CANADA

THE CORROSION RESISTANCE OF WROUGHT IRON AND OPEN-HEARTH STEEL
A LITERATURE SURVEY

by

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MINERAL DRESSING AND PROCESS METALLURGY DIVISION

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ABSTRACT

A survey of the available literature on the corrosion resistance of wrought iron and open-hearth steel has revealed that these materials have essentially similar corrosion behaviour in most common media. The opinions of several eminent corrosion scientists, which are included, support this conclusion. References to the published data are given.

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CONTENTS

INTRODUCTION

The corrosion resistance of wrought iron, compared with that of other ferrous metals, was discussed as far back as 1838(1). Since then this question has been raised from time to time, the manufacturers of wrought iron claiming superiority for their product, and engineers and scientists generally appearing to be skeptical. In response to a recent enquiry, the Mines Branch decided to make an extensive survey of the technical literature and, on the basis of the information obtained, to compare the relative merits of wrought iron and open-hearth steel from the standpoint of corrosion resistance.

Two types of mild steel are usually mentioned in the published reports on corrosion testing, namely open-hearth and Bessemer steels. There also are three forms of wrought iron: British or "puddled", Swedish slagless, and Aston-Byers (produced by the A. M. Byers Co. of Pittsburgh by a process invented by James Aston).

Somewhat less than 10% of today's steel production is made by the acid Bessemer process in which the charge and combustion products are all mixed intimately, and heat is supplied by the combustion of the impurities in the pig iron charge. The carbon content of the product usually is considerably lower than 0.35%, and rarely is higher than that amount. The phosphorus content is 0.08-0.11%, sulphur 0.07-0.08%, manganese as high as 1%, silicon very low. More than 85% of the steel used today is made by the basic open-hearth process. Fuels such as oil, gas or pulverized coal produce flames which are directed against a charge of pig iron and scrap steel, and preheated air is blown over the molten mass. The phosphorus and sulphur contents of open-hearth steel range from 0.02 to 0.05%; manganese can be as high as 1%,and silicon as high as 0.30%. Carbon is varied depending on the intended use for the steel.

According to Samans(2),"puddled" wrought iron is so called because the charge is stirred with a long iron rabble after the carbon begins to oxidize. Silicon and manganese are oxidized during the melting of the pig iron, and phosphorus and sulphur oxidized ahead of the carbon, by adding iron oxide or rolling scale and lowering the temperature. When the carbon begins to oxidize, the carbon monoxide formed agitates the bath into a "boil". The bath swells and begins to force the slag out of the furnace. The "puddling" consists of removing the purer iron which forms on the top, together with accompanying slag. Subsequent squeezing and rolling remove much of the slag, and orient the remainder into fibres in the rolling direction. "Piling" consists of welding together layers of the wrought iron and re-rolling them into a single sheet. It removes more slag and tends to homogenize the metal. The slag content in this wrought iron is generally 1-2%.

Swedish wrought iron is slag-free, un-puddled iron produced by melting down pig iron and oxidizing out the impurities as in the process above, but separating the metal from the slag.

Since 1930 Aston-Byers wrought iron has been made by melting pig iron of standard Bessemer grade in a cupola, desulphurizing in ladles, blowing in a small Bessemer converter to eliminate silicon, manganese and carbon, and tapping into a ladle. Meanwhile an iron silicate slag is made up, melted in a small tilting open-hearth furnace, and held in a ladle, in a molten condition but still at a temperature several hundred degrees lower than that of the refined iron. The iron then is poured into the slag ladle in a continuous stream, an operation known as "shotting". Because of the difference in temperature the iron is solidified continuously and rapidly. This rapid solidification liberates the dissolved gases with sufficient force to shatter the metal into small fragments which settle into the bottom of the ladle, weld together, and are collected as a sponge ball when the excess slag is poured off. The sponge ball is then squeezed into a solid bloom for rolling, and rolled into sheet for fabrication into the various forms desired.

