NATIONAL BUREAU OF STANDARDS REPORT

9545

REPORT ON

REVIEW OF INFORMATION RELATING TO
CORROSION OF STEEL AND WROUGHT-IRON
PIPE IN STEAM-CONDENSATE SYSTEMS

by

Robert S. Wyly

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards[1] provides measurement and technical information services essential to the efficiency and effectiveness of the work of the Nation's scientists and engineers. The Bureau serves also as a focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To accomplish this mission, the Bureau is organized into three institutes covering broad program areas of research and services:

THE INSTITUTE FOR BASIC STANDARDS . . . provides the central basis within the United States for a complete and consistent system of physical measurements, coordinates that system with the measurement systems of other nations, and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. This Institute comprises a series of divisions, each serving a classical subject matter area:

—Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic Physics—Physical Chemistry—Radiation Physics—Laboratory Astrophysics[2]—Radio Standards Laboratory,[2] which includes Radio Standards Physics and Radio Standards Engineering—Office of Standard Reference Data.

THE INSTITUTE FOR MATERIALS RESEARCH . . . conducts materials research and provides associated materials services including mainly reference materials and data on the properties of materials. Beyond its direct interest to the Nation's scientists and engineers, this Institute yields services which are essential to the advancement of technology in industry and commerce. This Institute is organized primarily by technical fields:

—Analytical Chemistry—Metallurgy—Reactor Radiations—Polymers—Inorganic Materials—Cryogenics[2]—Office of Standard Reference Materials.

THE INSTITUTE FOR APPLIED TECHNOLOGY . . . provides technical services to promote the use of available technology and to facilitate technological innovation in industry and government. The principal elements of this Institute are:

—Building Research—Electronic Instrumentation—Technical Analysis—Center for Computer Sciences and Technology—Textile and Apparel Technology Center—Office of Weights and Measures —Office of Engineering Standards Services—Office of Invention and Innovation—Office of Vehicle Systems Research—Clearinghouse for Federal Scientific and Technical Information[3]—Materials Evaluation Laboratory—NBS/GSA Testing Laboratory.

---

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C., 20234.

[2] Located at Boulder, Colorado, 80302.

[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT — 42103-40-4212135

NBS REPORT — 9545

June 6, 1967

REPORT ON

REVIEW OF INFORMATION RELATING TO

CORROSION OF STEEL AND WROUGHT-IRON

PIPE IN STEAM-CONDENSATE SYSTEMS

by

Robert S. Wyly

For Use of Sponsor and NBS Staff Only
Not for Publication or Distribution

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

Report

on

Review of Information Relating to Corrosion of Steel and Wrought-Iron Pipe in Steam-Condensate Systems

by

Robert S. Wyly

Report

on

Review of Information Relating to
Corrosion of Steel and Wrought-Iron
Pipe in Steam-Condensate Systems

by

Robert S. Wyly

Results are summarized from a review of a number of publications and reports relating to corrosion of iron and steel pipe under various conditions of exposure. Particular attention was given to the information relating to corrosion and corrosion control in condensate-return lines of steam-generating systems.

A great many diverse factors affect the corrosion of pipes, so that the planning of tests and the interpretation of results present considerable difficulties, and different engineers may interpret a given set of data in different ways.

Based on the information studied, it was concluded that measurements of corrosion of steel vs wrought iron in condensate return lines are too meagre to show a general superiority of one over the other. Further, it was considered that extrapolation of results from one exposure environment to predict results in another environment is unwarranted in this case, and that accelerated or short-time exposure tests may have only limited value in predicting long-time corrosion.

CONTENTS

1. INTRODUCTION

1.1 Authorization and funds

The study was undertaken by the National Bureau of Standards as a part of the Tri-Services Program on Engineering Investigations of Building Construction and Maintenance, as authorized in July, 1965. The sum of $4,000 was allocated to the study.

1.2 Statement of the problem

For various reasons, large quantities of ferrous piping are used to convey water, steam, steam condensate, and other materials. Because of a cost differential between steel and wrought-iron pipe, an optimum choice between the two materials depends on a knowledge of the corrosion that may be expected. Because opinions on the relative performance of steel and wrought iron have differed, and field observations have yielded inconsistent indications, it became necessary to review available information to determine whether existing data are adequate as a basis of selecting either steel or wrought iron in preference to the other on the basis of corrosion resistance. In addition, the review was needed as a basis for identifying any new laboratory or field studies that may be needed. Adequate information on corrosion behavior could result in improved standards and specifications for pipe to meet a desired level of performance.

