakness, especially if the bitumen is an asphalt. If this reinforcement cannot be avoided entirely it can be made thin, like closely woven cotton fabric, instead of thick and loose like rag felt and burlap. Such materials should be deeply imbedded in the bitumen and not in contact with the metal.

5. To be considered at all, a coating should be capable of affording some protection in poorly drained soils, because it is in these soils that leaks are most likely to occur. It is difficult, but not impossible, to properly protect a pipe line in these soils with bituminous coatings, but the better bituminous coatings, and perhaps concrete, seem to be the most economical means for maintaining pipe lines in such soils.

20. Ewing, Scott, Laboratory tests of new pipe coatings. Proc. AGA, p.648, (1936).

Since the AGA and API field tests were started, several new pipe coatings have been developed. It seemed desirable to learn as much as possible about these coatings. The object of the laboratory tests was to secure information on the resistance of the coatings to soil stress and to water absorption. Impact tests and low temperature tests of the coatings were also made. The coatings were applied by their manufacturers to 24-inch lengths of 2-inch steel pipe. The types of coating tested are specified by trade name and manufacturer in the report. Specimens of the coatings were buried in an outdoor soil box constructed of porous brick and filled with clay loam containing considerable organic matter. One percent by weight of sodium carbonate was added to the soil. This increased the shrinkage of the soil to 53.5 percent. The height of the soil above the specimens was 6 inches. The soil was tamped lightly around the specimens when they were buried and again tamped after it was wetted. The results of the pattern and conductance tests before and after the specimens were buried are given in the paper. Specimens were also placed in large crocks containing water to which sodium chloride was added until the resistivity was about 500 ohm-cm.

A test was made to find the minimum height from which a 1.65-lb ball could be dropped on a coated pipe to produce failure of the coating. Specimens of the coatings were placed in a mechanical refrigerator. After 6 hours the temperature was -10°F. After another 16 hours the temperature was -16°F. Examination of the coatings after removal showed no visible effects.

Fifteen coatings were tested, of which 6, consisting of thin paints, are definitely inadequate because of their tendency to blister. Of the remaining 9, 2 are susceptible to moisture absorption, another (a synthetic resin) is likely to crack if it is exposed to low temperatures, and a third (a vitreous enamel) is especially liable to injury by impact. Five of the coatings showed no appreciable weaknesses or defects, but the tests are not sufficiently sensitive or severe to arrange these coatings in order of merit. These coatings all consist of a waterproof bitumen next to the pipe, shielded or reinforced by some more or less rigid material. If these coatings are properly applied they will in all probability protect a buried pipe line for a long time. Whether the use of any of these coatings in any practical case is economical will depend upon many other considerations, the most important of which is cost. Readers are cautioned to ascertain costs as accurately as possible before evaluating the results of these tests.

21. Hayes, Harry, Laboratory control of protective treatment of steel pipe lines by the Bureau of Water Works and Supply of Los Angeles, Jour. AWWA 28, 1372 (1936).

This paper presents the methods used by the Bureau of Water Works and Supply for selecting, testing and applying coating materials to steel mains.

Plasticized tar pitch has eliminated the objectionable features of old-time pitch enamels. Enamels from this material withstand temperatures of 160°F for 24 hours without sagging, will withstand temperatures as low as -20°F without cracking, and have a ductility approaching that of asphalt coatings. They retain all the corrosion-resistant properties of the old coal tar coating. A much better primer is also available.

Several methods of testing coating materials are described, including an electrical test for pinholes. A table of performance test results is given.

A whitewash mixture of quicklime, water, salt and an oil plasticizer is applied to pipes after completion of the outside coating. This does not flake off when dry and it resists soil stress. It also enables inspectors to detect injuries to the coating.

22. <u>Goit, L.E., Steel pipe cleaning and coating plant of the Bureau of Water Works and Supply of Los Angeles. Jour. AWWA 28, p.1393 (1936).</u>

The layout of the plant is described and illustrated by a diagram. Grease is first removed. The inside and outside of the pipe are blasted simultaneously by using #50 steel grit with 70-lb air pressure. The pipe rotates as it is cleaned.