Analysis of wrought iron generally shows 0.02-0.08% carbon; 0.10-1.20% silicon, ordinarily present almost entirely in the slag as silicates; 0.02-0.03% sulphur, although values of 0.05% or higher are not uncommon; 0.10-0.23% phosphorus, existing partly in the base metal and partly in the slag; and usually below 0.05% manganese, with amounts greater than 0.10% indicating steel scrap adulteration as a rule. Wrought iron made by the "puddling" process and that made by the Aston-Byers process do not differ greatly in chemical analysis, but the puddled wrought iron generally has a somewhat higher phosphorus content.

LITERATURE ABSTRACTS

Prior to 1925

F. N. Speller, Corrosion Consultant, and Former Director of Metallurgical Department, National Tube Company. "Corrosion, Causes and Prevention", First Edition (1926) (3).

In Chapter VII of this book the corrosion of ferrous metals is discussed. This chapter is summarized briefly as follows:

The work performed between 1839 and 1900 was summarized by Howe(4). In this early work the effects of important variables such as velocity of flow, film formation, hydrogen-ion concentration, humidity of the air, and oxygen concentration at the surface of the metal, were not taken into account. Nevertheless, although there were variations in the results from individual tests, in general the corrosion rates of steel, wrought iron and cast iron were found to be very similar to each other under atmospheric, fresh water and salt water conditions.

In 1902, Rudeloff(5) reported that wrought iron plates resisted the action of smelting furnace gases much better than did steel plates, in tests over a period of 8 years. In air, sea water, and ditch water, however, there was little to choose between these two metals.

Tests on pipe carrying domestic water, performed by the National Tube Company, beginning in 1906(3), and work reported by Howe and Stoughton(6) in 1908, and by Walker(7) in 1912, showed that the corrosion of wrought iron and steel pipe was identical in water service.

In 1906 the National Tube Company erected a test fence at McKeesport, consisting of panels and posts of wrought iron and steel pipe(3). After 11 years the corrosion on the two materials was found to be essentially identical. A similar result was obtained when both wrought iron and steel pipe were used in an atmospheric ammonia condenser for 10 years, with cooling water flowing over it continuously.

Service tests underwater and in acid mine water, up to 10 years in duration, by the National Tube Company in 1911, and by the American Society for Testing Materials(3), also showed little difference between wrought iron and steel piping.

About 1914, the American Society for Testing Materials carried out service tests on the corrosion of ferrous metals in the atmosphere(3). They found that wrought iron was more resistant than either basic open-hearth steel or Bessemer steel in the atmosphere, whether industrial, rural, or sea-coast.

Six different groups of tests carried out between 1915 and 1923, by six different investigators, on the corrosion of wrought iron and steel pipe in hot water systems, are described(3). In summary, Speller wrote, "This is probably the most extensive series of tests that has been made on water pipe in service, and it is very significant that, on the whole, the steel shows up somewhat better than the wrought iron".

In 1920, Richardson(8) reported the results of laboratory tests lasting 1000 days, on various ferrous metals under four different conditions, as follows: 1) Distilled water at rest. 2) Distilled water with air agitation. 3) Salt brine at rest. 4) Salt brine with air agitation. Some of the specimens were removed from solution and dried semi-weekly, while others remained continually immersed. His results showed that in the alternate wet and dry tests there was little to choose between steel (open-hearth and Bessemer) and wrought iron; on the other hand, the steels consistently had weight losses somewhat smaller than the wrought iron in the tests in which the specimens were continuously immersed.

In 1923, Wood(9) reported the corrosion testing of wrought iron, open-hearth steel (with and without 0.21% copper) and open-hearth pure iron, in distilled water, tap water (Ann Arbor, Michigan) and boiler water, each saturated with pure oxygen at room temperature, for 12 months. The average loss in weight per unit of area was found to be practically the same for all these materials, whether they were exposed with the mill scale present, or with the mill scale removed.