1.3 Scope

While the investigation was to comprise a review of pertinent corrosion information over a relatively wide range of conditions as it relates to ferrous materials, the primary emphasis was on the corrosion performance of "black" iron and steel pipe as used in steam-condensate return lines.

2. SOURCES OF INFORMATION

2.1 Literature

Insofar as possible, the review was based on publications that show physical measurements. Among the literature sources were publications of the American Society for Testing and Materials, the New England Water Works Association, the National Bureau of Standards, the U.S. Naval Research Laboratory, the Canadian Department of Mines and Technical Surveys, individual iron and steel producers, producers' associations, professional and trade journals, and privately-authored books. American, Canadian, and British publications were included in the review. A partial list of these sources of information forms Section 5 of this report.

2.2 Consultation with experts

Correspondence and discussions with several corrosion authorities and engineers supplemented the literature review. This brought to light some additional information, and helped to clarify some questions about the literature.

3. SUMMARY OF FINDINGS

3.1 Discussion of corrosion and its control in condensate-return lines of steam-generating systems

The following comments on corrosion in condensate lines are based on various sources as indicated, and on other sources yielding similar information. The ASM Metals Handbook [27] states that condensate lines in steam-generating systems frequently deteriorate along their bottom, inside surfaces because of the formation of carbonic acid by the carbon dioxide gas in the condensing steam. The gas is present in the steam mainly through breakdown of the bicarbonate and carbonate alkalinity of the make-up water to the boiler.

Various materials, such as ammonia, alkalis, polyphosphates, neutralizing amines, and filming amines, may be employed for combatting return line corrosion caused by carbon dioxide. For various reasons, ammonia, alkalis, and polyphosphates were said to be undesirable or impracticable in most instances.

Volatile amines such as cyclohexylamine and morpholine can be used to control this type of corrosion. These compounds are fed directly to the boiler, volatilize with the steam, and neutralize the carbon dioxide in the condensate. These amines are non-corrosive to copper and zinc-bearing metals, but do not prevent oxygen corrosion. They can be expensive where carbon dioxide content is high and the loss of steam or condensate is great.

The filming amines have proven successful in combatting return-line corrosion. They lay down an impervious film on the metal surfaces, which protects against both carbon dioxide and oxygen. The required feed rate for these amines does not depend on the concentration of carbon dioxide or oxygen.

C. R. Cox [26] referred to a process for removing dissolved gases by spraying the water into a closed vessel (deaerator) operating under a sub-stmospheric pressure generated by a suction pump. He indicated this method is useful in the treatment of corrosive waters entering the hot-water systems of buildings. He also noted that deactivation with iron metal, such as scrap iron, steel wool, etc., placed in closed vessels may be used to neutralize oxygen, and that the resulting oxidized iron in the water may be removed by filtration. He also indicated that aeration will reduce the carbon dioxide content of most waters considerably, and stated that this treatment alone will suffice where alkalinity is above 80 ppm and the carbon dioxide content is above 3 ppm. It would appear, however, that oxygen content would be increased by this treatment. The A.M. Byers Company [28] noted that most of the oxygen in boiler feed water can be removed by heating to the boiling point in an open or deaerating type of preheater, but that a small percentage will usually remain.

Speller [13] stated that in the absence of oxygen, carbon dioxide in solution is usually a minor factor in corrosion, except as it affects the acidity of the solution and the accumulation of protective coatings. However, the depolarization effect of oxygen, when present, accelerates the action of the carbon dioxide, he noted. He cited experiments in which corrosion by a solution containing both gases was greater than the sum of the effects by each gas acting individually. He called attention to the fact that steam condensate is low in soluble salts and scale-forming matter; therefore remedial measures are generally not much dependent on the source of the water supply. He also stated that corrosion in low-pressure, closed systems is usually not so severe as in vacuum systems, and recommended pretreatment of feed water that is high in bicarbonates and free carbon dioxide. Speller noted that when the pH of condensate is less than 6, due to carbon dioxide, and when free oxygen is low, partly-full condensate return lines are usually corroded on the bottom in the form of a clean groove by the hot acid condensate. When the condensate is less acid and sufficient free oxygen is present, the pipes become more or less clogged with insoluble rust. Speller recommended, for low-pressure steam generating systems, feed-water treatment with soda ash or caustic soda and the maintenance of a minimum of dissolved oxygen in order to maintain a pH value sufficiently high to reduce corrosion. He suggested the use of deactivating materials or sodium sulphite to reduce oxygen corrosion from condensate return water.

