UNCLASSIFIED

RECORDS ADMINISTRATION
R0138789

DP - 170

Engineering

AEC Research and Development Report

CORROSION OF STEEL PIPE BY SAVANNAH RIVER WATER

by

F. Welty

Pile Engineering Division

August 1956

RECORD
COPY
DO NOT RELEASE
FROM FILE

E. I. du Pont de Nemours & Co.
Explosives Department - Atomic Energy Division
Technical Division - Savannah River Laboratory

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

Printed in USA. Price $0.20
Available from the Office of Technical Services
U. S. Department of Commerce
Washington 25, D. C.

253381 ✓

UNCLASSIFIED

DP - 170

ENGINEERING

CORROSION OF STEEL PIPE BY SAVANNAH RIVER WATER

by

Fred Welty
Pile Engineering Division

Work done by

R. W. Barret | R. F. Bree
A. C. Dutton | R. S. Kirkland
E. C. Nelson | C. K. Nicholson
R. C. Peterson

August 1956

E. I. du Pont de Nemours & Co.
Explosives Department - Atomic Energy Division
Technical Division - Savannah River Laboratory

Printed for
The United States Atomic Energy Commission
Contract AT(07-2)-1

ABSTRACT

Test sections of carbon steel pipe were pitted to a maximum depth of 0.06 inch during 30 months of exposure to flow of raw river water. The rate of pitting penetration of new pipe decreased with time during the first year of exposure and thereafter levelled off at approximately 0.01 inch per year.

External Distribution according to
TID-4500 (11th Ed.)

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

CORROSION OF STEEL PIPE BY SAVANNAH RIVER WATER

INTRODUCTION

Quantitative information on the rate of corrosion of steel pipe by Savannah River water was required in order to estimate the service life of cooling water lines. Since no published data were available, work was undertaken to determine the rate of corrosion of plant piping in continuous service on river water, and of coupons of ferrous alloys suspended in the pipe lines.

SUMMARY

Carbon steel pipe was pitted to a maximum depth of 0.06 inch in 30 months of continuous service on raw Savannah River water. The rate of pitting penetration decreased with exposure time until after about one year it reached a nearly constant value of about 0.01 inch per year. Chlorination of the river water to a residual chlorine content of 0.1 to 0.5 ppm had no measurable effect on the corrosion rate at 10° to 30°C. The depth of pitting by chlorinated water was the same at 55°C as at 10° to 30°C, but a greater proportion of the pipe surface was attacked at the higher temperature.

DISCUSSION

EXPERIMENTAL PROCEDURE

The heat exchanger system at the CMX Semiworks was employed as the site of the corrosion measurements. Cooling water was pumped from the Savannah River to the semiworks building through ten-inch carbon steel pipe at an average velocity of between two and three feet per second. After chlorination and settling, the water was passed through shell-and-tube heat exchangers and then returned to the river. The fluid velocity in the four-inch steel lines carrying water to and from the exchangers was five feet per second. The cooling water system was operated without interruption except for occasional maintenance shutdowns during which sections of the four- and ten-inch piping were removed for examination. The piping, which was Schedule 40 seamless, was new at the start of the corrosion tests.

Typical analyses of raw river water used in the corrosion tests are presented in Table I. The composition of chlorinated water is identical except for the increase of chloride and free chlorine due to the gaseous chlorination process. During the larger part of the test period, continuous chlorination to a residual free chlorine content of 0.1 to 0.5 ppm was employed. Intermittent chlorination - that is, for one hour per day to a chlorine residual of 1 ppm - was also used. As will be shown below, the chlorination procedure had no apparent effect on the corrosion rate. The temperature of water from the river varied seasonally between 10° and 30°C, while that of the water discharged from the heat exchangers was maintained at 55°C.