In 1923, also, Friend(10) reported the results of laboratory investigations on various ferrous metals in tap water (in alternate wet and dry conditions), and in 3% sodium chloride solution. In tests lasting 4 months and others lasting one year he found almost identical corrosion rates for wrought iron and carbon steel.

Speller carried out tests with wrought iron and steel pipes in sea water over a period of 2 years(3). Taking the penetration rate from the depth of the deepest pit and also from the average of the 10 deepest pits, the steel had a lower corrosion rate in the sea-water.

Tests carried out by the U. S. Bureau of Standards(11) around 1924 showed that in soils the corrosion rates of the common ferrous metals are remarkably similar.

Gas companies(12) (13) (14) (15) (16) also found that the corrosion of wrought iron and steel piping underground was practically identical.

Little difference was found in the corrosion of wrought iron and steel in 6 months' service in steam lines(12).

At the end of his summary of the work done between 1838 and 1924, Speller concludes as follows:(3)

"In the atmosphere, wrought iron seems to have some advantage in certain cases over ordinary steel. Steel containing more than 0.15% copper is more durable than wrought iron or ingot iron carrying the same amount of copper.

"Underwater, long-time laboratory and service tests have demonstrated that, in general, there is no difference between the commercial grades of wrought iron and steel when they are subjected to corrosion in hot or cold fresh water. In sea water, some tests show an advantage for wrought iron, while others show no marked difference.

"In acid solutions, steels are somewhat more resistant than wrought iron.

"Underground, there appears to be no conspicuous difference between wrought iron and steel."

J. H. Woolson, Consulting Engineer to National Board of Fire Underwriters. "Corrosion of Hot-Water Piping in Bath Houses", Engineering News, Dec. 3 (1910), p. 630 (17).

This engineer examined corroded piping in 8 bath houses in New York City, which had been in service for 4 years or more. Some of this piping was wrought iron and some was steel. His conclusion was, "In my judgment, from the evidence collected, there was absolutely no difference in the corrosion of the two classes of pipe (i.e. wrought iron and steel). They appeared to be equally susceptible to the attack".

Jas. O. Handy, Director of Departments of Chemistry, Metallurgy and Mining, Pittsburgh Testing Laboratory(18).

In 5 reports issued between October 31, 1916 and January 22, 1920, Handy describes work carried on in cooperation with the National Tube Company. Two-inch pipes of wrought iron and steel were used in hot water service for periods of from one to four years, at the Irene Kaufmann Settlement Building, Pittsburgh. No significant differences in corrosion resistance between the two metals were found. He concludes, "This test, and other similar tests, have shown beyond question that in the Pittsburgh district wrought iron and steel pipes in hot water lines are rapidly corroded by pitting, and that the laminated or fibrous structure of wrought iron produced by the included layers of slag does not give any added durability to wrought iron, as compared with steel pipe."

J. S. MacGregor, Instructor in Civil Engineering, Columbia University. "Report of Comparative Corrosion Tests upon Steel and Wrought Iron Pipe", March, 1917 (19).

Four tests were carried out in bath houses in New York City, varying in length from 2 years and 5 months, to 2 years and $9\frac{1}{2}$ months. The steel tubing showed consistently greater resistance to corrosion than the wrought iron pipe, the average depth of the deepest pit in steel being 0.059", compared to 0.077" in wrought iron.

Wm. H. Kennerson, Professor of Mechanical Engineering, Brown University. "Report of Test of Wrought Iron and Steel Pipe", June 7, 1918 (20).

Kennerson carried out tests with several different ferrous materials in a hot water system, for a period of about one year. He concluded, "There is evidently no marked superiority of either the wrought iron or steel for the test conditions described. All the samples would have failed in a short time, indicating that hot water is a very active corrosive agent in iron pipe.