He indicated that in large systems operating at pressures below 5 psig, free and half-bound carbon dioxide should be converted to the normal carbonates by keeping the water alkaline with caustic soda.

Spring [22] attributed condensate line corrosion largely to the condition of the boiler water, which may result in contamination of the steam and consequent corrosivity of the condensate. He referred to oxygen removal from the feedwater by a deaerating heater, followed by treatment with sodium sulphite or hydrazine to scavenge traces of oxygen. He recommended the use of amines to control carbon dioxide in the condensate. He concluded by stating that because a great many variables affect condensate line corrosion, a complete engineering survey is advisable to obtain a planned, effective solution.

Hudson [23] made the following recommendations regarding the minimization of corrosion in steam piping:

a. Where corrosion is a problem, treat feed water to minimize oxygen and carbon dioxide introduced into the steam.

b. Design to prevent air intake.

c. Ensure that condensate lines drain freely--this can be enhanced by providing a slope of at least two degrees.

d. Use a minimum of threaded connections.

The A.M. Byers Company [28] in a special report on the use of wrought iron pipe for steam condensate lines indicated that the sources of oxygen in condensate include: (a) oxygen in the feed water, (b) leakage at pumps, valves, and fittings where a partial vacuum exists inside the condensate system, and (c) intermittent intake of air due to fluctuating water level where a condensate receiving tank is used. Corrosive attack by oxygen can be identified by a pitting of the metallic surface with the pits wholly or partially filled with corrosion products. As the attack continues, the pits usually increase both in depth and area and the nodules of corrosion products become enlarged. In some cases the entire surface may be more or less uniformly covered by the corrosion product.

According to the A. M. Byers Company, carbon dioxide is generally the primary cause of return line corrosion. While some carbon dioxide is present in the feed water, the major portion that occurs in the condensate results from the decomposition of the bicarbonate or carbonate content of the boiler feed water. Sodium carbonate, either added to the feed water to reduce hardness or formed by decomposition of sodium bicarbonate, will also decompose and yield additional carbon dioxide. Because of the carbonate or bicarbonate breakdown taking place in the boiler, carbon dioxide is present in all types of steam regardless of the feed water conditioning employed. When the steam condenses, the carbon dioxide is absorbed by the condensate and forms a carbonic acid solution which is aggressive to the metals commonly found in return systems. The corrosive attack from carbon dioxide in return lines is generally evidenced by a grooving or channeling along the bottom of the pipe, although any portion of the metal in contact with the condensate may be affected. The attacked surfaces are generally clean and uniformly thinned in contrast to the encrusted and pitted surfaces characteristic of oxygen attack.

Two types of failures may occur, depending on the nature of the attack. The pipe may be grooved or pitted to complete penetration, or a build up of corrosion products may plug the pipe and render it useless.

Among the measures recommended by the A. M. Byers Company to minimize condensate return line corrosion are (a) deaeration and chemical treatment of broiler feed water to prevent undue amounts of deleterious gases, (b) the injection of neutralizing chemicals into the boiler water with the intention that they carry along and condense with the steam, thus neutralizing any deleterious substances present, and (c) the introduction of film-forming chemicals into the boiler water that will pass with the steam to the condensate lines and prevent contact between the condensate and the metal surfaces, (d) maintenance of air-tight joints in all portions of return lines operating under sub-atmospheric pressures, (e) maintenance of adequate slopes in return lines, (f) elimination or proper trapping of low points or pockets in the lines, (g) reaming of pipe ends to remove burrs, (h) avoidance of cold-water injection into return lines ahead of vacuum pumps, and (i) use of extra-heavy nipples.

As to the corrosion resistance of piping materials, Aston [29] has stated that no one material is best suited for all uses. He noted that the characteristics of various materials make it necessary to exercise judgment in the choice of a material that will render the necessary service at minimum cost.