The test sections of pipe that were removed from the cooling water system were between one and two feet in length. Four-inch-square specimens were sawed out of the center portion of the pipe sections and cleaned chemically as described in the Appendix. Pit depths were then measured by a 100-power microscope with a calibrated focusing mount. Unpitted portions of the pipe surface were used as reference points for the measurement of pit depths. In the case of widespread pitting where there was uncertainty as to whether any of the original surface remained, the wall thickness of the specimen was estimated by micrometer.

Weighed coupons of ferrous alloys were suspended in the cooling water streams passing through the test sections of pipe. The coupons were mounted rigidly on rods which held them in position at the center of the piping. "Teflon" washers were used to insulate the coupons from the support rod and from each other. After chemical removal of corrosion products from the coupon surfaces, the loss of metal was determined by reweighing. Pit depths were measured with a microscope. The alloys tested were SAE No. 1020 carbon steel, SAE No. 304, 310, and 430 stainless steels, and cast iron. Couples of the carbon and stainless steels with 304 stainless steel were also tested.

PIPE CORROSION MEASUREMENTS

The test sections of pipe removed from service were free of algae and slime but were covered to a variable extent with rust-colored, tightly adhering tubercles. Each tubercle originally represented the products of corrosion from an isolated pit beneath it. As the number of pits increased with exposure time, the individual tubercles grew together into large aggregates that eventually covered the entire pipe surface with a coating 1/8 to 1/4 inch thick. Complete coverage usually occurred in about one year of exposure.

Water temperature and chlorination had little effect on the amount and type of corrosion products deposited. The coatings laid down at river temperature by chlorinated and unchlorinated water were nearly identical. The deposit left by chlorinated water at 55°C was similar to the others in bulk and general appearance but was darker and, when dry, more easily broken away from the base metal. The darker color may have been due to MnO_2 precipitated from the river water.

After the corrosion products were removed from the pipe specimens by chemical cleaning, pits appeared as crater-like depressions up to 1/8 inch in diameter, as shown in Figure 4. Pit depth measurements are summarized in Table II. The "average" values of pit depth represent in general the mean penetration of the 15 to 20 deepest pits on each four-inch-square specimen. For the three specimens on which fewer pits were measured, the average depths are considered to be on the high side when compared to the values for the other specimens.

Maximum and average pit depths are plotted against exposure time in Figure 1, curves of almost the same shape being drawn through the two sets of data. The rate of pitting penetration, represented by the slopes of these curves, decreased sharply during the first 12 months of exposure and approached a nearly constant value between 12 and 30 months. The drop in corrosion rate was probably due to the protection afforded the pits by the increasing thickness of accumulated corrosion products. The pitting rate at the end of 30 months could not be accurately determined due to scatter of the data points, but maximum and probable values of 15 and 5 mils per year, respectively, were estimated. A representative figure would be 10 mils (0.01 inch) per year.

The data plotted in Figure 1 reveal that the temperature and chlorination of the river water had no significant effect on the depth of pitting. After 30 months of exposure, the maximum pit depth was approximately 60 mils (0.06 inch) for each type of water used. The same average pit depth, 40 mils, was also observed in each case at the end of 30 months. The lateral extent of pitting, however, increased more rapidly at 55°C than at river temperature. After 16 months of exposure at 55°C, very little, if any, of the original pipe surface remained on the specimen examined. The same condition was not observed on the specimens exposed to cold water until 30 months had elapsed. When it was doubtful whether any original surface remained to serve as a reference point for depth measurements, the wall thickness of the specimen was measured and compared with that of new pipe. For all specimens that were so examined, the minimum wall thickness was greater than that calculated from the nominal ASTM wall thickness and the average pit depths. The maximum wall thickness of the specimens was equal to or as much as 10 mils greater than the ASTM value. Consequently, the pit depth measurements made on such specimens are considered to have an uncertainty in absolute value of less than 10 mils.

COUPON CORROSION MEASUREMENTS

Pit depth and weight loss data for carbon steel coupons are presented in Table III-A. The pits were one-tenth to one-half as deep as those on the pipe specimens, and there was no discernible correlation of pit depth with exposure time. The divergence in pitting rates was probably due to metallurgical differences between pipe and coupon metals and to the fact that the fluid velocity past the coupons was higher than that at the pipe wall. Because of these differences, corrosion rates for the coupons are believed to correspond only approximately to the attack on the pipe wall.

Over-all corrosion rates for carbon steel coupons, calculated from weight losses, are plotted against exposure time in Figure 2. The trend of the data is similar to that for pitting of the pipe wall; namely, a sharp decrease at first, followed by a levelling off after several months of exposure. There were no significant differences between the data for isolated coupons and for coupons coupled to 304 stainless steel. Variations in temperature and chlorination of the river water had no effect on the corrosion rate. It is interesting to note that the corrosion rate at the end of six months, about 10 mils per year, is the same as the final pitting rate for the pipe wall specimens.

The corrosion of cast iron coupons was general, without pitting. The corrosion rates based on weight losses are listed in Table III-B and plotted in Figure 3. The shape of the curve and the final corrosion rate are the same as those for carbon steel coupons. Both were likewise unaffected by differences in temperature and chlorination of the water.

Stainless steel coupons of all the types investigated were essentially uncorroded, the measured rates being less than 0.1 mil per year.

F. Welty

F. Welty
Pile Engineering Division

TABLE I

COMPOSITION OF RAW SAVANNAH RIVER WATER*

Constituent	Concentration, ppm	
	Filtered	Unfiltered
Fe	0.03-0.3	1-6
Mn	0.001-0.03	0.04-0.4
Cu	0.004-0.04	0.01-0.05
Ca	3-6	- - - - -
Al	0.1-0.9	1-5
Mg	1-2	- - - - -
Cl	1-5	- - - - -
SO_4	2-4	- - - - -
SiO_2	9-13	10-40
Total Hardness	10-20	- - - - -
Total Solids	40-70	70-170
Volatile Solids	10-40	30-60
Fixed Solids	30-50	40-120

* Based on analyses of composite samples taken from the corrosion-test pipelines between 1952 and 1955.

TABLE II

PIT DEPTH MEASUREMENTS ON CARBON STEEL PIPE

Months Exposure	Water Temp., °C	Chlorination of Water	Number of Pits* Measured	Pit Depth, Mils Max.	Pit Depth, Mils Avg.
3	10-30	No	20	31	18
3	10-30	No	16	23	17
4	55	Yes	15	32	22
7	10-30	Yes	5	42	31
7	55	Yes	18	44	37
9	10-30	No	20	49	33
11	10-30	Yes	7	20	15
11	55	Yes	20	52	27
12	10-30	No	15	43	34
12	10-30	No	4	41	38
16	10-30	No	20	39	29
16	10-30	Yes	20	45	40
16	55	Yes	20	38	29
22	10-30	No	20	52	34
30	10-30	No	20	52	38
30	10-30	Yes	20	60	43
30	55	Yes	20	61	41

* Visually estimated as the deepest on the specimen.

TABLE III

PIT DEPTHS AND OVER-ALL CORROSION RATES OF COUPONS

A. Carbon Steel - SAE No. 1020

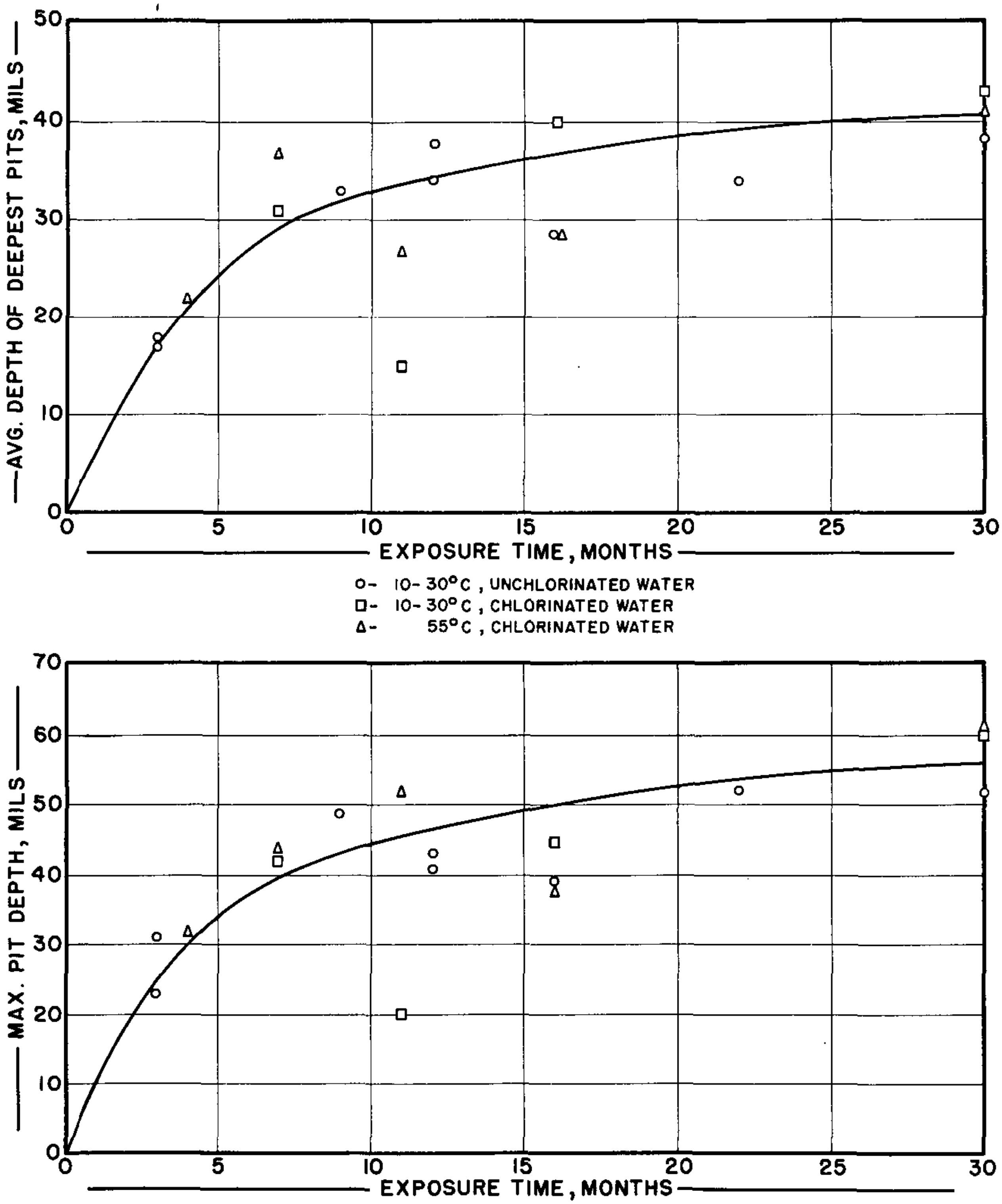
Months Exposure	Coupled to 304 Stainless Steel	Water Temp., °C	Chlorination of Water	Number of Pits* Measured	Pit Depth, Mils Max.	Pit Depth, Mils Avg.	Over-all Corrosion Rate, Mils/year**
0.5	No	10-30	No	10	6	4	24
0.5	Yes	10-30	No	10	6	5	35
0.5	No	10-30	Yes	10	8	5	14
0.5	Yes	10-30	Yes	10	6	5	14
0.5	No	55	Yes	8	3	2	47
0.5	Yes	55	Yes	10	5	4	38
0.7	No	10-30	No	10	6	4	25
0.7	Yes	10-30	No	10	8	6	33
0.7	No	10-30	Yes	10	5	3	23
0.7	Yes	10-30	Yes	10	6	5	13
0.7	No	55	Yes	10	3	2	27
0.7	Yes	55	Yes	10	5	5	23
1.7	No	10-30	No	10	8	5	11
1.7	Yes	10-30	No	10	9	5	21
1.7	No	10-30	Yes	10	10	7	14
1.7	Yes	10-30	Yes	2	3	2	13
1.7	No	55	Yes	10	5	4	13
1.7	Yes	55	Yes	10	6	3	15
3.5	No	10-30	No	7	4	2	3
3.5	Yes	10-30	No	5	11	8	4
3.5	No	10-30	Yes	6	11	6	5
3.5	Yes	10-30	Yes	10	6	3	11
3.5	No	55	Yes	7	8	5	12
3.5	Yes	55	Yes	10	5	3	18
6.2	No	10-30	No	10	6	4	7
6.2	No	10-30	Yes	10	5	3	8
6.2	Yes	10-30	Yes	10	20	17	9
6.2	No	55	Yes	10	7	5	9
6.2	Yes	55	Yes	10	6	3	9

B. Cast Iron

Months Exposure	Water Temp., °C	Chlorination of Water	Over-all Corrosion Rate, Mils/year**
0.5	10-30	No	48
0.5	10-30	Yes	41
0.5	55	Yes	49
0.7	10-30	No	35
0.7	10-30	Yes	31
0.7	55	Yes	23
1.7	10-30	No	15
1.7	10-30	Yes	19
1.7	55	Yes	10
3.5	10-30	No	8
3.5	10-30	Yes	10
3.5	55	Yes	7
6.2	10-30	No	7
6.2	10-30	Yes	11
6.2	55	Yes	8

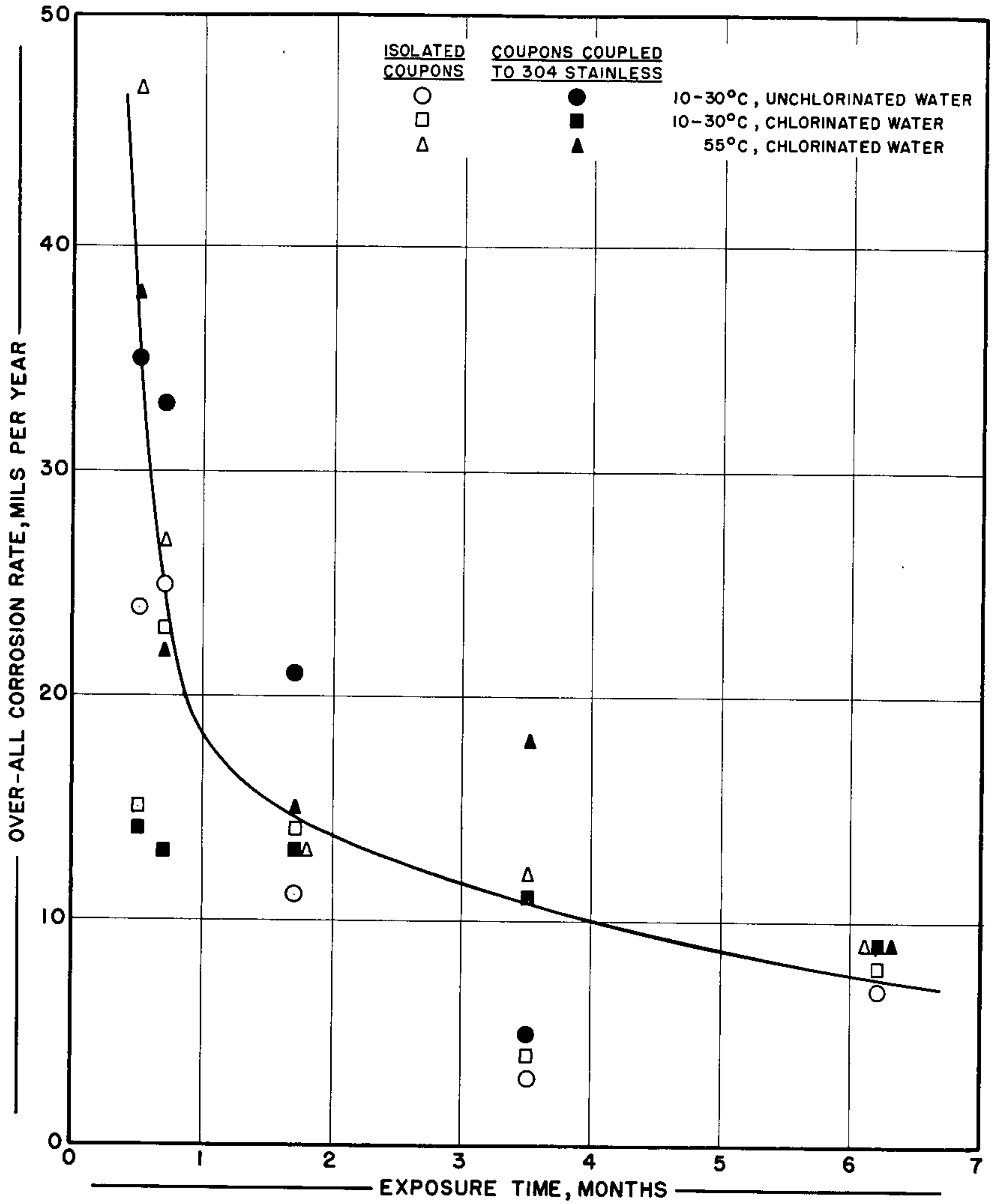
* Visually estimated as the deepest on the coupon.
** Based on weight-loss measurements.

FIGURE 1



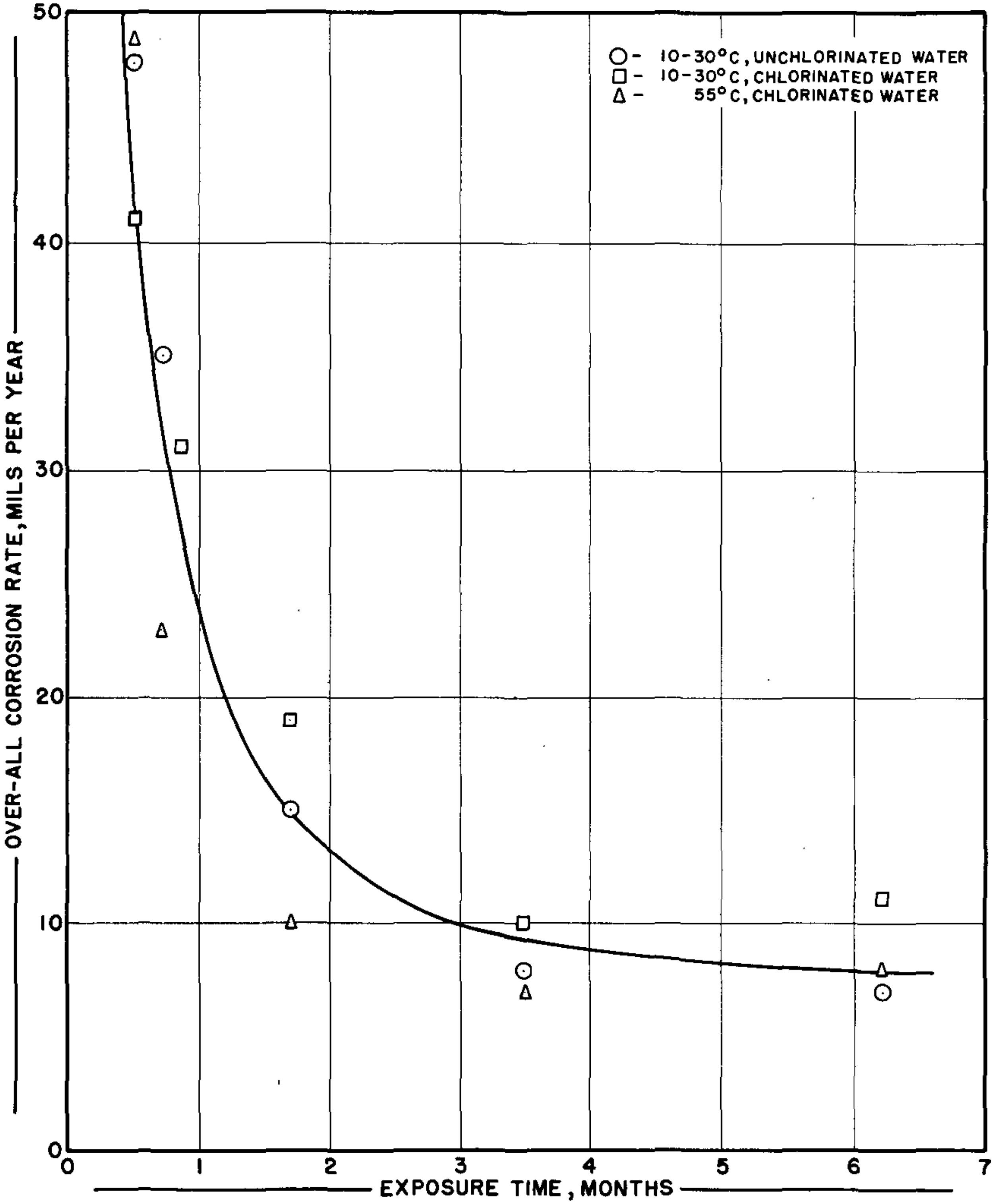
PITTING PENETRATION OF CARBON STEEL PIPE