The group of nozzles for blasting the outside of the pipe are directed straight down in a hood hinged at approximately the ground line and counterweighted to give only a slight pressure on the pipe. The opening against the pipe carries a rubber gasket to prevent the escape of air and grit. The inside blasting nozzle group is directed upward. The grit is confined in a hopper by means of rubber gaskets. The hopper is mounted on a 35-foot boom made of 12-inch pipe which serves as an air vent from the hopper.

After blasting, the pipe passes before a long table where it is primed inside by spraying in a single pass. The outside of the pipe is then primed by a spray gun. Coverage of the primer is about 600 sq ft per gallon. The pipe then passes to a station where it is rotated at 930 feet per minute linear surface speed. A trough long enough to reach to the middle of the pipe is run in from the end and dumped. Another trough is then run in from the other end. The thickness of the enamel applied is 0.11 inch. At the outside coating station the pipe is revolved at a surface speed of 165 ft per minute. Enamel is applied by pouring from a bucket with a flat spout and is spread by a canvas pad held against the pipe as the stream of enamel strikes it.

A second coat is applied with the pipe rotating in the opposite direction. The minimum thickness of enamel is 0.09 in. The coating is then inspected for flaws. Finally the pipe is coated with whitewash by long-handled mopping daubers.

23. <u>Barbour, F.A. Economic significance of improved pipe linings. Jour. AWWA 28, 1344 (1936).</u>

Discusses results of a N.E.W.W.A. Committee and a Committee of the A.W.W.A. on pipe line friction.

Results of 477 tests of friction loss show a capacity loss of 44% for 20-year old pipe and 52% for 30-year pipe. Cement lining adds 3 to 5% to cost of pipe and bitumastic lining 5 to 8% without allowance for paving costs.

24. Banks, W.G. Rehabilitation of large water mains in Newark. N.J. Jour. AWWA 28, 1348 (1936).

This paper describes the rehabilitation of 50 miles of 36" to 60" steel mains, including the cleaning and recoating of the pipe.

25. Central Corrosion Committee. Third Report of the Dutch Corrosion Committee II for the study of the corrosive effect of soils on pipes. Regulations for the asphalting of pipes with asphaltic bitumen of the blown type. March, 1937.

The paper is a report the English translation of which covers 89 single-space 8x12-inch typewritten pages. The committee has undertaken the investigation of three types of coating materials: tar, asphaltic materials not of the air-blown type, and asphaltic materials of the air-blown type. This report deals only with air-blown asphalts.

The first requirement is that the coating should insulate the pipe efficaciously. Investigations have demonstrated the necessity of ascertaining whether this requirement has been met at the time the coating is applied.

Experience gained so far is insufficient to allow of specifying with certainty the requirements with which the coating will have to comply to preclude loss of insulation during the time the pipe is buried in the soil. Possible factors are: ground pressure, penetration of the coating by stones and roots, mechanical damage, aging of materials, chemical changes and the absorption of moisture.

On the basis of these factors the following requirements for asphalting are set forth:

1. The bituminous coating after having been applied should be tight. 2. It is advisable to provide all asphalted pipes with a wrapping to protect against damage during transport and laying unless special precautions in handling are taken. 3. Asphalted pipes are to be provided with a reinforcement proof against the influences of soil stress in cases where there is a great risk of the coating being damaged in the soil by mechanical influences. 4. The physical properties of the material used in the bituminous coating should comply with the three following requirements: (a) the brittleness should be as slight as possible; (b) the flow of the material at high temperature due to its own weight should be as small as possible; (c) the resistance to deformation should be as high as possible.

The committee has worked out specifications for four groups of protections:

1. Light protection for insulating the pipe during the minimum life required. The minimum thickness of this type is 0.5 mm. In addition, it is advisable to apply a wrapping to protect the coating against mechanical damage during transport and laying.

2. Moderate protection consisting of (1) a primary coat of blown asphaltic bitumen; (2) a top coat of blown asphaltic bitumen with a filler. The minimum thickness of this coating should be 2.5 mm. In addition, it is advisable to apply a wrapping for protection against mechanical damage in transport.