Discussions with several engineers and corrosion authorities having experience with condensate line corrosion indicated that adequate treatment and monitoring of the feed water, sometimes in combination with chemicals introduced into the condensate system, may do more to prevent corrosion than any choice of metals that might be made in the ordinary course of events. Several authorities have recommended that, due to the number of variables encountered, choice of material and selection of the method of corrosion control to be employed be placed in the hands of a consultant thoroughly familiar with the problem. One engineer stated that, in his opinion, no single fixed control procedure is adequate without frequent tests of the boiler water and the condensate in conjunction with adjustments indicated by the tests. Several stated that condensate line corrosion could be mininized by appropriate treatment of the feed water and by providing adequate pitch in the condensate return lines.

3.2 Review of literature for data on relative corrosion of steel and wrought iron

a. Atmospheric corrosion

Case [2] concluded that the corrosion of mild steel and wrought iron is not strikingly different in atmospheric enviroments. Speller [13] concluded from a review of various atmospheric exposure tests that differences in corrosion rates for wrought iron and steel seemed to be related more to the copper content of the metals than to whether steel or wrought iron. However, he indicated that in certain cases of atmospheric corrosion, wrought iron seemed to have some advantage over ordinary steel.

A review of the literature by Tingley and Rogers [4] led them to conclude that the corrosion rates of ordinary steel and wrought iron are quite similar in many atmospheric exposures, but in some atmospheric tests wrought iron had been found superior to steel.

Tingley and Rogers attribute to Hudson the finding that in atmospheric exposure the particular type of wrought iron involved affects results, "British" wrought iron being the most resistant, "Aston" wrought iron being inferior to the "British" variety, and "Swedish" wrought iron being the least resistant to corrosion. Only the British wrought iron had been found superior to mild steel, according to Tingley and Rogers.

Southwell [20] cited works of earlier investigators which seemed to establish that some hand-puddled wrought irons were somewhat superior to mild steel in atmospheric corrosion, but which also had shown differences in corrosion rates between various wrought irons that were often more significant than differences between wrought iron and mild steel. Southwell's 8-year tests of wrought iron and low-alloy structural steels in tropical atmospheric environments showed the wrought iron to be much more heavily damaged than the low alloy steels.

b. Soil corrosion

Speller [13] described results with wrought iron couplings on steel pipe buried in soils that indicated approximately equal corrosion rates for the two methods.

Some investigators, in commenting on the significance of the soil corrosion data obtained by the National Bureau of Standards [30], have found evidence of a general superiority of either steel or wrought iron over the other, based on average values for many soils. Speller [13] commented "Under corrosive soil conditions, the specific rates of corrosion and pitting appear to be about the same in all these materials (wrought iron, steel, and cast iron), so that the problem is not solved by selecting any particular kind of iron or steel." Pennington [31] concluded from some of the NBS data that "wrought iron is as good as steel and possibly a little better."

However, the rates for both materials varied greatly with respect to the nature of the soils and other aspects of the exposure sites. Romanoff [30], speaking of the engineering significance of results on ferrous materials, stated:

> "There are so many diverse factors that affect the corrosion of pipes and other structures underground that the planning of adequate tests and the proper interpretation of results are matters of considerable difficulty. It is not surprising, therefore, that even experienced corrosion engineers often interpret the same experimental data in different ways."

He also indicated that caution must be exercised in extrapolating the data to conditions outside the range of the tests, and where such extrapolations are made the indications should be looked upon as only approximate.

A limited comparison of certain data on specimens of ungalvanized ferrous pipe, obtained in the NBS soil corrosion investigation [30], was made during the course of the present review. Replicate specimens had been buried in forty seven different soils, and two specimens of each material at each site removed for observation and measurement at intervals of time ranging up to approximately eighteen years, from the time of burial. From an examination of these data, the following comments seem pertinent:

1. Penetration. Noticeable differences in results for both steel and wrought iron occurred between different exposure sites, apparently due in large measure to differences in the properties of the soils. In some soils penetrations were greater in some steels than in wrought iron, while in other soils the reverse was true.

2. Weight loss. Variations in weight-loss results were also noted between different exposure sites, and in some soils steel suffered the most weight loss while in other soils wrought iron suffered the most loss. Differences in weight loss between the different materials in a given soil were less striking than the differences in penetration.