FIGURE 2



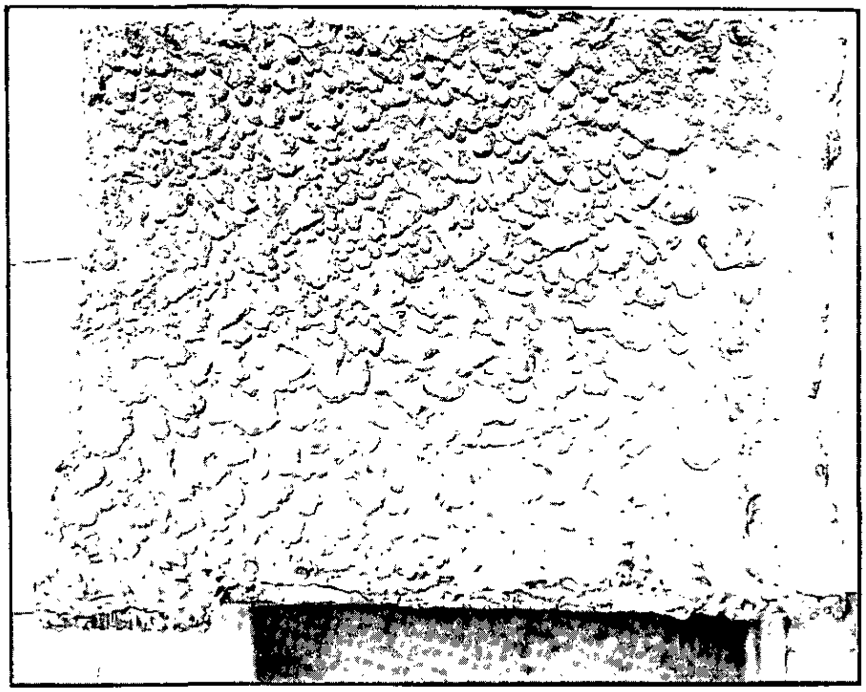
OVER-ALL CORROSION RATE OF CARBON STEEL COUPONS

FIGURE 3

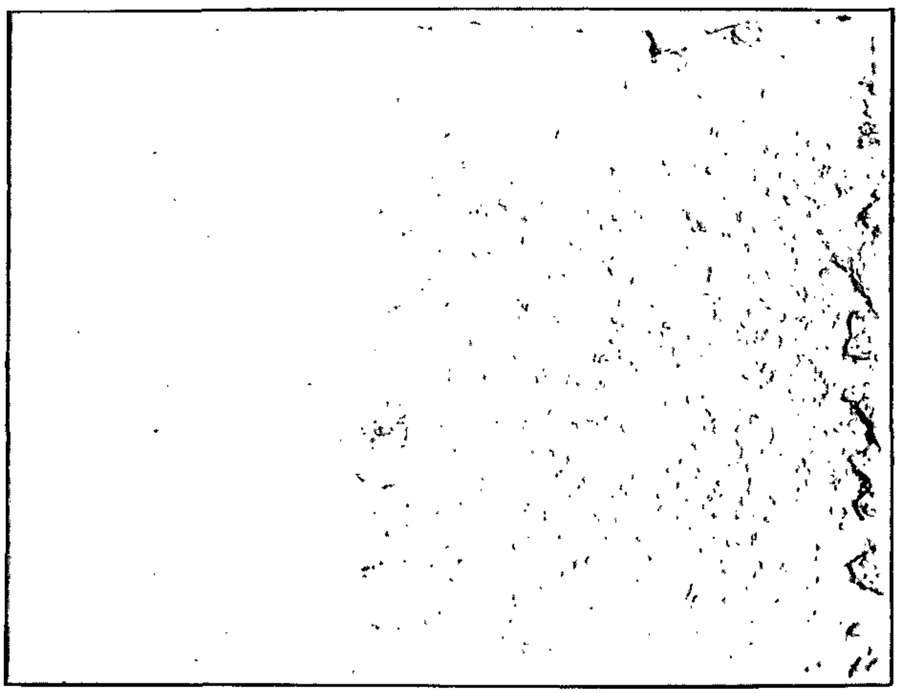


OVER-ALL CORROSION RATE OF CAST IRON COUPONS

FIGURE 4



SPECIMEN EXPOSED TO COLD UNCHLORINATED SAVANNAH RIVER WATER FOR 9 MONTHS.



SAME SPECIMEN. LEFT HALF CLEANED WITH INHIBITED SULFURIC ACID. RIGHT HALF WIRE-BRUSHED ONLY.

PHOTOGRAPHS OF 10-INCH CARBON STEEL PIPE SPECIMEN BEFORE AND AFTER CLEANING

APPENDIX

PROCEDURE FOR CLEANING AND INSPECTION OF CORROSION SPECIMENS

Pipe Specimens

Cleaning

Immerse specimen in a ten per cent solution of inhibited sulfuric acid at 40°C for about five minutes. Wire-brush, then immerse in acid for another five minutes. Wash and dry.

Inspection

Place the specimen under the objective of the microscope. Traverse the stage along lines parallel to the pipe axis. For each traverse, establish the position of the focusing mount required to focus on a portion of the original pipe surface. Then determine the number of revolutions of the fine adjustment knob required to focus on the bottom of each pit measured. From the calibration of the focusing mount obtain the pit depths. (The microscope used was a Bausch and Lomb binocular type, with 16 mm 10X objective and 10X eyepiece.)

Coupons

Cleaning Before Testing

Clean with a rubber eraser and, if the specimen is rusty, with emery cloth. Dry with acetone and weigh.

Cleaning After Testing

Immerse specimen in a 20 to 50 per cent oxalic acid solution at 40°C until deposits are loosened. This treatment alone is usually adequate for stainless steels and cast iron, but for carbon steel it may be necessary to follow the oxalic acid immersion by a 10- to 15-second dip in ten per cent inhibited sulfuric acid. Then wash and, if necessary, remove the last traces of corrosion products by scrubbing with household cleaning powder, using a rubber stopper. Dry with acetone and weigh. Loss of metal due to cleaning by this procedure is 1 to 4 mg.

Inspection

As with pipe specimens, except that it is not necessary to traverse in any particular direction, since the coupons are flat.