"The wrought iron failed first by developing the deepest pits. The steel developed a greater number of shallower ones."

Melville C. Whipple, Instructor in Sanitary Chemistry, Harvard University. "Discussion of a Paper by Professor William H. Walker on Prevention of the Red Water Plague", New England Water Works Journal, March (1920) (21).

Experiments were carried out in a hot water service line at Harvard University, with $1\frac{1}{2}$" pipe of several different metals, including wrought iron and steel. The test lasted three years. At the end of this time it was found that the mild steel pipe had undergone much less pitting and the depth of the pits was much less than in the case of the wrought iron.

F. N. Speller, "Corrosion, Causes and Prevention", Third Edition (1951) (3).

In this edition of his book Speller wrote: "In the first decade of this century many held to the opinion that puddled iron was inherently superior in durability to steel. The results of a detailed study of this question with data and evidence from experience were compiled and published as a separate chapter in the first (1926) and second (1935) editions of this book. As this traditional opinion is now generally recognized to be unsound and erroneous, Chapter VII of the previous editions has been omitted here in order to conserve space. Those who wish to examine the data concerning the wrought iron vs steel controversy are referred to the 1935 (or 1926) editions."

1925 to 1957

Committee of the Institution of Civil Engineers of Great Britain. 18th Report, "Deterioration of Structures in Sea Water", 1940 (22).

It was found that, generally, wrought iron was somewhat more resistant than mild steel in sea water. This, however, was British-made wrought iron.

J. C. Hudson, Official Investigator to the Corrosion Committee of the Iron and Steel Institute and the British Iron and Steel Federation. "The Corrosion of Iron and Steel", (1940) (23).

In this book Hudson compared the corrosion rates of various ferrous metals under different conditions.

Atmospheric Corrosion. It was found that Swedish wrought iron was 40 to 50% more corrodible than ordinary mild steel. British wrought iron, however, corroded only 80% as much as mild steel. These were in 5-year tests. Aston-Byers wrought iron, after one years' exposure only, was considerably inferior to British wrought iron, and in fact, even slightly more corrodible than mild steel.

Sea Water. It was found that the rate of rusting was about 15% less for British wrought iron than for mild steel.

Salt Solutions. Reference was made to the work of G. D. Bengough and F. Wormwell at the Chemical Research Laboratory, Teddington, in which they found that British wrought iron rusted less rapidly than mild steel.

In a later paper(24) Hudson reported that Aston-Byers wrought iron was approximately 10% more susceptible to corrosion than mild steel, but British wrought iron was 25% to 36% less susceptible than mild steel. These results were obtained in atmospheric tests of more than 5 years' duration at Sheffield.

U. R. Evans, Reader in the Science of Metallic Corrosion, Cambridge University. "Metallic Corrosion, Passivity and Protection" (1946) (25).

Evans stated that in some cases of service, and in some tests, wrought iron has proved itself more corrosion resistant than mild steel. In view of his statement in reference (33) below, he was apparently referring to British wrought iron in this particular context.

H. H. Uhlig, Associate Professor of Metallurgy in Charge of the Corrosion Laboratory, Massachusetts Institute of Technology, Cambridge, Mass. "Corrosion Handbook", John Wiley and Sons, Inc., (1948) (26).

In the section on Iron and Steel, p. 139, Uhlig wrote, "Although controversy once existed as to the relative corrosion resistance of wrought iron and steel, it is now recognized that in natural waters the inherent corrosion rates are essentially identical. In acids the rates may differ greatly, depending upon the metal compositions."

F. L. LaQue, International Nickel Co., in "Corrosion Handbook", John Wiley and Sons, Inc., (1948) (27).

The data given for iron and steel in sea water "show a surprising uniformity of rates of attack for specimens exposed under conditions of continuous immersion at several points throughout the world".