3. Apparent effect of duration of exposure. The ranking of the materials as to weight loss or penetration in a number of instances was different at intermediate periods of exposure than at the end of the exposure period. To what extent this may have been due to measurement difficulties, statistical limitations, or variations in soil moisture or soil chemistry, and to what extent it may have been due to real differences in performance characteristics of the ferrous materials is not clear from the data studied.

c. Corrosion in water and steam

Various references to tests in water were found. Speller [13] in reviewing various test results commented that (1) in carrying acid mine waters, no appreciable differences were noted between performance of steel and wrought iron, (2) in 100 cases of domestic hot-water lines, no consistent differences were found, (3) in external surface exposure under water the performance was similar to that for internal corrosion carrying the same waters, (4) in 64 cases involving hot or cold water or steam lines, 20 cases showed wrought iron more corrodible than steel, 18 cases showed steel more corrodible than wrought iron, 9 cases showed equal corrosion, and 17 cases showed negligible corrosion for both, and (5) tests with cooling water flowing outside of condenser tubes for 10 years showed no difference in corrosion of steel and wrought iron. Speller also cited the results of seven tests on steam heating lines covering a period of six months that showed no significant differences in penetration of the two materials. He noted that in sea water, some tests have shown an advantage for wrought iron, some an advantage for copper-bearing steel, and others no marked differences. He cited various additional laboratory and service tests which, he stated, for the most part indicated no inherent difference between the two materials with respect to durability.

Tingley and Rogers' literature survey [4] also indicated, for the most part, similar performance for steel and wrought iron on exposure to water and steam. They referred to work by Hudson that they indicated had shown superior performance of British wrought iron in sea water and salt solutions.

Speller [13] advised the use of copper-bearing steel in steam condensate lines to combat carbon dioxide corrosion. However, he considered that the particular composition of iron or steel used in steam heating systems is of minor importance.

La Que [25] indicated that, in general, steel and wrought iron corrode at similar rates. He noted that steam is less damaging than water, and steam-air mixtures are much worse than steam alone.

Uhlig [24] concluded that there is no essential difference between corrosion rates of steel and wrought iron in natural waters, but that in acids the rates may differ greatly, depending on metal composition.

Laboratory tests with Washington, D. C. tap water for a 10 year period were reported by Ellinger, Waldron, and Marzolf [1]. Continuous, non-turbulent flow was maintained in their tests, a condition not generally prevalent in piping systems in buildings. In general, the difference between steel and wrought iron specimens was not marked although the ranking as to corrosion depended somewhat on the time of exposure at which the comparison was made.

Unpublished results of service tests on hot and cold water lines at the National Bureau of Standards with Washington, D. C. water extending over a 12-year period showed pitting and weight loss for Bessemer steel and Toncan not greater than for Aston wrought iron. Hydraulic resistance measurements at intervals showed similar losses in hydraulic capacity for steel and wrought iron.

Fair, Whipple, and Hsiao [3] reported hydraulic resistance measurements on hot and cold water pipes which showed no striking differences between steel and wrought iron pipes.

The ASM Metals Handbook [27] refers to immersion tests of ferrous plates in sea water, brackish water, and fresh water which at 5 years showed no significant differences between the corrosion rates for plain carbon steel and wrought iron.

Tests of ferrous plates have been reported by Southwell, Forgeson, and Alexander [20,21], showing superior corrosion resistance of wrought iron over mild structural steels at eight years exposure in Panama under tropical conditions. At least four years of exposure was required to reach a condition of approximately linear relationship between corrosion and time, according to the authors. For periods of exposure greater than eight years, the investigators expected that continuous immersion in sea-water would cause the greatest corrosion, mean tide exposure an intermediate amount, and fresh-water the least in these particular tests. At the end of the first four years in continuous sea-water and fresh-water immersion no significant differences were noted between rates for the steels and the wrought iron. At mean tide, the wrought iron showed less corrosion damage than steel at 1, 2, 4, and 8 years of exposure.

d. Corrosion in steam condensate return lines

While a number of writers have commented on service experience with condensate return lines, and the literature includes recommendations as to corrosion control practices that should be employed, this review failed to disclose adequate, specific numerical data from tests on condensate lines, nor were data generally given on the chemical nature of the water or on corrosion-control methods used, if any. Tests were initiated in one program at the National Bureau of Standards but recurring experimental difficulties and major repiping of the Bureau's steam system forced cancellation of these tests; therefore conclusive results were not obtained.

e. Service records

Numerous reports commenting on relative performance of steel and wrought iron in field service were found in reviewing the literature. The limitations of the present effort precluded follow-up with the originators of the service reports; hence it cannot be said that the information is complete or altogether accurate. It was considered that most service reports lacked adequate numerical data, particularly as regards the conditions of exposure throughout the periods of time involved. Thus, the results may have been affected by external factors unrelated to the particular material used. Some reports indicated a preference for wrought iron, while others indicated satisfaction with steel.