3. Heavy protection comprises: (a) a primary coat and (b) a top coat as in (2); (c) a reinforcement for protecting the undertlying top coat against mechanical injuries during the minimum life required; (d) a protective coat of blown asphaltic bitumen with filler for sealing the reinforcement from surroundings.

4. Very heavy protection comprises in addition to the coating specified in (3), (e) a wrapping with paper which should form a smooth base for (f) a wrapping with straw ropes serving to preclude damage to reinforcement during transport and laying.

The specifications for the above-named coatings are preceded by an explanation of the specifications. These explanations give the reasons for the selection of the tests and the choice of limiting values.

These explanations are followed by 35 pages of specifications for coatings suitable for different services. In general these specifications cover softening point (R&B) breaking point (Frass) adhesion, types of filler permissible, the use of red lead, pickling with phosphoric acid, character of wrappers, methods of application of asphalt, cleaning of old pipe, inspection by spark test and determination of conductance of the coating after 4 days' exposure to the soil.

26. <u>Thomas, G.O. Fundamental requirements for pipe coatings. Commonwealth Eng. 24, #9, p.293 (Apr.1, 1937).</u>

"In any discussion of pipe coatings.....it is an essential premise that the ideal to be aimed at is a covering which permanently excludes water from the surface of the pipe. All properties of the coating must be directed toward this one great end." Failures of coatings occur in the following ways: (1) Defects in manufacture such as bubbles, pinholes, holidays and thin spots. (2) Damage occurring in transport and laying. (3) Effects of soil stress. (4) Loss of adhesion. (5) Progressive absorption of water. Resistance to water absorption is an essential property of a satisfactory coating.

The report gives curves showing that for mixtures of coal tar pitch and natural asphalt the absorption of water increases with increased amounts of asphalt. Another set of curves shows that for mixtures of coal tar pitch and limestone filler the absorption of water increases as the amount of filler is increased. A third set of curves shows that the higher the melting point of the pitch in an enamel the less will be the absorption of water. All curves indicate that after an initial period of exposure the absorption of water is proportional to the time of exposure up to periods of 31 months.

27. Larson, Erick. Pipe Corrosion protection. American Gas Journal 147, No.3, p.21 (Sept. 1937).

This is part 15 of a series of articles on pipe corrosion and coatings which, when completed, may be published in book form.

Various studies of corrosion indicate that the need for pipe protection is quite general. In a survey made by the American Gas Association, 124 companies reported on 4,169,000 services. 98 companies reporting 2,531,359 services reported service lives of 30 years or less. Most of these ranged between 16 and 30 years.

Localized protection on services is not recommended. On distribution systems the preferable practice is to standardize on a protection which will resist the most severe conditions to be enountered. A frequent experience on transmission lines has been that a more general initial use of the better grades of protection would have produced the best economic results.

The general requirements of any subsurface pipe coating are an adequate supply, simple and easy application, protection of the pipe from corrosion under all conditions, and economy.

The coating should be chemically inert with respect to the pipe, be unaffected by soil bacteria, vegetation, water, acids,alkalis, insects or other soil ingredients, and be stable. Very few coatings of any type fail because of chemical reaction. An outstanding exception is the disintegration of concrete under certain conditions. Plant life, particularly in the form of roots, is an important cause of deterioration of coatings. The impregnation of organic wrappers with inert materials cannot prevent decay. Cellulose materials may be attacked by soils and therefore require protection by additional layers of coating.

The physical resistance of coatings is discussed and the conclusion reached that coatings can be obtained which do not require excessive care in handling.

28. Larson, Erick. Coating requirements. Amer. Gas Journal 147 No. 4, p.73, (Oct. 1937).

This is Part 16 of the series on pipe corrosion and coatings, and discusses injuries to coatings caused by soil stress, trench settlement, freezing temperatures, and roots.

The effect of soil stress is to distort or displace the coating material over large or small areas.

The most usual appearance of the coating resulting from the displacement type of soil stress damage is that of a honeycomb, although not as regular in design. Soil stress of the displacement type has been observed in soils varying from beach sand composed of fine grains to rock. 164°F enamel was penetrated to the steel in numerous places within 4 years.