L. F. Collins, F. J. Schlachter, and G. D. Winans, The Detroit Edison Co., Detroit, Mich. "Corrosion of Underground Steam Line Supports", Heating and Ventilating, 45, No. 6, pp. 83-5 (1948) June (28).

These workers found that the corrosion resistance of all the common ferrous metals, including mild steel and wrought iron, was very similar.

G. A. Ellinger, L. J. Waldron, and S. B. Marzolf, United States National Bureau of Standards. "Laboratory Corrosion Tests of Iron and Steel Pipes", Proc. A.S.T.M., 48, (1948), pp. 618-627 (29).

These investigators compared the corrosion resistance of pipes made from 10 different materials. These included wrought iron, Aston-Byers process; wrought iron, hand puddled; open-hearth steel; and copper-bearing steel. Washington tap water was circulated through a system of columns built up of test sections of these pipes. At the end of 7 years, it was found that the Aston-Byers wrought iron had a higher weight loss than the other three metals mentioned here. With regard to the average depth of pits, Aston-Byers wrought iron and the two steels were in the same class, with intermediate pit depths; while the hand-puddled wrought iron had deeper pits. From the figures obtained, Aston-Byers wrought iron and open-hearth steel were very similar, with the steel having a lower weight loss. Both were very much the same with regard to the deepest pit; and in the average depth of the five deepest pits the wrought iron had some advantage, 39 mils as against 45 mils for open-hearth steel.

S. L. Case, Technical Advisor, Battelle Memorial Institute, Columbus, Ohio. "Corrosion Resistance of Wrought Iron and Steel Pipe", Metal Progress, March, 1951, p. 378 (30).

This investigator found little to choose between wrought iron and steel pipe. He quoted the work of Hudson, Logan, and others mentioned above.

J. L. Wilson, Consultant. "How Does Wrought Iron Stand Up in Corrosive Marine Services?", Marine Engineering, February (1954) (31).

The writer apparently was attempting to show that wrought iron is superior to steel with regard to corrosion resistance. However he presented no new experimental data, but referred only to wrought iron installations which had proved to be successful. One of his main contentions was that present day testing procedures are inadequate. Corrosion specialists probably would not be greatly impressed by this article.

J. W. Green, Tube Turns of Canada Ltd. "Piping Materials for the Process Industries", Canadian Chemical Processing, October (1955), p. 46 (32).

This writer groups carbon steel and wrought iron together without any distinction in properties.

J. P. Chilton and U. R. Evans, Department of Metallurgy, University of Cambridge. Paper MG/B/12/55 of the Corrosion Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, "The Corrosion Resistance of Wrought Iron", J. Iron and Steel Institute, 181, Part 2, pp. 113-122 (1955) October (33).

They wrote "The corrosion of wrought iron differs from that of typical steel by its zonal character; a superior resistance is obtained in wrought iron only if the geometrical arrangement is such as to take advantage of the zonal character". They mentioned Q (quickly corroding) and R (resistant) zones, differing in the accessibility of combined sulphide. "V (very resistant) zones are only present in piled wrought iron, and represent internal layers of a noble alloy, due to selective oxidation of the surfaces of the pieces composing the pile, with consequent enrichment in copper and nickel".

They stated also that Aston-Byers iron is not piled and does not corrode in a zonal manner. Its sulphide is largely present in readily attackable, unsegregated form.

H. M. Spring, business connection unknown. "How to Stop Condensate Line Corrosion", Southern Power and Industry, June (1956) (34).

Includes the statement "There is evidence that wrought iron for condensate piping has an important place - - -".

Melvin Romanoff, National Bureau of Standards Circular 579. "Underground Corrosion", issued April, 1957 (35).

Romanoff described the work carried out by the U. S. Bureau of Standards from 1910 to the date of publication. He found that the differences in soils and in locations had much more influence on rates of corrosion in ferrous materials than did any differences in composition or structure, and that in general wrought iron and steels corroded very similarly.

E. P. Best, Chief Metallurgist, A.M. Byers Co., Pittsburgh, Penn., U. S. A. "Iron-Silicate Slag Network Helps Wrought Iron Resist Corrosion", Corrosion, 14, No. 2 (1958) (36).

He described the structure of the Aston-Byers wrought iron, and explained its corrosion resistance as due to its slag network. However, no experimental data were given in support of his contention that the material has exceptional corrosion resistance.

CONCLUSION

It would be easy to compile a list of successful applications of either of these materials. However, this survey has been directed to an examination of the published data in which the corrosion resistance of these materials is compared.

Consideration of the data given in the many papers referred to in this survey (covering field tests of long duration as well as laboratory experiments), and of the opinions of many investigators, including such eminent British and American corrosion scientists as Evans, Hudson, Speller and Uhlig, leads to the inescapable conclusion that there is little or no difference in the corrosion resistance of wrought iron and steel in the great majority of applications. British-made "puddled" wrought iron seems to have a slight advantage in atmospheric corrosion, but this does not seem to apply to Aston-Byers wrought iron. The corrosion resistance of British wrought iron is due largely to its "piling", and this would not apply to such forms as wire and pipe, which could not be "piled".

Letters have recently been received from H. H. Uhlig, Head of the Corrosion Laboratory at the Massachusetts Institute of Technology; G. A. Ellinger, of the National Bureau of Standards; F. N. Speller, corrosion consultant and author; and J. C. Hudson, of the British Iron and Steel Institute. These authorities all wrote that the opinions and conclusions stated in their earlier publications, which are given in this report, are still held by them.

REFERENCES

(1) Mallet, R., "On the Corrosion of Cast Iron and Wrought Iron", Brit. Assoc. Advancement Sci., Reports, 7, pp. 253-312 (1838).

(2) Samans, C. H., "Engineering Metals and Their Alloys", The MacMillan Company, 1949.

(3) Speller, F. N., "Corrosion Causes and Prevention", 1st Edition (1926), 2nd Edition (1935), 3rd Edition (1951), McGraw-Hill Book Company, Inc., New York.

(4) Howe, H. M., Congrès International des Méthodes d'essai des Matériaux de Construction, 2, pt. 1, pp. 229-266 (1901).

(5) Rudeloff, M., Mitt. kgl. techn. Versuchsanstalten, 20, pp. 83-206 (1902).

(6) Howe, H. M., and Stoughton, B., "The Relative Corrosion of Steel and Wrought Iron Tubing", Proc. Am. Soc. Testing Materials, 8, pp. 247-253 (1908).

(7) Walker, W. H., "The Relative Corrosion of Iron and Steel Pipe as Found in Service", J. New England Water Works Assoc., 26, pp. 7-10 (1912).

(8) Richardson, W. D., "Experiments on the Corrosion of Iron and Steel", Trans. Am. Inst. Chem. Eng., 13, pt. 1, pp. 169-263 (1920).

(9) Wood, W. P., "Corrosion of Rust-Proofed Iron and Steel", Chem. Met. Eng., 28, pp. 769-772 (1923).

(10) Friend, J. N., "The Corrosion of Iron", Iron Steel Inst., Car. Sch. Mem., 11, pp. 1-161 (1922) and "Second Report on the Relative Corrodibilities of Various Commercial Forms of Iron and Steel", Iron Steel Inst., Car.Sch. Mem., 12, pp. 1-25 (1923).

(11) Logan, K. H., "Soil Corrosion Investigation", Trans. Am. Foundrymen's Assoc., 32, pt. 1, pp. 144-166 (1924); "Corrosion of Underground Pipe Lines", Chem. Metal. Eng., 31, pp. 1011-1012 (1924).

(12) Report of Committee on Corrosion, Proc. Nat. Dist. Heat Assoc., 16 (1925).

(13) Vincent, G. I., "Street Main Standards", Proc. Am. Gas Inst., 8, pt. 2, pp. 191-232 (1913).

(14) Duncan, R. B., "The Installation and Maintenance of Services", Proc. Am. Gas Inst., 9, pt. 2, pp. 1052-1161 (1914).

(15) "Report of the Distribution Committee", J. D. Von Maur, Chairman, Proc. Am. Gas Assoc. Tech. Sec., pp. 1204-1312 (1924).

(16) "Report of Committee on Corrosion", Proc. Nat. Dist. Heat Assoc., 16 (1925).

(17) Woolson, J. H., "Corrosion of Hot-Water Piping in Bath Houses", Engineering News, Dec. 3 (1910), p. 630.

(18) Handy, Jas. O., "Reports of the Pittsburgh Testing Laboratory", collected in a bulletin of the National Tube Company, No. 2, 6th edition. Also abstracted in Trans. Am. Soc. Heating Ventilating Eng., 23, pp. 125-136 (1917), and 26, pp. 195-200 (1920).

(19) MacGregor, J. S., "Report of Comparative Corrosion Tests upon Steel and Wrought Iron Pipe", March 1917, National Tube Bulletin, No. 2, 6th Edition.

(20) Kennerson, W. H., "Report of Test of Wrought Iron and Steel Pipe", June 7, 1918, National Tube Bulletin, No. 2, 6th Edition.

(21) Whipple, M. C., "Discussion of a Paper by Professor Wm. H. Walker on Prevention of the Red Water Plague", New England Water Works Journal, March, 1920.

(22) "Deterioration of Structures of Timber, Metal and Concrete Exposed to the Action of Sea Water". Eighteenth Report of the Committee of the Institution of Civil Engineers, by J. Newton Friend, edited by H. J. Grose, published by the Institution in 1940.

(23) Hudson, J. C., "The Corrosion of Iron and Steel", Chapman and Hall Ltd., London, 1940.

(24) Hudson, J. C., "Atmospheric Corrosion Tests on Unpainted Irons and Steels", J. Iron and Steel Inst., No. II (1943), p. 178.

(25) Evans, U. R., "Metallic Corrosion, Passivity and Protection", Edward Arnold and Co., London, Second Edition (1946).

(26) Uhlig, H. H., "Corrosion Handbook", John Wiley and Sons, Inc., (1948).

(27) La Que, F. L., "Corrosion Handbook", John Wiley and Sons, Inc., (1948).

(28) Collins, L. F., Schlachter, F. J., and Winans, G. D., "Corrosion of Underground Steam Line Supports", Heating and Ventilating, 45, No. 6, pp. 83-5, (1948) June.

(29) Ellinger, G. A., Waldron, L. J., and Marzolf, S. B., U. S. National Bureau of Standards. "Laboratory Corrosion Tests of Iron and Steel Pipes", Proc. A.S.T.M., 48, (1948), pp. 618-627.

(30) Case, S. L., "Corrosion Resistance of Wrought Iron and Steel Pipe", Metal Progress, March 1951, p. 378.

(31) Wilson, J. L., "How Does Wrought Iron Stand Up in Corrosive Marine Services?", Marine Engineering, February (1954).

(32) Green, J. W., "Piping Materials for the Process Industries", Can. Chem. Processing, October, 1955, p. 46.

(33) Chilton, J. P., and Evans, U. R., "The Corrosion Resistance of Wrought Iron", J. Iron and Steel Institute, 181, Part 2, pp. 113-122 (1955) October.

(34) Spring, H. M., "How to Stop Condensate Line Corrosion", Southern Power and Industry, June (1956).

(35) Romanoff, Melvin, "Underground Corrosion", National Bureau of Standards Circular 579, issued April, 1957.

(36) Best, E. P., "Iron-Silicate Slag Network Helps Wrought Iron Resist Corrosion", Corrosion, 14, No. 2, p. 118 (1958).