3.3 Explanations that have been offered with respect to observed differences in corrosion of wrought iron and steel

Statistical explanations have been offered. Case [2] suggested that the differences in corrosion resistance of different wrought irons may often be greater than the differences in resistance of wrought iron and steel as sometimes reported.

Chilton and Evans [11] suggested that the remarkable longevity of some ferrous objects may not be characteristic of all objects of that particular material. According to their explanation, erroneous conclusions may sometimes be drawn from field observations on old metal objects because:

(a) a representative sample of the original quality may no longer be available, since most samples of the poorest quality will have already perished,

(b) sometimes investigators tend to attribute performance of a material to its composition when in reality the performance may have been greatly affected over a period of time by an environment which may be known to only a limited degree and which may have varied over a wide range, and

(c) protective coatings during early periods of exposure may extend the life of ferrous objects; however, the prior existence of such coatings may be unknown to an observer at a later time.

Chilton and Evans [11], Southwell et al [20], and others have stated that short-time or accelerated tests frequently give erroneous indications of long-time performance in service. This is partly because not all the conditions of the long-time environment can be duplicated in a short-time test. White and Chandler [10] noted that the conditions causing corrosion may not be the same throughout the period of service exposure; hence the environmental conditions at the time of failure may be unrepresentative. They cite as one example changes in water treatment methods that may occur during the life of a water system.

Aston and Story [12] attributed the corrosion resistance of wrought iron mostly to protective film formation, and to inclusions of silicate fibers. They indicated that the slag inclusions act as barriers against corrosion, causing the corrosion to spread over the surface rather than to pit or penetrate. In addition, they indicated the purity of the base metal contributes to corrosion resistance. Evidently they based these conclusions at least in part on evaluations of wrought iron installations that had been in service for extended periods of time. As to the effect of foreign elements in iron and steel, Speller [13] stated that, in general, such elements have more influence on physical properties than on the rate of corrosion, and considered it impractical to rely on high-purity iron to provide superior corrosion resistance. However, he noted that some evidence suggests that a high phosphorous content may retard corrosion, especially in the atmosphere, and that sulphur content in the air may be harmful under certain conditions. He indicated that silicon in amounts over 3% inhibits corrosion, and stated that copper content inhibits corrosion of iron and steel. He recommended the use of copper-bearing steel in condensate lines to resist the action of carbon dioxide.

Speller suggested that some wrought-iron installations may have given exceptional service in atmospheric environments because of the copper content of some of the early wrought iron, and that the rough surface of wrought iron used for roofing purposes may have favored the adherence of protective coatings. He believed that, with few exceptions, external factors largely determine the rate of natural corrosion of ordinary iron and steel, and that composition is of minor importance in water and soil. Copper content may be a significant factor for ordinary rolled iron and steel in air, he noted.

Southwell [21], in describing the results of tests of steel and wrought iron plates in a tropical environment, noted that variations in corrosion intensity may be expected in different bodies of fresh water or in different atmospheric exposures, so much so that results from different exposures must be delineated for the specific prevailing conditions of exposure. He stated that short-time tests would have given erroneous conclusions as to long-time, relative corrosion behavior of some of the specimens.

Some authorities have indicated that in the "old" wrought irons, the presence of phosphorous and silicon might have been beneficial in atmospheric exposures. This effect is referred to as a "film phenomenon."

Chilton and Evans [11] stated that although tests have, for the most part, indicated no marked differences in corrosion resistance of wrought iron and mild steel, field observations on full-scale structures have sometimes indicated exceptional service for wrought iron. In attempting to explain this apparent superior performance of wrought iron in some instances, they concluded from investigative and experimental work that the superior corrosion resistance of some wrought irons is due to the "zonal" character of such irons, the zones being designated Q, R, and V. The Q zones corroded easily, the R zones were resistant to corrosion, and the V zones were very resistant. The Q and R zones were found in all samples of contemporary British wrought iron. The V zones occurred only in piled iron. Since Aston wrought iron is not piled, it could contain no V zones according to Chilton and Evans. They noted that Aston wrought iron did not corrode in a zonal manner. Through special tests, they compared the "probability of rusting" of steel and wrought iron. These tests showed steel with a higher probability than the R zones of wrought iron, but less than the Q zones. The V zones showed exceptionally high resistance. They noted that in very old British wrought iron there were no zones at all--the same being true of Aston wrought iron. They conclude that the superiority of wrought iron is likely to become evident when corrosion proceeds to a V zone, which may take several years; therefore short-time tests may not give a true indication of long-time corrosion resistance. They also suggested that wrought-iron scale (containing phosphates and silicates) may offer corrosion protection in the early stages of exposure, that it would be more resistant to removal by weathering than the scale on steel, and that it would retain a heavier layer of paint or other protective coating than would steel.