The second type of damage from soil stress, distortion, affects comparatively large areas of coating. The appearance is frequently that of a cloth after it has been pushed into a confined space on a smooth surface. The cause of the distortion is that the gripping power of the soil exceeds the adhesion of the coating to the pipe or the cohesion of the coating particles.

Coatings without shields have been damaged by both types of actions so that the bare metal was exposed in less than one year.

Ductility and several other properties of coating materials are also discussed.

29. Logan, Kirk H. Soil corrosion studies 1934. Bituminous coatings for underground service. NBS Journal of Research 19, 695 (Dec. 1937).

Summarizes the results of all the field work on bituminous pipe coatings conducted under the supervision of the National Bureau of Standards. Scott's pit depth-area formula is applied to some of the data for the purpose of computing the effectiveness of certain coatings. The following is the summary of the paper.

Although protective coatings have been applied to pipe lines for half a century or more, and although many tests of protective coatings have been made, few data are available upon which an engineer can base a reliable estimate of the saving which can be expected through the use of a protective coating.

There are several methods by which certain characteristics of coatings can be indicated but there is no recognized way of expressing the condition or serviceability of a coating. Because of this, ideas as to the protective value of coatings are vague and lead to uncertain results when applied to the design of a pipe line.

The experiments upon which this report is based were started between 1922 and 1930 and represent pipe coating practice at that period. They have resulted in the modification of pipe-coating practice and in the development of better coatings. Unfortunately, the testing of new coatings in the field by national organizations has been discontinued. The effectiveness of the newer coatings must be determined largely by the experience of users of the coatings. Data obtained in this way are accumulated but slowly. They are usually lacking in essential details of the conditions which determine the success or failure of the coating, and are sometimes influenced by the interests of those who report the data. The reader of this report should neither assume that the results presented are the best that can be obtained with protective coatings nor that the causes of failures of coatings have been overcome completely.

The results of the tests under the general supervision of the National Bureau of Standards seem to warrant the following generalizations.

The performance of a protective coating is controlled by the soil condition to which it is subjected. The shrinkage and the relative density of the soils are important factors in the distortion of coatings. Distortion is especially severe in dense soils which undergo marked changes in volume with changes in moisture content. Because of the effect of soil characteristics on coating behavior, when practicable, coatings should be selected with reference to the soil conditions to which they are to be exposed.

Although no coating tested completely prevented corrosion under all soil conditions for as long as four years, almost all of them materially reduced the loss of metal during the period of test.

Coatings which are somewhat porous, such as cut-backs and asphalt emulsions, are effective in preventing pitting in well aerated soils.

The thickness of the bitumen is an important factor in the effectiveness of a coating. Very thin bituminous coatings are unsuitable for severe soil conditions.

Thickness for thickness, coal-tar-base coatings absorb less water and have better insulating qualities than coatings having asphalt as a base.

The coal-tar-base coatings are, in general, more severely affected by soil stresses, sudden changes in temperature, and shocks.

The application of coatings by means of a sling as used in the A.P.I. tests results in imperfect coatings.

Shields and reinforcements reduce the depth of the deepest pit to a great extent during the first few years of exposure, probably because of their resistance to soil stress, although the relatively great thickness of reinforced and shielded coatings may be a factor.

Asbestos felt offers more permanent reinforcement to bituminous materials than rag felt.

No bituminous coating or coating material is inherently greatly superior to all others. It is possible to secure similar results by several methods.

Although protective coatings have been in use many years, there are few detailed records of the performance of coatings covering periods of more than 5 years. The life of protective coatings is therefore somewhat uncertain.

Bituminous coating materials suitable for the service required of them materially reduce corrosion losses. However, because of the nature of the materials used and the conditions under which pipe lines are usually laid, a pipe coating free from imperfections and injuries is scarcely to be expected.

The conclusions drawn above are based on the performance of types of coatings. The best coating in each type was somewhat more effective than the average upon which the conclusions are based. It is probable that the tests have resulted in the production of coatings that are better than any in the tests which form the basis for these conclusions.

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