Aston [29] has been critical of some of the literature comparing corrosion of wrought iron and steel, indicating that (1) some of the results attributed to wrought iron were obtained on materials not properly classified as wrought iron, (2) "average" results from a large number of soil corrosion tests in different soils have limited significance, (3) accelerated tests are unreliable unless correlated with actual experience in the service contemplated, (4) the effects of non-uniform composition, impurities, and "rimming" in steels indicate the relatively small confidence that may be placed in short-time tests as compared to long-time tests, and (5) short-time tests in non-corrosive water which yield low rates of corrosion give a less reliable comparison of corrosion resistance of different metals than if the tests were made for an extended period in waters of moderate to high corrosivity. Aston also indicated that in tests of pipes carrying water, the water velocity and size of the test specimens should be considered.

4. CONCLUSIONS

4.1 Reliability of tests in predicting corrosion

From the sources of information reviewed, it appears that accelerated or short-time tests may have limited value in predicting long-time corrosion resistance. In some instances, ranking of materials as to corrosion resistance depends on the length of exposure period at which the comparison is made. It also appears that many tests and field observations have been made without recording some of the significant information as to exposure conditions over the period of the test or service exposure. Adequate data on these factors may be quite expensive and the time consuming, and often are unavailable in connection with service installations.

4.2 Extrapolation of existing test results to predict corrosion in condensate lines

The extrapolation of findings in atmospheric, soil, and water exposures to predict performance in condensate lines is not considered reliable for the following reasons: (1) the predictive value of the results may be limited, even in applications similar to the conditions of exposure in the reported tests, (2) references to sufficient scientific tests and field measurements on relative corrosion resistance of iron and steel condensate lines were not discovered in the present study, and (3) uncertainty exists as to the value of data from tests in atmosphere, soil, and water in predicting performance in steam-condensate return lines where the environmental conditions of exposure may differ greatly from those associated with the tests and which may vary widely between installations and from time to time in a given installation.

4.3 Some factors to be considered in evaluating corrosion resistance of condensate lines in controlled tests

Among the factors to be considered in evaluating the corrosion resistance of condensate lines would be (1) the metallurgy of the test materials as to composition and process of manufacture should be determined and classified so that the various test specimens could be treated equally from a statistical standpoint and so that the desired range of properties can be selected for test, (2) provisions should be made for accurate control and measurement of the properties of source water, boiler water, steam, and condensate, such as hardness, temperature, pH, chemical nature and quantity of additives, carbon dioxide and oxygen content, etc., and (3) the allowance of sufficient time for test to establish a meaningful trend in results. Tests would probably need to be made with one or more untreated waters of selected nature, as well as with treated waters in order to obtain a necessary knowledge of the effectiveness of corrosion control practices as related to composition of condensate piping. The effectiveness of pH control additives, amines, and adequate line slopes should be investigated. Periodic measurements of the extent of corrosion should be made.

4.4 Effect of corrosion control practices

The general indication obtained from the literature review and discussions with informed individuals was that corrosion resistance of all ferrous materials commonly used for condensate lines can be greatly improved if adequate corrosion control procedures are used. Where this is done, any inherent effect of pipe composition on corrosion performance should be of less practical significance than where corrosion control is not practiced. Thus, it can be concluded that regardless of the materials selected, an adequate corrosion control procedure should be utilized, based on the advice of competent and experienced consultants.

5. REFERENCES

1. Ellinger, C. A., Waldron, L. J., and Marzolf, S. B., Laboratory Corrosion Tests of Iron and Steel Pipes, Proceedings, ASTM, 1948.

2. Case, S. L., Corrosion Resistance of Wrought Iron and Steel Pipe, Metal Progress, March 1951.

3. Fair, G. M., Whipple, M. C., and Hsiao, C. Y., Hydraulic Service Characteristics of Small Metallic Pipes, Journal of New England Water Works Association, Volume XLIV, No. 4, 1930.

4. Tingley, I. I., and Rogers, R. R., The Corrosion Resistance of Wrought Iron and Open-hearth Steel--A Literature Survey, Mines Branch Information Circular IC 111, Department of Mines and Technical Surveys, Ottawa, 1958.

5. Kane, J. D., Comparative Corrosion Study of Soil, Waste, and Vent Pipe Materials, Yearbook of the American Society of Sanitary Engineering (approximately 1950).

6. Coleman, W. E., Comparative Corrosion Behavior of Wrought Iron and Steel Pipe, Republic Steel Corporation.

7. A. M. Byers Company, Comments on the Report, 'Comparative Corrosion Behavior of Wrought Iron and Steel Pipe.'

8. A. M. Byers Company, Results of Eight-year Corrosion Tests Conducted by the U. S. Naval Research Laboratory on Ten Structural Steels and Wrought Iron.

9. Rawdon, H. S. and Knight, O. A., Comparative Properties of Wrought Iron Made by Hand Puddling and by the Aston Process, RP 124, Journal of Research, National Bureau of Standards, 1929.

10. White, E. E. and Chandler, K. A., The Investigation of Corrosion Failures of Ferrous Metals, Chemistry and Industry, August 15, 1959.

11. Chilton, J. P. and Evans, V. R., The Corrosion Resistance of Wrought Iron, Journal of the Iron and Steel Institute, October 1955.

12. Aston, J. and Story, E. B., Wrought Iron--Its Manufacture, Characteristics and Applications, A. M. Byers Company, 1957.

13. Speller, F. N., Corrosion--Causes and Prevention, second edition (1935), third edition, 1951, McGraw-Hill.

14. Romanoff, M., Results of Bureau of Standards' 45-year Corrosion Study, Petroleum Engineer, March-April 1957.

15. Sussman, S. and Fullman, J. B., Corrosion in Closed Circulating-water Systems, Heating and Ventilating, October 1953.

16. Shuldener, H. L., Ferrous Piping Systems in Buildings, Corrosion and Material Treatment, August 1945.

17. Hale, Frank E., Experiments in Pipe Corrosion, Water Works Engineering, Volume 87.1, January-June 1934.

18. Unpublished report on 12-year hot- and cold-water line corrosion tests at the National Bureau of Standards.

19. Denison, I. A. and Romanoff, M., Soil Corrosion Studies, 1946: Ferrous Metals and Alloys, RP2057, V44, NBS Journal of Research, 1950.

20. Southwell, C. R., Forgeson, B. W. and Alexander, A. L., Corrosion of Metals in Tropical Environments, Part 4 -- Wrought Iron, 16th Annual Conf., Nat. Assoc. of Corrosion Engrs., March 14-18, 1960.

21. Forgeson, B. W., Southwell, C. R. and Alexander, A. L., Corrosion of Metals in Tropical Environments, Part 3 -- Underwater Corrosion of Ten Structural Steels, 15th Annual Conf., Nat. Assoc. of Corrosion Engr., March 16-20, 1959.

22. Spring, H. M., Jr., How to Stop Condensate Line Corrosion, Southern Power and Industry, June, 1956.

23. Hudson, J. C. and Wormwell, F., Corrosion of Metals in Buildings, Chemistry and Industry, August 10, 1957.

24. Uhlig, H. H., Corrosion Handbook, Wiley and Sons, 1958.

25. La Que, F. L., Corrosion Handbook, Wiley and Sons, 1948.

26. Cox, C. R., Corrosion Control by Water Treatment, Water Works Engineering, December 4 and 18, 1940.

27. Metals Handbook, Vol. 1, Properties and Selection of Metals, 8th Edition, American Society for Metals, 1961.

28. A. M. Byers Company, Special Report--The Use of Wrought Iron Pipe for Steam Condensate Lines.

29. Aston, J. D., Corrosion Resistance of Wrought Iron Pipe, A. M. Byers Company

30. Romanoff, M., Underground Corrosion, National Bureau of Standards Circular 579, 1957.

31. Pennington, W. A., Corrosion of Some Ferrous Metals in Soil with Emphasis on Mild Steel and on Gray and Ductile Cast Irons, Bureau of Reclamation, Department of the Interior, Report No. ChE-26, 1965.

DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS