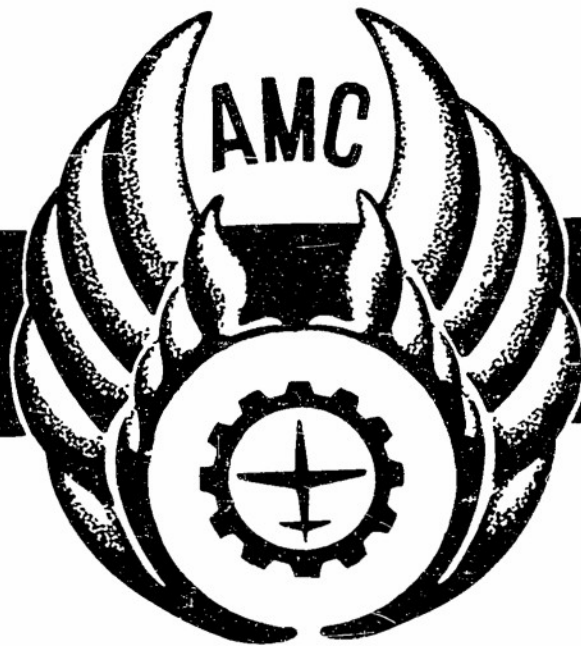


Reproduced by

CENTRAL AIR DOCUMENTS OFFICE



**HEADQUARTERS AIR MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE
DAYTON, OHIO**

The
U.S. GOVERNMENT

IS ABSOLVED

**FROM ANY LITIGATION WHICH MAY
ENSUE FROM ANY INFRINGEMENT ON
DOMESTIC OR FOREIGN PATENT RIGHTS
WHICH MAY BE INVOLVED.**

REEL - C

19000

A.T.I.

2 2 1 3 8

UNCLASSIFIED

An Investigation of Electrodeposited Alloys and Pure Metals as Substitutes for
Zinc and Cadmium for Protective Finishes for Steel Parts of Aircraft

Snively, C. A.; Tripler, A. B.; Faust, C. L.

Battelle Memorial Institute for USAF

Air Materiel Command, Wright-Patterson Air Force Base, Dayton, O.

22138

(None)

(None)

AFTR-5692

Nov '47 Unclass. U.S. English 145 photos, tables, diagr, graphs

Data are presented on static and dynamic potentials of selected pure metals and alloys relative to SAE-4130 steel, to serve as the basis for selecting the prospective substitutes for pure zinc and cadmium plate. Satisfactory protection of steel in the tropics would require metallic coatings which are inherently more stable than pure zinc and pure cadmium as represented in commercial electroplates on steel. Pure metals such as manganese and aluminum would increase the electrochemical stability without significantly decreasing galvanic protection. Little or no effect on the corrosion resistance of zinc was observed with minor additions of various metals, with the exception of copper, which did make zinc more resistant. Cadmium-zinc alloys were found superior to either zinc or cadmium.

Copies of this report obtainable from Central Air Documents Office; Attn: MCIDXD

Materials (8)

Steel - Protective finishes (90398.3);

Dopes, Paints and Finishes (7)

Metals - Electroplating (61045)

Air Documents Division, T-2
AMC, Wright Field
Microfilm No.

RC-1900 F

AF Technical Report 5692

A.T.I. No. 22138

AN INVESTIGATION OF ELECTRODEPOSITED ALLOYS AND PURE METALS AS SUBSTITUTES FOR ZINC AND CADMIUM FOR PROTECTIVE FINISHES FOR STEEL PARTS OF AIRCRAFT

**UNITED STATES AIR FORCE
AIR MATERIEL COMMAND
Wright-Patterson Air Force Base
Dayton, Ohio**

Date: 27 April 1948

UNITED STATES AIR FORCE
AIR MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE
DAYTON, OHIO

TECHNICAL REPORT
No. 5692

AN INVESTIGATION OF ELECTRODEPOSITED ALLOYS AND PURE
METALS AS SUBSTITUTES FOR ZINC AND CADMIUM FOR
PROTECTIVE FINISHES FOR STEEL PARTS OF AIRCRAFT

By

Lewis E. Michael
LEWIS E. MICHAEL (Project Engineer)

Approved:

J. B. JOHNSON
J. B. JOHNSON
Chief, Materials Laboratory
Engineering Division

For the Commanding General:

W. M. MORGAN
W. M. MORGAN, Brigadier General, USAF
Chief, Engineering Operations
Engineering Division

Laboratory No. M5381

E.O. No. 601-277

No. of Pages 139

No. of Photos

TABLE OF CONTENTS

	<u>Page</u>
AUTHORITY FOR PROJECT	1
Objective for This Report	1
INTRODUCTION	2
RESULTS ACCOMPLISHED	3
SUMMARY OF ESSENTIAL DATA	7
Literature Survey	7
Comparison of the Electrode Potentials of Cast and Electrodeposited Alloys. Static Electrode Potential Measurements of Electrodeposited Alloys and Pure Metals . .	9
Zinc - Copper Alloys	9
Zinc - Tin Alloys	10
Cadmium - Silver Alloys	10
Zinc - Lead Alloys	10
Porous Zinc Electroplate	10
Manganese	11
Conclusions	11
Static and Dynamic Potential and Corrosion Current Density Measurements of Fourteen Cast Binary Alloy Systems	11
Alloys Considered Prospects for Further Study	12
Zinc - Copper Alloys	13
Cadmium - Zinc Alloys	13
Zinc - Silver Alloys	13
Cadmium - Silver Alloys	14
Zinc - Tin Alloys	14

TABLE OF CONTENTS (CONTINUED)

	<u>Page</u>
Zinc - Nickel Alloys	15
Zinc - Chromium Alloys	15
Zinc - Manganese Alloys	16
Alloys Showing Little or No Prospects or Incompletely Studied	16
Zinc - Lead Alloys	16
Cadmium - Lead Alloys	17
Cadmium - Tin Alloys	17
Cadmium - Nickel Alloys	17
Zinc - Indium Alloys	18
Cadmium - Indium Alloys	18
Pure Metals	18
Tests in "Wet-Dry Program" Cabinet	19
Corrosion Test Check of Static Electrode Potential Values for Distilled Water	20
EXPERIMENTAL	21
APPENDIX I	22
Preparation of the Media in Which Electrode Potentials Were Measured	22
Three Per Cent Sodium Chloride Solution	22
Distilled Water	22
Distilled Water Saturated with Carbon Dioxide	22
Static Electrode Potential Measurements	23
Apparatus	23
Method	25

TABLE OF CONTENTS (CONTINUED)

	<u>Page</u>
Dynamic Potential and Corrosion Cell Current Density Measurements	26
Apparatus	26
Method	28
Preparation of Cast Alloys	29
Low-Melting Alloys	29
High-Melting Alloys	30
Preparation of Specimens for Potential Measurements . . .	31
Corrosion Test Check of Static Electrode Potential Values for Distilled Water	31
Preparation of Electrodeposited Alloys	32
Zinc - Copper Electrodeposits	32
Zinc - Tin Electrodeposits	33
Cadmium - Silver Electrodeposits	33
Zinc - Lead Electrodeposits	34
Procedure for Depositing Porous Zinc Plate	35
Electropolishing Bath	35
Operating Conditions	35
Operating Details	36
Method for Determining Porosity	36
Effect of Variation of pH on Porosity	37
Chemical Analysis	37
The Wet-Dry Program Cabinet	38
Details of Electrical Circuit for Wet-Dry Program Cabinet	39
APPENDIX II	42
APPENDIX III	80

TABLE OF CONTENTS (CONTINUED)

	<u>Page</u>
APPENDIX IV	123

FINAL REPORT

on

AN INVESTIGATION OF ELECTRODEPOSITED ALLOYS AND PURE METALS
AS SUBSTITUTES FOR ZINC AND CADMIUM FOR PROTECTIVE FINISHES
FOR STEEL PARTS OF AIRCRAFT

to

ARMY AIR FORCES MATERIALS LABORATORY
WRIGHT FIELD, OHIO

from

BATTELLE MEMORIAL INSTITUTE

by

G. A. Snavely, A. B. Tripler, Jr., and C. L. Faust

November 30, 1947

AUTHORITY FOR PROJECT

This is the Final Report on the project being conducted under
U. S. Government Contract W-33-038-ac-15723 (16940) dated October 23, 1946.

Objective for This Report

The ultimate objective is to define electrodeposited coatings,
which, in substitution for zinc and cadmium plate on aircraft steel parts,
will provide better protection, particularly in tropical regions.

The immediate objective of the present contract was to provide
data on static and dynamic potentials of selected pure metals and alloys
relative to S.A.E. X-4130 steel, to serve as the basis for selecting the
prospective substitutes for pure zinc and cadmium plate.

INTRODUCTION

Examination of aircraft materiel during and after service and storage in tropical regions revealed that zinc and cadmium plate did not give satisfactory protection to steel parts. Study of the corrosion data and environment showed that moisture condensate from the very humid atmosphere, and salt-containing dusts near the sea shore, considerably decreased the efficacy of galvanic (or sacrificial) protection known for zinc and cadmium on steel exposed in temperate climates.

It was concluded that satisfactory protection of steel in the tropics would require metallic coatings, which offer sacrificial protection, but which are inherently more stable than pure zinc and pure cadmium as represented in commercial electroplates on steel. Evidence pointed toward alloys of zinc and cadmium with metals that would increase the electrochemical stability without significantly decreasing galvanic protection, and toward less noble, pure metals such as manganese and aluminum.

Those alloys having prospects for meeting the requirements would have electrode potentials appreciably more negative than steel in corroding media. First segregation would be revealed by measurement of static electrode potentials and, further, by measurement of dynamic potentials of the substitute metal or alloy in electrical contact with SAE X-4130 when both were submerged in corroding media.

For corroding media in this laboratory survey, the following were selected: 3 per cent sodium chloride solution, distilled water, and distilled water saturated with carbon dioxide.

The results of the potential measurements study would indicate those substitutes most likely to succeed. Any coatings selected as prospective substitutes would need further evaluation under conditions simulating the cyclic condensation of moisture on and drying of the parts in the tropics. Substitute coatings selected on the basis of all tests would be evaluated in field tests, and commercial plating methods would be developed for those finally making the grade.

The successful substitute coating will retain or exceed the large potential difference between zinc and steel (be appreciably less noble than, and, therefore, protective to steel), yet through polarization or passivation effects, the corrosion current will be considerably less than that exhibited by a zinc-steel couple. Consequently, loss of coating will be slower in sacrificial protection. Corrosion products should be as little hygroscopic as possible.

Alloys, which are very near steel in electrode potential or have more noble values, cannot be expected to protect other than because of "envelope" coverage similar to that of nonmetallic coatings.

RESULTS ACCOMPLISHED

The following binary alloys have electrode potentials indicative of prospects for better protection of steel than zinc or cadmium provide:

<u>Alloy System</u>	<u>Range</u>
Zinc - copper	8 - 28 per cent copper
Cadmium - zinc	3 - 90 per cent cadmium
Zinc - silver	4 - 25 per cent silver
Cadmium - silver	3 - 8 per cent silver
Zinc - tin	25 - 90 per cent tin

<u>Alloy System</u>	<u>Range</u>
Zinc - nickel	10 - 12 per cent nickel
Zinc - chromium	2 - 5 per cent chromium
Zinc - manganese	3 - 5 per cent manganese

The preparation of alloys and measurement of electrode potentials required a major portion of the efforts on this project. In all, 81 alloys, representing 14 binary systems (as shown below), were investigated:

<u>Alloy System</u>	<u>Composition Range</u>
Zinc - copper	0 - 28 per cent copper
Cadmium - zinc	Complete
Zinc - silver	0 - 44 per cent silver
Cadmium - silver	0 - 32 per cent silver
Zinc - indium	0 - 40 per cent indium
Cadmium - indium	0 - 40 per cent indium
Zinc - tin	Complete
Cadmium - tin	Complete
Zinc - nickel	0 - 47 per cent nickel
Cadmium - nickel	0 - 3 per cent nickel
Zinc - lead	0 - 1 per cent lead and 99 per cent lead
Cadmium - lead	0 - 13 per cent lead
Zinc - chromium	0 - 5 per cent chromium
Zinc - manganese	0 - 10 per cent manganese

Static potentials of all were measured in 3 per cent sodium chloride solution, in distilled water, and in distilled water saturated with carbon dioxide. Dynamic potentials and corrosion currents were measured for all when electrically connected to SAE X-4130 steel in 3 per cent sodium chloride solution. These measurements were made at 90°F. for first examination, and the data are reported herein. Values of electrode potentials at higher and lower temperature are to be made after indication of prospective alloys is complete at 90°F.

Preliminary experiments revealed that solid, cast alloys could be used for this first work in place of electrodeposited alloys. Considerable timesaving resulted because electrodeposition methods were not known for all compositions of alloys studied. Electrodeposition methods will be needed only for those metals or alloys of ultimate selection. Commercial and/or laboratory methods are known for codeposition of metals in the first six alloy systems of the eight showing the most promise at this stage. Further study of plating details remains to be undertaken, in accordance with the findings of the present and subsequent work in continuation of this project.

Relative potential measurements cannot alone completely evaluate the improvement prospects of substitute coatings. For this reason, an accelerated, simulated tropical atmosphere test was developed. Preliminary results with this test indicate that it can further segregate the alloys in regard to performance under tropical conditions. The procedure, a "wet-dry program cycle" was developed in the latter part of the project period, so that evaluation of alloys, selected on the basis of electrode potential measurements, is not yet complete.

Such data as are available show a correlation between alloy composition and resistance to "wet-dry program exposure" for cadmium - zinc and zinc - nickel alloys. Resistance was superior to that of pure zinc as cast metal. Plated coatings of cadmium - zinc and zinc - nickel alloys on SAE X-4130 steel have not yet been evaluated, nor have representatives of the other preferred systems been tested to date.

Examination of aircraft parts, after exposure in the tropics, revealed that improved performance for zinc and cadmium plate results from passivation in chromate solutions. The protective film was superficial and subject to destruction by abrasion. Such a passivation throughout the zinc (or cadmium) could, conceivably, provide the degree of improvement being sought. A method is known for electrodepositing zinc appearing solid throughout, but actually containing microscopic porosity. An attempt to passivate and "fill" such a zinc plate "internally" by capillary action to "soak up" chromating solution was not successful in producing a more resistant zinc plate.

It is to be noted that tin is a metal among those showing beneficial alloying effects. Although tin may become a "strategic" metal, its inclusion affords completeness in the testing program. Knowledge of benefits from using tin could be valuable in case of extreme need for critical applications. Two compositions of zinc - lead alloys were produced, containing 13.3 and 17.7 per cent lead, by electrodeposition. Each had essentially the same static potential as pure zinc in 3 per cent sodium chloride solution. These two alloys might show improvement over pure zinc in corrosion protection. Before they can be included in the list of good prospects, data will be needed on dynamic electrode potentials in couple with bare steel and in "wet-dry program exposure".

A part of this project related to a literature survey, the results of which are summarized herein. Pertinent references are appended in the Bibliography.

SUMMARY OF ESSENTIAL DATA

Literature Survey

An extensive literature survey was conducted prior to the commencement of experimental work. While knowledge concerning tropical corrosion was, in general, scarce; nevertheless, certain important details were gathered. A complete survey of tropical climates and effects was given in the report of the Army Air Forces Tropical Science Mission (40)*. In general, the tropics are characterized by high-atmospheric humidity at moderately high-atmospheric temperatures. Because of the ever present high relative humidity, condensation is prevalent during the nights. The rapid deterioration of zinc in the tropics has been traced to these conditions. Condensed moisture promotes a rapid accumulation of the zinc corrosion products. At relative humidities of 75 per cent or higher, these corrosion products are hygroscopic (26, 47) so that, even in the absence of condensed moisture, enough water apparently is absorbed to support corrosion. The failure of cadmium is probably also related to moisture condensation, but beyond this no knowledge was available.

*Numbers in parentheses refer to the Bibliography in Appendix IV.

This Bibliography is the result of the literature survey and is given in its entirety.

The literature survey showed that pure metal coatings have been thoroughly exploited and indicated that there was little possibility of improvement over pure zinc or pure cadmium with the possible exception of manganese. The best chance for success appeared to be in the alloy field, with zinc or cadmium being used in binary combination with elements having better corrosion resistance.

One difficulty with many zinc and cadmium binary alloys is the small range of solid solubility. Solid solutions are, in general, more resistant to corrosion than multiphase systems.

The use of cast alloys for the survey of relative electrode potentials was visualized as being expedient. Evidence in the literature (1, 2, 6, 7, 8, 119, 120, 121, 122, 123) was not conclusive as to the magnitude of the difference, if any, of electrode potential of cast alloys from that of electrodeposited alloys of the same composition. Experiments, which are described later in this report, were performed to determine the magnitude of any difference.

Little or no effect on the corrosion resistance of zinc was observed with minor additions of various metals, (57, 62) with the exception of copper, which did make zinc more resistant (57, 59). Cadmium - zinc alloys were found superior to either zinc or cadmium (65, 66). Zinc - indium alloys (70), zinc - tin alloys (78, 79), zinc - nickel alloys (74), and cadmium - antimony alloys (80) were reported as being superior to zinc or cadmium in salt-spray tests. The Bureau of Mines has prepared zinc - manganese alloys, but no data were available on their corrosion characteristics.

Brown and Mears have developed the most simple and ingenious apparatus for making potential and corrosion current-density measurements (19, 20, 21).

A general discussion of alloy plating is presented in (125), and a Bibliography of alloy plating was prepared by the Engineering Division of the Air Materiel Command of the Army Air Forces (Serial No. TSFAM - M5236).

Comparison of the Electrode Potentials of Cast and Electrodeposited Alloys. Static Electrode Potential Measurements of Electrodeposited Alloys and Pure Metals

Zinc - Copper Alloys

Static electrode potentials of cast and electrodeposited zinc - copper alloys were measured in 3 per cent sodium chloride solution. Relatively little difference (the average was approximately 30 millivolts) was observed between the potentials of the two forms. (Figure 5, Appendix II, Tables 1 and 3, Appendix III). The observed differences are not significant when it is considered that the alloy containing as much as 28 per cent copper is approximately 300 millivolts less noble than SAE X-4130 steel, which is -0.706 volt on the calomel scale.

Two pairs of zinc - copper specimens, each pair consisting of one cast and one electrodeposited alloy having the same or very nearly the same composition, were tested for corrosion current density and polarization characteristics, when coupled to specimens of SAE X-4130 steel and immersed in an electrolyte of 3 per cent sodium chloride solution at 90°F. The alloys of the same composition showed corrosion current densities and polarization characteristics very much the same regardless of whether they were electrodeposited or cast (Figure 6, Appendix II, Table 4, Appendix III).

Zinc - Tin Alloys

The static potentials of the zinc - tin alloys in 3 per cent sodium chloride solution show good agreement with those of the cast alloys (Figure 32, Table 39) up to 50 per cent tin. From this point on, the electrodeposited alloys become noble more rapidly than do the cast alloys.

Cadmium - Silver Alloys

Static electrode potentials of two alloys, containing 2.95 per cent and 5.75 per cent silver, respectively, were measured in 3 per cent sodium chloride solution (Table 39), and were in good agreement with the cast alloys being some 20 millivolts less noble than the corresponding cast specimens.

Zinc - Lead Alloys

Two alloys, containing 13.3 per cent and 17.7 per cent lead, respectively, showed potentials within a few millivolts of pure zinc when measured in 3 per cent sodium chloride solution (Table 39).

Porous Zinc Electroplate

The static potentials of porous zinc plate with and without chromate treatment were measured in 3 per cent sodium chloride solution (Table 40). Untreated porous zinc plate is but slightly less noble than cast zinc. With the chromate treatment, the potential becomes approximately 30 millivolts more noble.

Manganese

The potential of electrodeposited manganese in 3 per cent sodium chloride solution (Table 40) is approximately 200 millivolts less noble than that of zinc. The potential becomes more noble with time. (See also Table 27).

Conclusions

Following the results of comparing cast and electrodeposited high zinc - copper alloys, the decision was made to use cast alloys for the electrode potential measurements in first separation of likely from unlikely alloys. The results with the cast alloys are summarized in the immediately following major section of this report.

After that series of measurements with cast alloys, the above-mentioned data were obtained for additional checks with the electrodeposited alloys of zinc - tin, cadmium - silver, and zinc - lead. Porous zinc plate and electromanganese were included in this series of tests on the electrodeposited alloys.

Static and Dynamic Potential and Corrosion Current Density Measurements of Fourteen Cast Binary Alloy Systems

Following the decision to use cast alloys for electrode potential measurements, specimens were prepared representing thirteen binary systems. The methods of preparation are described in Appendix I. The static potentials were measured in 3 per cent sodium chloride solution, in water saturated with carbon dioxide, and in distilled water, at 90°F. against

saturated calomel electrodes. From these measurements were drawn the conclusions as to whether an alloy could be expected to protect steel sacrificially.

The dynamic measurements were made in 3 per cent sodium chloride solution at 90°F. These measurements provided information relative to polarization and corrosion current density as influenced by alloying. In developing substitute alloys, it is desired to provide the lowest possible corrosion current-density commensurate with sacrificial protection. Such alloys should also retain an electrode potential appreciably less noble than that of steel. The larger the difference the more effective will the alloy coating be in protecting "bare" areas of steel. Alloys more noble than steel will not give the kind of protection desired in this work. In the following discussions, "less noble" is used synonymously with "anodic to steel", and "more noble" with "cathodic to steel". The 24-hour corrosion current densities are close to the equilibrium values and were used in determining the relative worth of the alloys under corroding conditions.

Appendix II contains graphs of the static and dynamic potential and corrosion current density data. The tables which contain the time-potential data and the dynamic data are found in Appendix III.

Alloys Considered Prospects for Further Study

On the basis of electrode potential data, the following systems contain alloys that are considered prospects for further study.

Zinc - Copper Alloys. In the range studied, up to 30 per cent copper, these alloys are less noble (retention of protective tendency) than steel in 3 per cent sodium chloride solution (Figure 5, Tables 1 and 2), and in water saturated with carbon dioxide (Figure 22, Table 21). In distilled water, however, the potential becomes more noble (loss of protective tendency) than that of steel at approximately 17 per cent copper (Figure 18, Table 15).

Increase in copper content lowers the corrosion current density, so that, at 28 per cent copper, the current density is approximately one-half that of pure zinc (Figure 6, Table 4) in the sodium chloride solution.

Gadmium - Zinc Alloys. This system is anodic to (less noble than) steel over the entire composition range in 3 per cent sodium chloride solution (Figure 7, Table 9), and in water saturated with carbon dioxide (Figure 24, Table 25). In distilled water, the alloys become cathodic to (more noble than) steel at approximately 65 per cent cadmium. (Figure 20, Table 19) The corrosion current density decreases uniformly with increase in cadmium content and reaches its lowest value at 90 per cent cadmium (Figure 13, Table 13) in the sodium chloride solution.

Zinc - Silver Alloys. In 3 per cent sodium chloride solution, and in water saturated with carbon dioxide, zinc - silver alloys are anodic to (less noble than) steel where the silver content does not exceed 28 per cent (Figure 7, Table 8, and Figure 24, Table 24). Alloys containing more than 28 per cent silver are cathodic. In distilled water, the

effect of silver is more marked, since a 5 per cent addition to zinc causes the alloy to be cathodic to steel (Figure 20, Table 18), the transition from the anodic side taking place at about 4 per cent silver. Silver causes a pronounced effect on the corrosion current density in 3 per cent sodium chloride solution where a 25 per cent silver alloy has a current density less than one-half that of pure zinc (Figure 11, Table 12).

Cadmium - Silver Alloys. Cadmium - silver alloys are anodic to steel in 3 per cent sodium chloride solution if they contain less than 18 per cent silver. At 18 per cent silver, they reverse and become cathodic to steel (Figure 7, Table 8). In carbon dioxide saturated water, the transition from anodic to cathodic relationship occurs at about 16 per cent silver (Figure 24, Table 24). In distilled water, the entire cadmium - silver system is cathodic to steel (Figure 20, Table 18). The dynamic measurements in 3 per cent sodium chloride solution show a slight decrease in corrosion current density (Figure 11, Table 12) and also show that protection is not given to the steel if the silver exceeds 8 per cent.

Zinc - Tin Alloys. Zinc - tin alloys, containing up to 95 per cent tin, are anodic to steel in 3 per cent sodium chloride solution (Figure 9, Tables 5, 11) and in water saturated with carbon dioxide (Figure 23, Table 22). It is also observed in Figure 9 that the as-cast specimens have potential values almost identical with those of the machined specimens. At approximately 35 per cent tin, zinc - tin alloys become more noble than steel in distilled water (Figure 19, Table 16). The 24-hour corrosion current-density curve (Figure 17, Tables 7, 13) shows

the large drop in current density in 3 per cent sodium chloride solution, due to increase in tin content. The current density for the 90 per cent tin alloy is approximately one-fourth that of pure zinc.

Zinc - Nickel Alloys. Zinc - nickel alloys, through 12 per cent nickel, are less noble than steel in 3 per cent sodium chloride solution, CO_2 -saturated water, and distilled water (Figure 26, Table 33). At some point between 12 per cent nickel and 47 per cent nickel, the alloys become cathodic to steel. This point was not determined because the alloys having compositions between these points were very brittle and specimens could not be prepared by melting and casting techniques. A gradual decrease in current density is observed with increase in nickel (Figure 33, Table 41), so that, at 12 per cent nickel, the current density is half that for pure zinc in the sodium chloride solution.

Zinc - Chromium Alloys. Zinc - chromium alloys, through 5.36 per cent chromium, are anodic to steel in 3 per cent sodium chloride solution, CO_2 -saturated water, and distilled water (Figure 30, Table 37). Slight changes are observed in the potential with small additions (0.5 per cent to 2 per cent) of chromium. An appreciable lowering of the current density in 3 per cent sodium chloride solution is observed (Figure 38, Table 41) with increase in chromium.

In the present work, this system was limited to the composition range given because of difficulties attendant upon the melting technique. This system has no known method for alloy electrodeposition, but, in case of outstanding prospects, a deposition study can be justified.

Zinc - Manganese Alloys. Through 9.6 per cent manganese, these alloys are anodic to steel in 3 per cent sodium chloride solution, CO_2 -saturated water, and distilled water (Figure 31, Table 38). The current density gradually decreases with increase in manganese up to about 5 per cent (Figure 40, Table 42). From 5 per cent to 9.6 per cent, there is a slight rise in current density. This system was also limited in the present work, because of melting difficulties.

Alloys Showing Little or No Prospects or Incompletely Studied

Electrode potential data show that the following alloys are unlikely to be improvements over pure zinc or pure cadmium, or the systems have not been completely investigated to date.

Zinc - Lead Alloys. Because of the very limited miscibility of zinc and lead, alloys of these two elements could not be prepared by casting beyond one per cent at either end of the constitution diagram. Alloy preparation by electrodeposition methods appears more promising. One per cent lead in zinc does not appreciably affect the potential in 3 per cent sodium chloride solution, CO_2 -saturated water, and distilled water (Figure 28, Table 35), the alloys being less noble than steel in all three media.

At 99 per cent lead, the potentials in CO_2 -saturated water and distilled water are more noble than that for steel, while, in 3 per cent sodium chloride solution, the potential is less noble than that of steel. This latter result is due to a slow attainment of equilibrium of the high-lead alloy. The 24-hour corrosion current-density curve (Figure 36,

Table 42) shows a slight decrease in current density as the lead increases up to one per cent.

Cadmium - Lead Alloys. Lead in amounts up to 13 per cent does not influence the potential of cadmium - lead alloys in 3 per cent sodium chloride solution and CO_2 -saturated water. In distilled water, a change of approximately 200 millivolts in the more noble direction takes place with the addition of 2 per cent lead to the cadmium (Figure 29, Table 36), with further additions causing only a slight change to less noble values. No change in corrosion current density in 3 per cent sodium chloride solution is observed with addition of lead (Figure 36, Table 42) to cadmium.

Cadmium - Tin Alloys. The cadmium - tin alloys are less noble than steel in 3 per cent sodium chloride solution if the tin content does not exceed 80 per cent (Figure 9, Table 6). In water saturated with carbon dioxide, tin does not cause the alloys to become more noble than steel until its content reaches 95 per cent (Figure 23, Table 23).

In distilled water, the entire cadmium - tin series is more noble than steel (Figure 19, Table 17). Tin up to 80 per cent appears to have little effect on the corrosion current density in 3 per cent sodium chloride solution (Figure 17, Table 7).

Cadmium - Nickel Alloys. Thus far, these alloys have been investigated over a very narrow composition range, because of the difficulty of preparing them thermally. Through 2.75 per cent nickel, the alloys are anodic to steel in 3 per cent sodium chloride solution and CO_2 -saturated water, but, in distilled water, they are cathodic to steel

(Figure 27, Table 34). No significant change in current density, in sodium chloride solution, was observed due to the addition of nickel (Figure 34, Table 41).

Zinc - Indium Alloys. Additions of indium to zinc in amounts up to 40 per cent have essentially no effect on the static potentials in 3 per cent sodium^{chloride} solution (Figure 8, Table 10) or in water saturated with carbon dioxide (Figure 25, Table 26). In distilled water, indium causes the potential to become 200 millivolts less noble with a 3.0 per cent addition (Figure 21, Table 20), but further additions have little effect. The twenty-four-hour curve (Figure 15, Table 14) shows that, up to 40 per cent indium, the corrosion current density is the same as that for zinc.

Cadmium - Indium Alloys. The cadmium - indium alloys, containing 3 per cent or more indium, have potentials which are a few millivolts less noble than steel in 3 per cent sodium chloride solution (Figure 8, Table 10). In water saturated with carbon dioxide, the addition of one per cent indium to cadmium causes the potential to become more noble than that of steel (Figure 25, Table 26). The cadmium - indium alloys are more noble than steel when immersed in distilled water (Figure 21, Table 20). Indium in amounts greater than 10 per cent causes a slight drop in corrosion current density (Figure 15, Table 14) in 3 per cent sodium chloride solution, but none of the alloys tested gave complete protection to the steel. Small amounts of iron rust were observed in each case.

Pure Metals

The static potentials of the cast pure metals are found in Tables 27 and 28.

Tests in "Wet-Dry Program" Cabinet

The "wet-dry program" cabinet was designed to provide a period of condensation followed by a period of dryness, simulating the tropical conditions.

The cadmium - tin and cadmium - zinc cast alloys were tested first. The initial cycling was arbitrary and consisted of a condensation period of 25 minutes and a dry period of 11 minutes. During the condensation period, the air temperature was in the range 115° - 120°F., while, for the dry period, it was between 65°F. and 75°F. This is recognized as not exactly duplicating tropical conditions, but is believed to be sufficiently comparable for this initial work. After 162 hours and 275 cycles, the specimens were removed and examined. The corrosion resistance of the cadmium - tin alloys appeared to be equal to that of pure cadmium. With the cadmium - zinc series, there was a definite correlation between composition and corrosion resistance, the attack being least on the high-cadmium alloys and heaviest on the high-zinc alloys.

Cast zinc - nickel and cadmium - nickel specimens were exposed for 383 hours and 582 cycles (the dry period had been increased to 14-1/2 minutes). The zinc - nickel alloys with 12 per cent nickel showed less corrosion than those with lower nickel contents, one of which contained only 0.03 per cent nickel and probably can be considered equal to pure zinc in corrosion properties. In the case of the cadmium - nickel alloys, no improvement over pure cadmium was observed for alloys containing up to 3 per cent nickel.

Also exposed were specimens plated with porous zinc that had received a chromate passivating treatment and specimens coated with regular zinc plate that had also received a chromate treatment. Before being placed in the cabinet, each of the specimens was scratched with a file to expose some of the metal coating beneath the passivated surface. After 499 hours and 758 cycles, the regular zinc plate with chromate passivated surface showed no corrosion whatsoever, either in the scratches or elsewhere. The porous zinc plate, which had also received the passivation treatment, had "moderate to heavy" corrosion in the scratches and "slight to moderate" corrosion in general.

Corrosion Test Check of Static Electrode Potential
Values for Distilled Water

To test the relative value of static potential measurements made in distilled water, two cast alloy systems, the zinc - tin and the cadmium - zinc (Figures 19 and 20), were chosen for further experiments. A series of galvanic cells was set up, using X-4130 steel and specimens of the two above-mentioned alloy systems. These couples were immersed in distilled water and held at 90°F. for 24 hours. Examination at the end of this period showed that, in every case where an alloy did not protect the steel, the static electrode potential measurements (again see Figures 19 and 20) showed values more noble than those for the steel.

EXPERIMENTAL*

The apparatus and methods used for this project are described in detail in Appendix I.

*Laboratory Record Book No. 2875, pp. 1-100.
Laboratory Record Book No. 3180, pp. 1-100.
Laboratory Record Book No. 3363, pp. 1-30.
Laboratory Record Book No. 3393, pp. 1-14.
Laboratory Record Book No. 3942, pp. 1-23.

APPENDIX I

This Appendix contains descriptions of all apparatus and all methods used for this project.

Preparation of the Media in Which Electrode Potentials Were Measured

Three Per Cent Sodium Chloride Solution

The water used for the sodium chloride solution was the regular laboratory distilled water having a pH of 6.3. The salt used was "Baker's Analyzed", chemically pure sodium chloride. The solution was filtered and the concentration checked by accurate specific gravity measurement.

Distilled Water

The distilled water, which was used alone for potential measurements, was a specially purchased product having a specific conductivity of 5×10^{-6} reciprocal ohms and a pH of 6.9 - 7.0. It was protected by a tube containing "ascarite", a carbon dioxide absorbing substance.

Distilled Water Saturated with Carbon Dioxide

Bottled carbon dioxide was bubbled through the special distilled water. At the end of one hour, the pH was 4.1, and further treatment with carbon dioxide did not change the pH. Lundell and Hoffman* give 3.7 as the pH of water saturated with carbon dioxide. The 4.1 value

*"Outlines of Methods of Chemical Analysis", John Wiley and Sons, 1938, p. 133.

was reproducible in the present work, however, and numerous checks showed no deviation from this value.

Static Electrode Potential Measurements

Apparatus

Figure 1 is a picture of the apparatus as set up for measuring static electrode potentials of four specimens concurrently. Also pictured in this figure are the additional pieces of equipment used in the dynamic measurements which are described later.

The potential differences were measured with a Leeds and Northrup student-type potentiometric circuit. No. 4970 saturated calomel cells, designed for use with the Beckman pH meter*, were used as reference electrodes. When measurements were made in distilled water or distilled water saturated with carbon dioxide, the calomel electrodes dipped directly into these media. For the measurements in 3 per cent sodium chloride solution, the calomel electrode dipped into a small cup containing a saturated solution of potassium chloride. A bent, 7-mm.-diameter glass tube, containing a 3 per cent sodium chloride solution, connected this cup to the beaker filled with a 3 per cent solution of sodium chloride, into which dipped the specimen. The end of the glass tube, which dipped into the 3 per cent sodium chloride solution, was drawn down to a small bore and a 5-mm. length of fibrous asbestos was sealed in. The asbestos tip reduced diffusion and, by having the calomel

*Manufactured by the National Technical Labs., Pasadena, California.

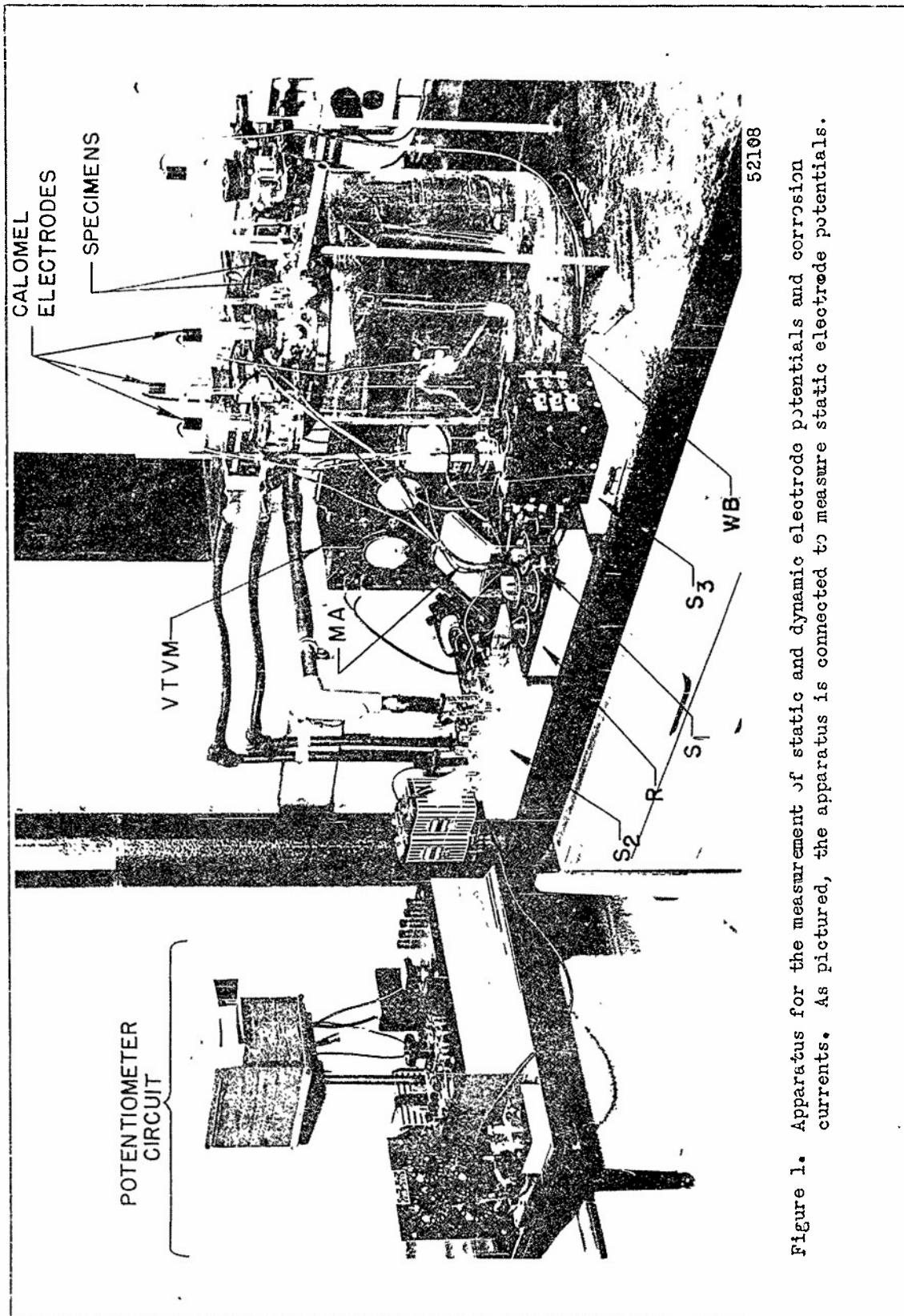


Figure 1. Apparatus for the measurement of static and dynamic electrode potentials and corrosion currents. As pictured, the apparatus is connected to measure static electrode potentials.

electrode dip into the saturated potassium chloride solution, contamination of the calomel electrode by sodium ions is minimized.

The corrosive media were contained in 250-ml. beakers. The beakers were immersed in a thermostatically controlled water bath (WB in Figure 1) which operated within $\pm 1^\circ\text{F.}$ of the desired temperature.

The specimens were supported in bakelite clamps which rested on the edges of the beakers. A four-way rotating double-pole switch (S_3 in Figure 1) was used so as to make possible the concurrent measurement of four specimens.

The potentiometric circuit was calibrated twice by the Battelle instrument laboratory and was found to be correct.

Method

The calomel electrodes were placed so that the dips dipped into the corrosive medium to a depth of $3/4$ inch. The clamped specimens were then immersed vertically to a depth of $1-1/2$ inches and placed so as to be $1/4$ inch from the calomel electrode tips. After one minute, the initial potential measurement was made (except for measurements in distilled water. See below . Subsequent measurements were then made at five or ten-minute intervals following the instant of immersion. The total elapsed time, in most cases, did not exceed 60 minutes. In the cases of several pure metals, the elapsed time ran as high as 160 minutes, since the rate of change of potential with time was still rapid at 60 minutes.

When the specimens were being tested in distilled water, the initial measurements were made after 60 minutes had elapsed and subsequent measurements were made at 75 minutes and 90 minutes. The reason for waiting 60 minutes before making the initial measurement was to allow a small amount of metallic material to dissolve, thus increasing the conductivity. The calomel electrodes were removed from the water when measurements were not being made, so that no contamination would result from potassium chloride.

In making the measurements, care was taken to tap the circuit-closing key, but momentarily, in order to minimize polarization.

Dynamic Potential and Corrosion Cell Current Density Measurements

Apparatus

The circuit developed by Brown and Mears*, for measuring potentials and currents in coupled cells, was used in this work. A schematic diagram of this so-called "zero resistance" circuit is given in Figure 2. As shown in Figure 1, the apparatus was connected for measurement of static electrode potentials. By disconnecting the potentiometer leads from the four-way switching box and reconnecting them to terminals 2 and 5 of S_2 (Figure 2), and connecting two calomel electrodes as shown in Figure 2, the apparatus was ready for dynamic measurements. MA (the code letters refer to Figures 1 and 2) is a 0-10 milliammeter. The battery between resistance R and S_1 in Figure 2, was a 1-1/2-volt dry cell.

*Trans. Electrochem. Soc., 74, 495 (1938)

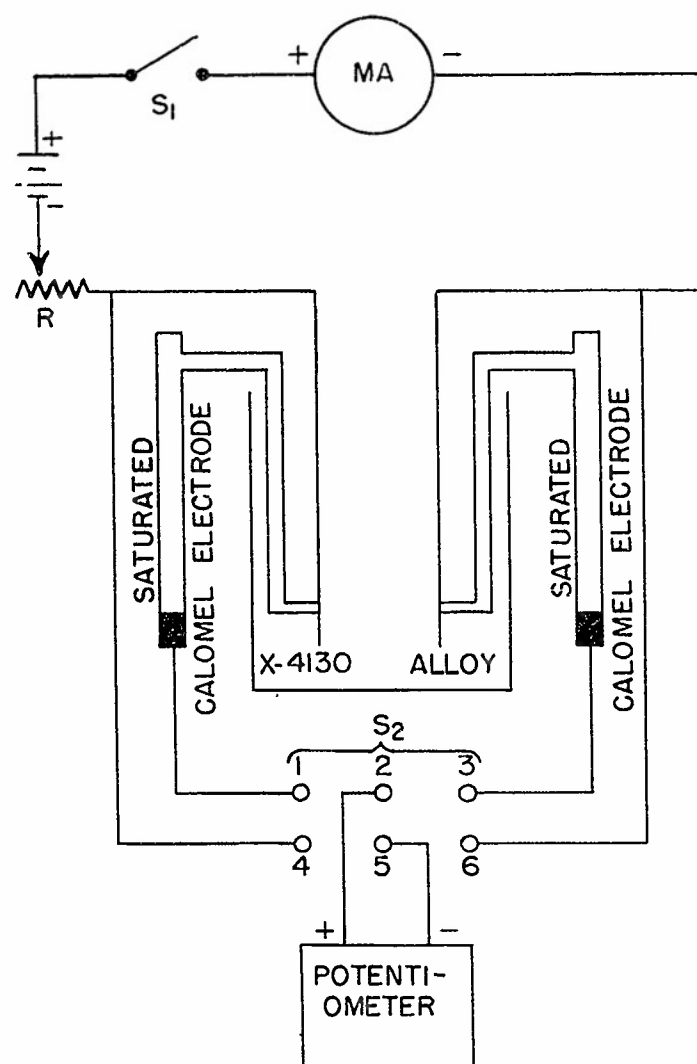


FIGURE 2 - SCHEMATIC REPRESENTATION OF THE "ZERO RESISTANCE" CIRCUIT FOR MEASUREMENT OF CORROSION CURRENTS AND ELECTRODE POLARIZATION

Resistance R comprised a 5000-ohm, a 3000-ohm, and two 1000-ohm variable radio potentiometers connected in series. Switch S_2 was constructed from two knife switches, one a double-pole double-throw type, and the other a double-pole single-throw type. In addition to the Leeds and Northrup potentiometer circuit, a simple slide back, vacuum tube voltmeter was used for rough measurements, and preliminary adjustments (VTVM in Figure 1).

The specimens were supported by bakelite clamps, which held the steel and alloy one inch apart. The alloy specimens measured 1 inch x 3 inches, while the steel specimens measured 1 inch x 4 inches. The specimens dipped into the solution 1-1/2 inches.

Method

The clamped specimens were immersed in the sodium chloride and were then connected in the circuit. Two calomel electrodes were placed so that the tips pressed against the surfaces of the steel and alloy, respectively. A period of twenty minutes elapsed, following the instant of immersion, and the measurements were made according to the following procedure:

1. With Switch S_1 open, and Switch S_2 thrown so that contacts 1 and 4 were connected to 2 and 5, respectively, the potential of the X-4130 steel was measured.

2. With Switch S_1 open, and S_2 thrown, so that contacts 3 and 6 were connected to 2 and 5, respectively, the potential of the alloy was measured.

3. With S_1 open, and S_2 thrown, so that Contacts 4 and 6 were connected to 2 and 5, respectively, the difference in potential between the steel and alloy was measured. This value should be very close to the calculated difference obtained from Steps 1 and 2.

4. With S_2 thrown as in Step 3, S_1 was closed and Resistance R was adjusted, so that the potential difference between the steel and alloy was zero. The corrosion current for the cell was then read on the milliammeter.

5. With S_1 closed, the separate potentials of the steel and alloy were measured as in Steps 1 and 2.

Preparation of Cast Alloys

Low-Melting Alloys

The low-melting alloys were prepared directly in a gas-fired crucible furnace. This furnace was composed of a fire clay crucible which fitted in a larger graphite crucible. The latter had a one-inch hole drilled in the side wall near the bottom, through which passed the nozzle of a blast burner. The flame swirled around the inner crucible, thus distributing the heat.

Measured amounts of two chemically pure metals were placed in the inner crucible and were covered with charcoal. During melting, the inner crucible was covered and the outer crucible partly covered. After melting was complete, the temperature was maintained for 10 - 15 minutes

(in the case of the zinc - copper alloys, the temperature was maintained for approximately one hour). The melt was then stirred thoroughly with a carbon rod and poured into a carbon mold. The ingots measured 1 inch x 3 inches x 1/8 inch.

High-Melting Alloys

The technique described in the previous section was inadequate in the case of zinc - chromium and zinc - manganese. These alloys were prepared as follows: For the zinc - chromium system, "master" alloys were first prepared by placing zinc in an alundum thimble crucible and melting it in an induction furnace. The melt was covered with a zinc chloride flux and heated to 1520°F. One-hundred-mesh chromium powder was then stirred into the flux and finally into the melt. The resulting alloys were poured at 1510°F. Two "master" alloys, containing 12.4 per cent and 15.2 per cent chromium, respectively, were prepared in this way.

Essentially the same procedure was used in the preparation of the zinc-- manganese "master" alloys. Small chips of electrolytic manganese were added to the molten zinc at 1480°F. The temperature was then raised and the pouring was done at 1620°F. The two "master" alloys contained 17.6 per cent and 19.2 per cent manganese.

In each case, the alloys which were used for measuring potentials were prepared by use of the "master" alloys in the gas-fired crucible furnace.

Preparation of Specimens for Potential Measurements

The ingots were machined on a shaper so as to produce a smooth surface. The same specimens were used for measurements in several media. Between measurements, the corrosion products were removed by light rubbing with fine steel wool. The machined surfaces of the specimens facilitated this and no significant change resulted from such light reworking of the original surface. The specimens were then cleaned by rubbing with a clean cloth saturated with carbon tetrachloride. This was followed by vapor degreasing in trichlorethylene. The steel specimens received the same treatment, but, in addition, were pickled for 20 seconds in 1-1 hydrochloric acid solution just prior to using.

Corrosion Test Check of Static Electrode Potential Values for Distilled Water

The cells contained an X-4130 cathode 1/16-inch thick and 1/4-inch wide. Facing this cathode on each of two sides and spaced 1/16-inch from it was a cast alloy anode one inch wide and 1/8-inch thick. An anode to cathode area ratio of 8 to 1, and the 1/16-inch spacing, were experimentally determined as being necessary if rusting of the cathode, when coupled to a less noble metal or alloy, was not to occur. With too small an area ratio and too great a spacing, even pure zinc did not protect steel in distilled water, since the minimum current density required for protection was not reached. The anodes and cathodes were immersed in distilled water to depths of 1-1/2 inches and 1-3/8 inches, respectively, and were coupled with short external "jumpers". The

distilled water was contained in 250-ml. beakers, and the electrodes were held in place by bakelite clamps, which rested on the edges of the beakers.

Preparation of Electrodeposited Alloys

Zinc - Copper Electrodeposits

Steel specimens were degreased in trichlorethylene vapor, followed by an anodic treatment for one minute in Anodex* at 5 volts and 190°F. A 30-second dip in 1-1 hydrochloric acid solution at room temperature, a thorough washing, and a quick dip in dilute KCN solution completed the pretreatment.

In the early experiments, a bath described by Oplinger** was used. This bath was developed to plate an alloy containing 26 per cent to 29 per cent copper and has the following composition:

NaCN	90 g./l.
CuCN	18 g./l.
Zn(CN) ₂	70 g./l.
NaOH	70 g./l.

Temperature - 105°F.

Current Density - 20 amp./sq. ft.

By using pure zinc anodes and "dummying" the bath for various periods of time, the solution was depleted in copper, and specimens within the desired composition range were produced.

*MacDermid, Inc., St. Louis, Missouri.

**Met. Ind. (N. Y.) 36, 513, 1938.

This method was soon found to be too slow, so a stock zinc plating solution was prepared. By adding copper cyanide in various quantities to the stock solution, alloys of different compositions were deposited. The stock solution was as follows:

NaCN	90 g./l.
Zn(CN) ₂	70 g./l.
NaOH	70 g./l.

The plating conditions were the same as for the Oplinger bath.

Zinc - Tin Electrodeposits

These were plated from an alkaline stannate - zinc cyanide bath, as described by R. M. Angles (J. Electrodepositors' Tech. Soc., 21, 45, 1946). SAE X-4130 steel specimens, measuring 1 inch x 4 inches, which had been polished on a 240-emery belt, were cleaned for one minute cathodically and one minute anodically in Anodex at 190°F. and 100 amp. sq. ft. This cleaning was followed by a three-minute dip in 6-N. hydrochloric acid at room temperature. The specimens were then electroplated according to the conditions given in Table 31, Appendix III. Alloy anodes of composition 20 per cent zinc - 80 per cent tin were used in all cases. No agitation was used.

Cadmium - Silver Electrodeposits

The bath developed by C. L. Faust, D. J. Henry, and W. G. France (Trans. Electrochem. Soc., 72, 479, 1937) was used for the two cadmium - silver alloys.

Specimens of SAE X-4130 steel were prepared in the same way as described for the zinc - tin alloys. The specimens were then plated as shown in Table 32, Appendix III, using steel anodes. No agitation was used.

Zinc - Lead Electrodeposits

Very little information on the electrodeposition of zinc - lead was available. Mason (U. S. Patent 2,136,629) described a method of codepositing small amounts of lead with zinc, in order to increase the stain resistance of zinc. He used an alkaline bath with gum Arabic and sodium fluoride as addition agents. In the present work, alloy deposits, containing from 5 per cent to 86 per cent lead, were produced from an alkaline tartrate bath. The compositions of the deposits varied widely even when plating conditions were apparently identical.

Pretreatment for the SAE X-4130 steel panels consisted of an anodic treatment in Anodex* at 190°F. and 25 amp./sq. ft. for one minute, followed by a 15-second dip in 3-N hydrochloric acid at room temperature.

The bath composition and the conditions for plating were as follows:

$\text{Zn}(\text{CN})_2$	90 g./l.
NaOH	96 g./l.
NaCN	37.5 g./l.
$\text{KNaC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$	1.2 g./l.
$\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot 3\text{H}_2\text{O}$	2.5 g./l.

*Mac Dermid, Inc., St. Louis, Missouri.

Gum Arabic	0.75 g./l.
NaF	4 g./l.
RH 774*	1.8 to 6.8 g./l.
Temperature	75 - 85°F.
Current Density	3.5 amp./sq. ft.
No agitation	
Steel anodes	

The 13 per cent lead alloy and the 18 per cent lead alloy were plated from the same bath, the only difference being that, for the former, the bath contained 6.8 g./l. RH-774*, while, for the latter, the RH-774 content was 1.8 g./l.

Procedure for Depositing Porous Zinc Plate

Electroplating Bath

$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	360 g./l.
$\text{NaC}_2\text{H}_3\text{O}_2 \cdot 2\text{H}_2\text{O}$	15 g./l.
NH_4Cl	30 g./l.
Aquadag** (20 per cent solids)	50 g./l.

Operating Conditions

Current density	100 amp./sq. ft.
Temperature	90°F. $\pm$ 2°F.
pH	2.0 to 4.3

*Du Pont antipit agent.

**Manufactured by the Acheson Colloids Corp., Pont Huron, Michigan.

Anodes

Cast zinc

Work-bar reciprocated 66 cycles/minute

1-1/4-inch stroke

Plating time - 6 minutes

Operating Details

Duplicate SAE X-4130 steel specimens, 0.042 inch x 1 inch x 4 inches, cleaned anodically in Anodex* (75 g./l., 180°F., 100 amp./sq. ft. 2 minutes) and dipped in 10 per cent hydrochloric acid, were immersed to a depth of 3-1/2 inches in 800-ml. electroplating baths. Current was applied after immersion and was adjusted to 100 amp./sq. ft. After plating for 6 minutes, the strips were removed and the edges were brushed with a soft bristle brush to remove trees. One of each pair was tested for porosity, as described in the following section.

Method for Determining Porosity

After plating, the specimens were rinsed in boiling water, dried in an oven at 120°F., and reweighed to obtain the weight of zinc deposited. Then they were placed in an oil bath containing uninhibited oil (SAE 10) at 240°F. and evacuated to a pressure of less than 1 mm. mercury. The specimens were removed after 30 minutes, cooled in air, and, after draining on edge for 30 minutes, were weighed once more. A blank, (0.015 gram) corresponding to the weight of oil that remained on the surface of nonporous steel strips (an average of three determinations), was subtracted from the increase in weight due to oil. Porosity was then

*Mac Dermid, Inc., St. Louis, Missouri.

calculated as follows:

$$\text{Porosity (per cent)} = \frac{wD}{wD + Wd}$$

where w was the weight of the oil in the pores

W was the weight of electrodeposited zinc

d was the density of the oil (0.890)

D was the density of the zinc plate (7.14)

Effect of Variation of pH on Porosity

The effect of variations in bath pH on porosity was found to be considerable and is shown in Figure 41, Appendix II. The effects of varying temperature, current density, etc., were not investigated.

Chemical Analysis

The chemical analysis of the cast alloys was accomplished using methods described in the standard texts such as:

"Applied Inorganic Analysis"

W. F. Hillebrand and G. E. F. Lundell
John Wiley and Sons

"Scotts Standard Methods of Analysis"

D. Van Nostrand Company

The compositions of the electrodeposits were determined by plating duplicate cathodes of platinum or stainless steel and stripping with nitric acid. The analyses were then performed as for the cast alloys.

Electroplating solution analyses followed the methods given in "Modern Electroplating", published by The Electrochemical Society, Inc., in 1942.

The Wet-Dry Program Cabinet

A lead-lined, cork-insulated plywood box, measuring 34 inches x 25 inches x 25 inches, is the basis for the wet-dry program cabinet pictured in Figure 3. This box is equipped with a 1/2-inch-thick Lucite door (a) (letters in parentheses refer to Figure 3), on which the specimens are supported by being clamped between Lucite washers in such a way that the test pieces do not make contact with the 18-8 stainless steel machine screws passing through the washers. Twenty-four specimens can be exposed simultaneously. It was necessary to bind the edges of the Lucite door with angle iron to prevent warping.

The Lucite door is opened and closed in a predetermined cycle by a small motor (B), which, in turn, is actuated by a timing device (C) operating through relay (D). The motor (B) is a special type having two field coils, one of which "shades" the other causing reversal.

To provide high humidity when the door is closed, water in a copper pan, measuring 16 inches x 16 inches x 5 inches, is warmed by an immersion heater. The heater (electrical leads at F) is controlled by a thermostat (hidden by plate G) and operates only when the door is closed. A constant-level device (E) is connected to the copper pan. The electric fan operates when the door is opened, cooling and drying the specimens. When the door is closed again and the humid atmosphere prevails, moisture

easily condenses on the chilled specimens. A schematic drawing of the electrical circuit is given in Figure 4.

Details of Electrical Circuit for Wet-Dry Program Cabinet

The following is a list of the parts with sources:

Motor - 110-volt A.C. Crise Electric Mfg. Co., Columbus, Ohio.

Time Control - Iron Fireman controller, Model C200-160, Iron Fireman Mfg. Co., Portland, Oregon.

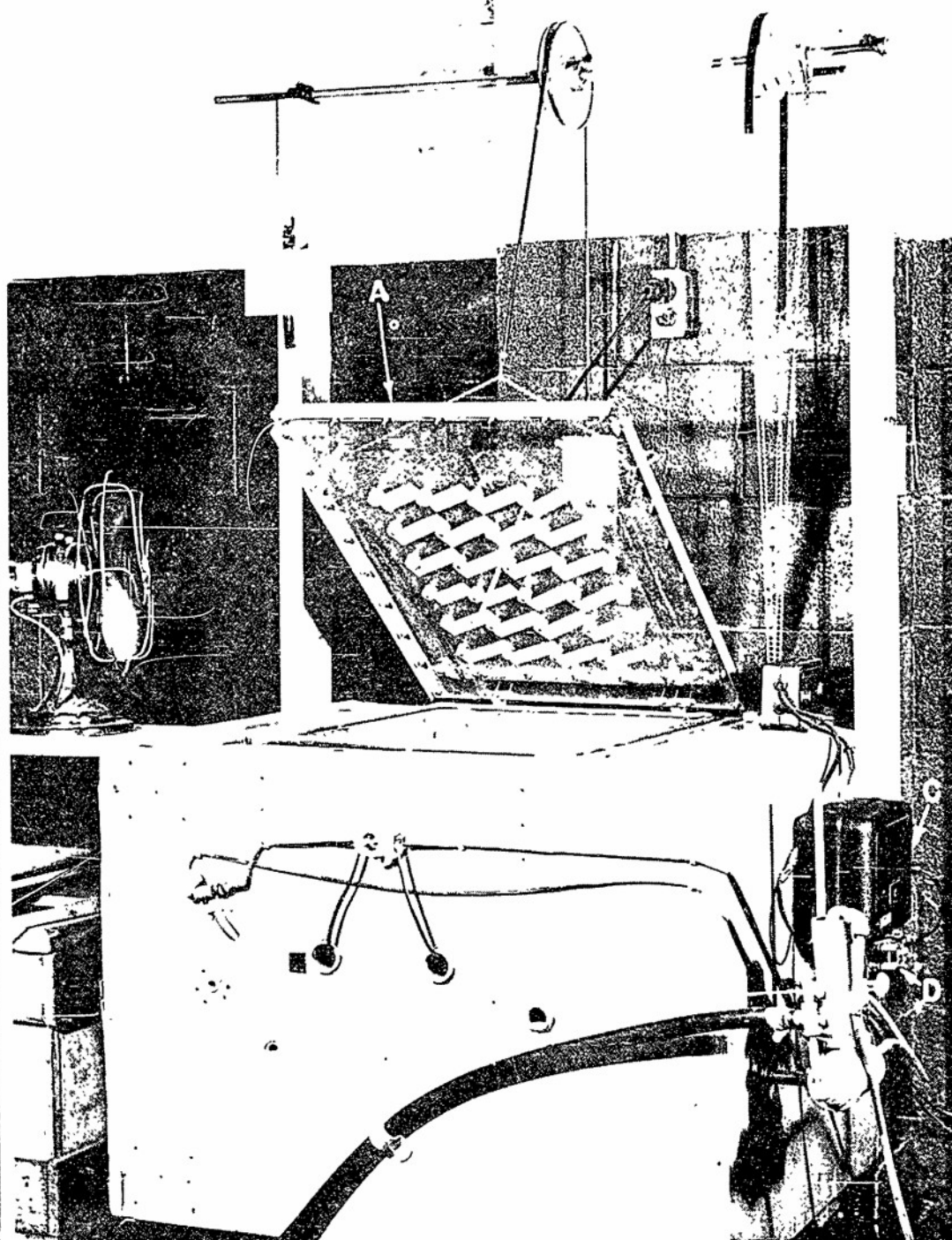
Heater - Lo Lag, 2000-watt, 230-volt copper-clad immersion heater. American Instrument Company, Silver Spring, Maryland.

Relay - Double-pole, double-throw relay. Struthers-Dunn, Inc., Philadelphia, Pa. (Note: In Figure 4, the relay was not represented as being of the DPDT type for reasons of simplicity).

Thermoregulator - 230 volts, 12 watt, using 0.1 mfd. condenser in parallel. Fenwall, Inc., Ashland, Mass.

When the relay is in position A, the door of the cabinet opens and the fan operates. When the relay is in position B, the door closes, the fan stops, and the heater operates.

CAS: A.B.T.
CLF:JBF
12-12-47



52109

Figure 3. "Wet-Dry Program" cabinet, showing door open and corroding specimens in place

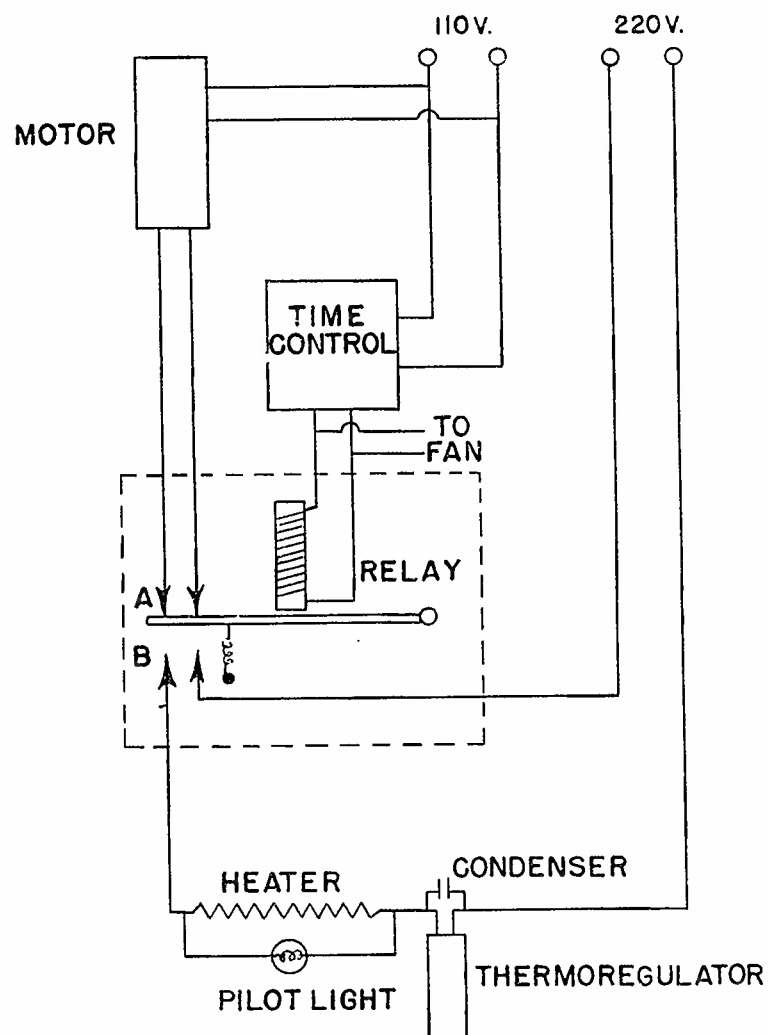


FIGURE 4. SCHEMATIC DIAGRAM OF ELECTRICAL
CIRCUIT FOR "WET-DRY PROGRAM"
CABINET.

APPENDIX II

This Appendix contains the graphs of the static and dynamic potential data and the corrosion current density data.

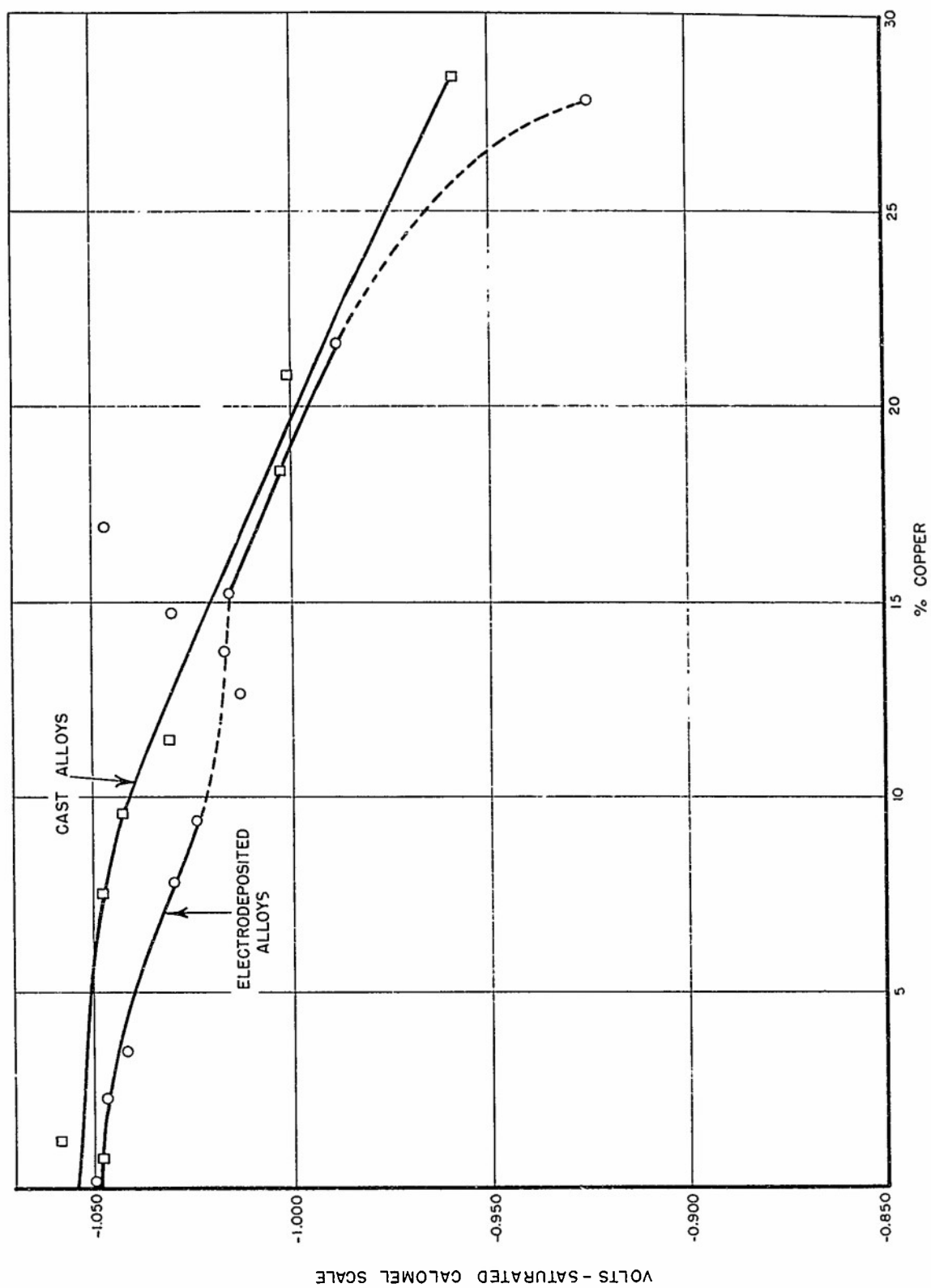


FIGURE 5 - GRAPH SHOWING POTENTIALS OF CAST AND ELECTRODEPOSITED ALLOYS IN 3% NaCl SOLUTION MEASURED AGAINST SATURATED CALOMEL CELL. ZINC-COPPER ALLOYS

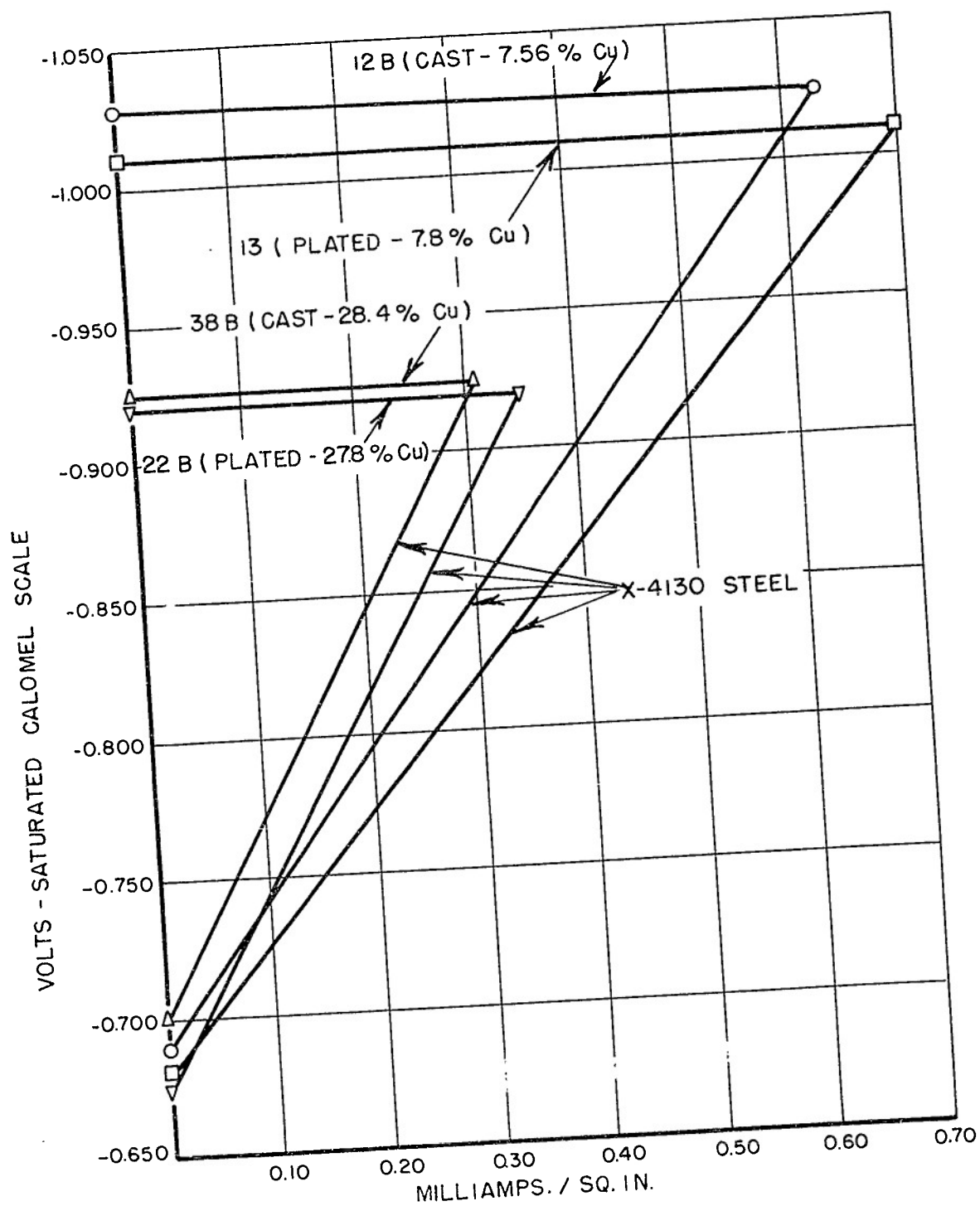


FIGURE 6 - GRAPH SHOWING SIMILAR POLARIZATION CHARACTERISTICS AND CURRENT DENSITIES FOR PLATED AND CAST WHITE BRASS ALLOYS

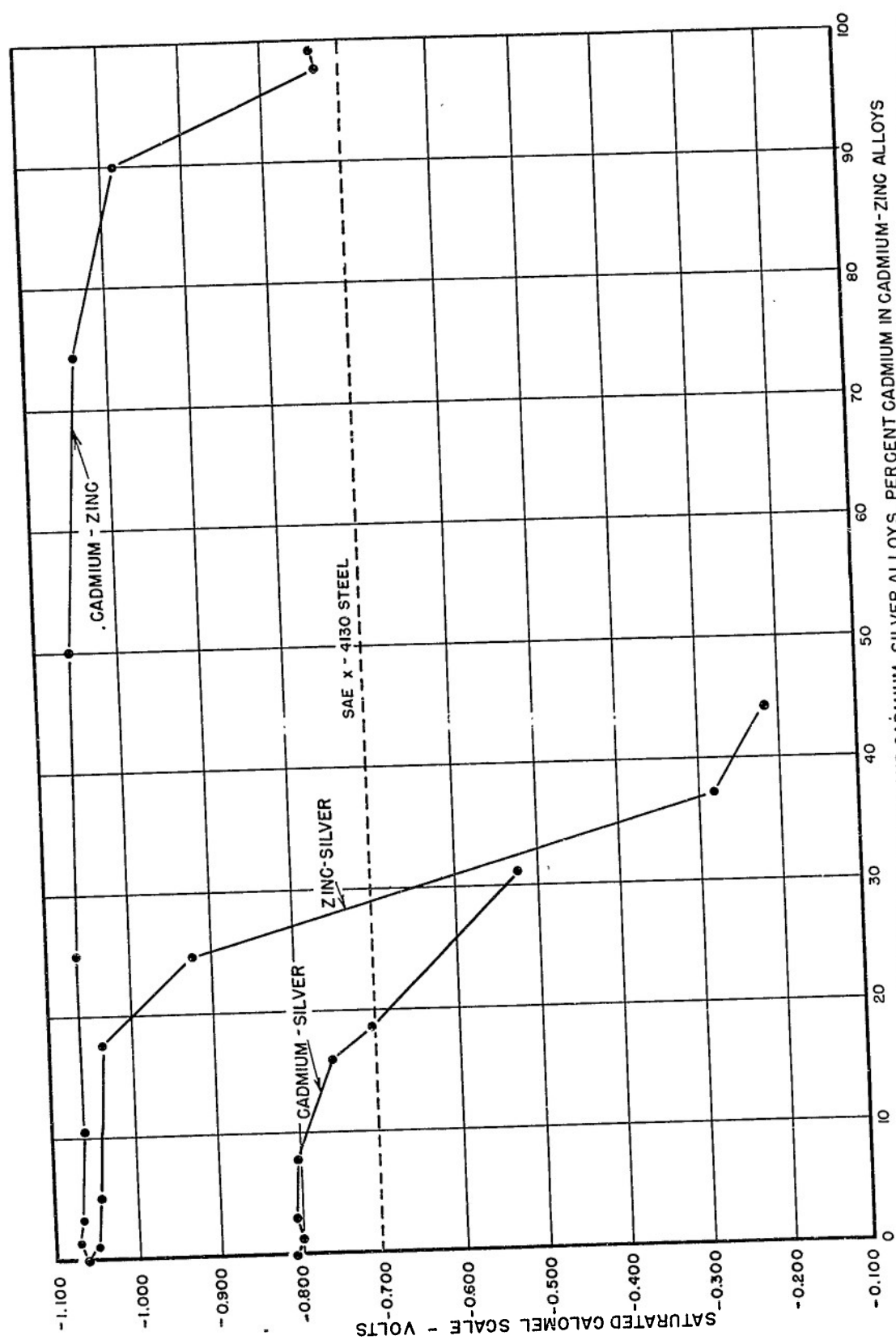


FIGURE 7. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST ZINC-SILVER, CADMIUM-SILVER, AND CADMIUM-ZINC ALLOYS IN 3% NaCl SOLUTION. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90° F. 60 - MINUTE IMMERSION.

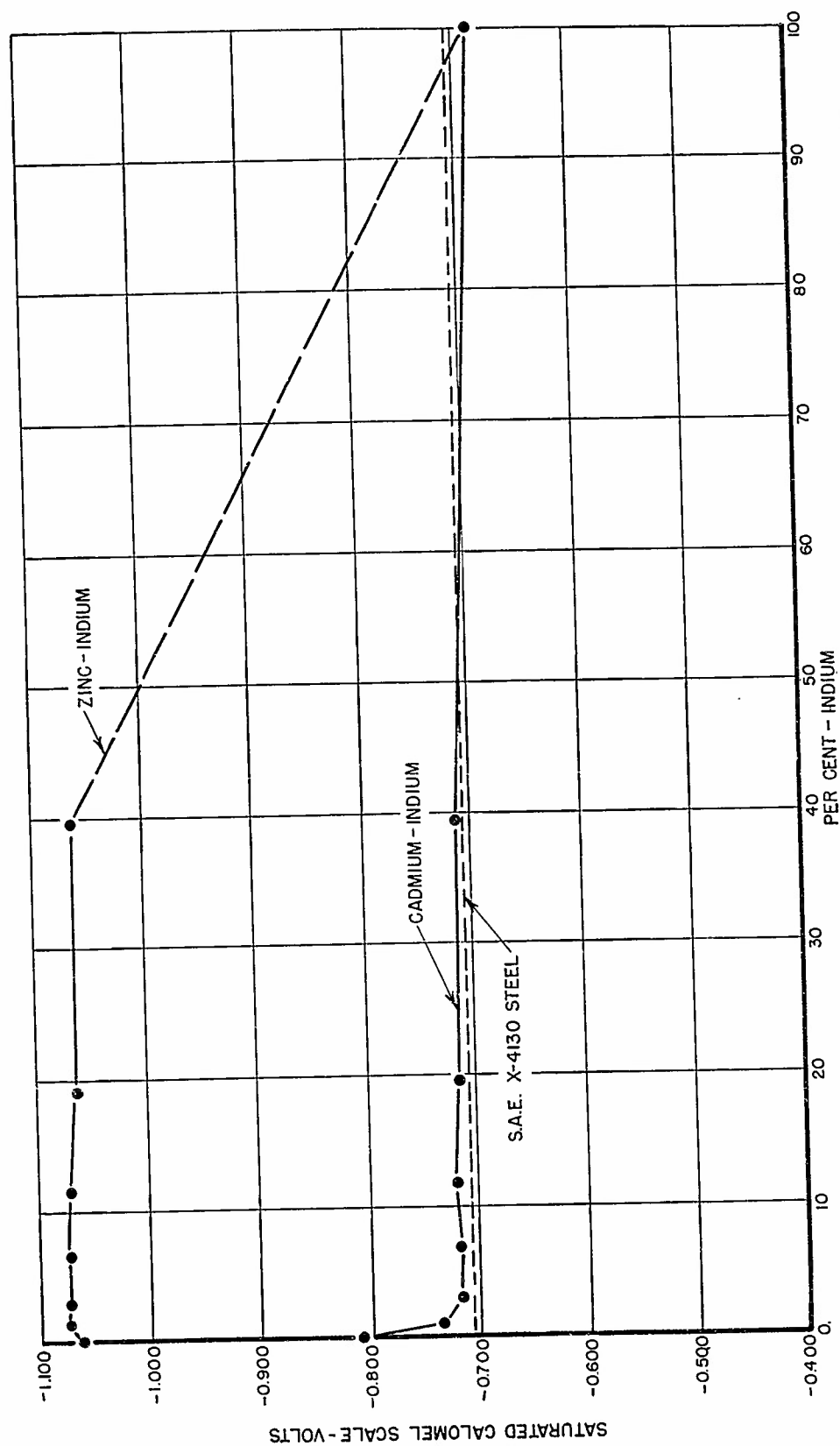


FIGURE 8. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST ZINC-INDIUM AND CADMIUM-INDIUM ALLOYS IN 3% NaCl SOLUTION. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90°F. 60-MINUTE IMMERSION

O-5042

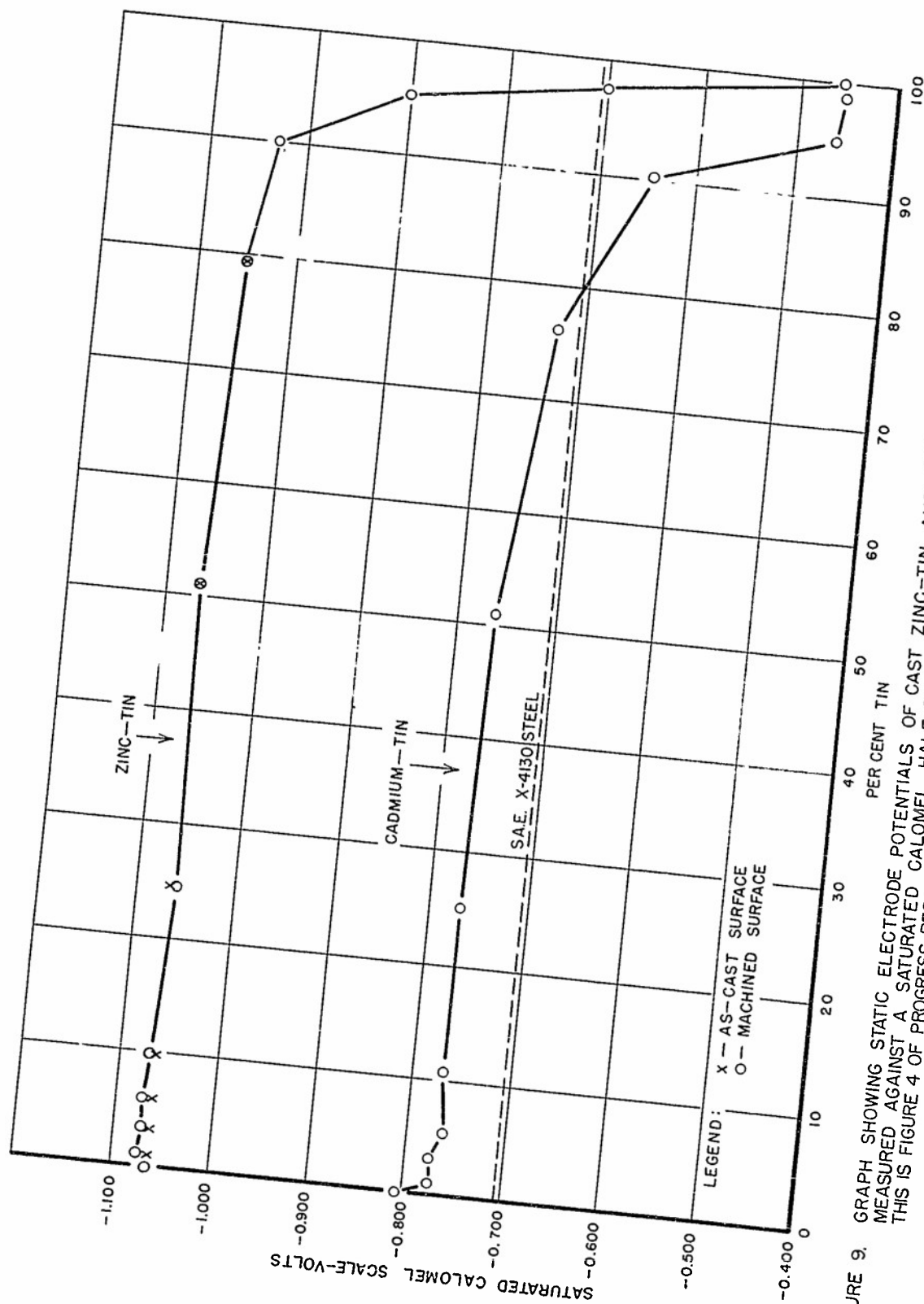


FIGURE 9. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST ZINC-TIN AND CADMIUM-TIN ALLOYS IN 3% NaCl SOLUTION. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90° F. 60-MINUTE IMMERSION. THIS IS FIGURE 4 OF PROGRESS REPORT NO.3 WITH THE HIGH-TIN END OF THE ZINC-TIN CURVE ADDED

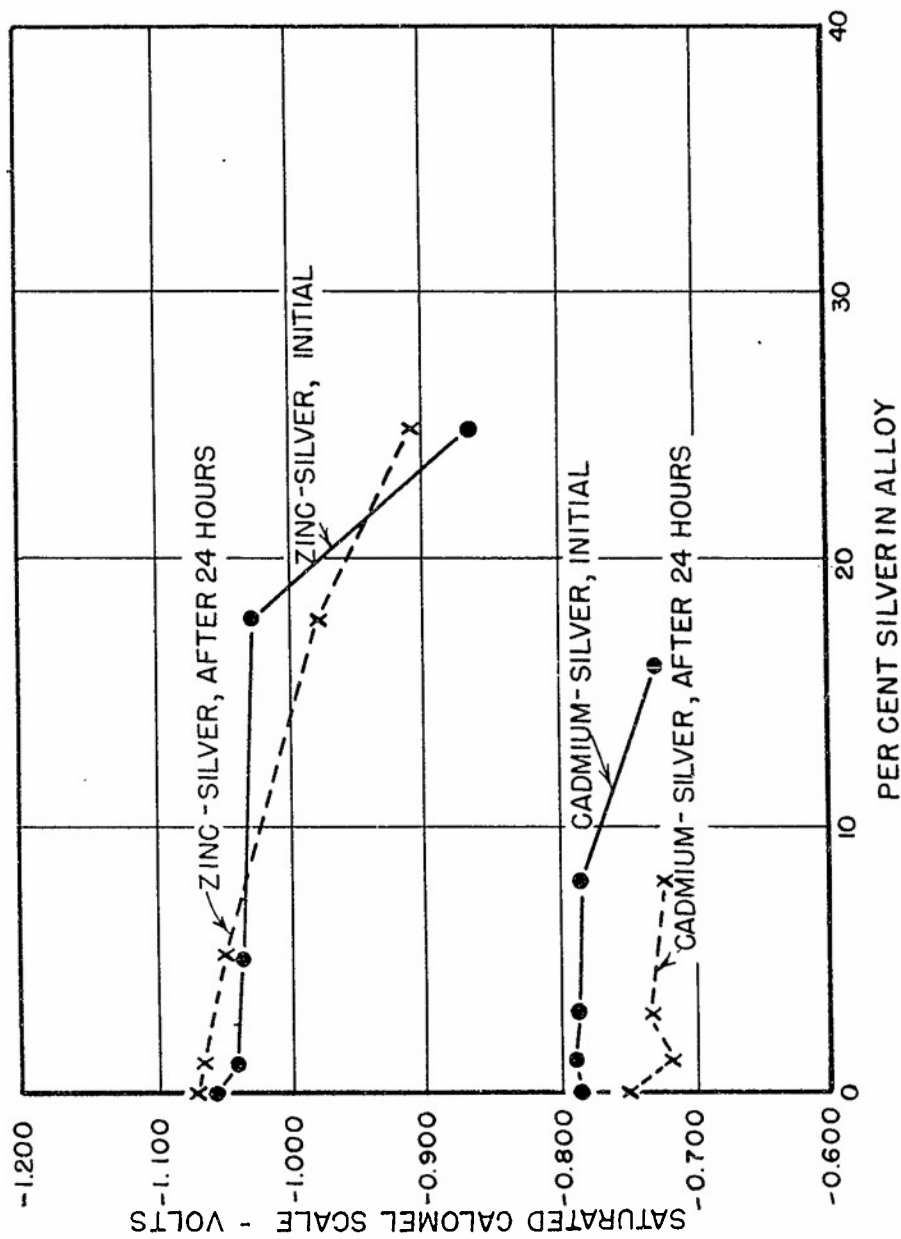


FIGURE 10. GRAPH SHOWING DYNAMIC ELECTRODE POTENTIALS OF CAST ZINC-SILVER AND CADMIUM-SILVER ALLOYS COUPLED WITH STEEL IN 3% SODIUM CHLORIDE SOLUTION. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL, TEMPERATURE 90° F.

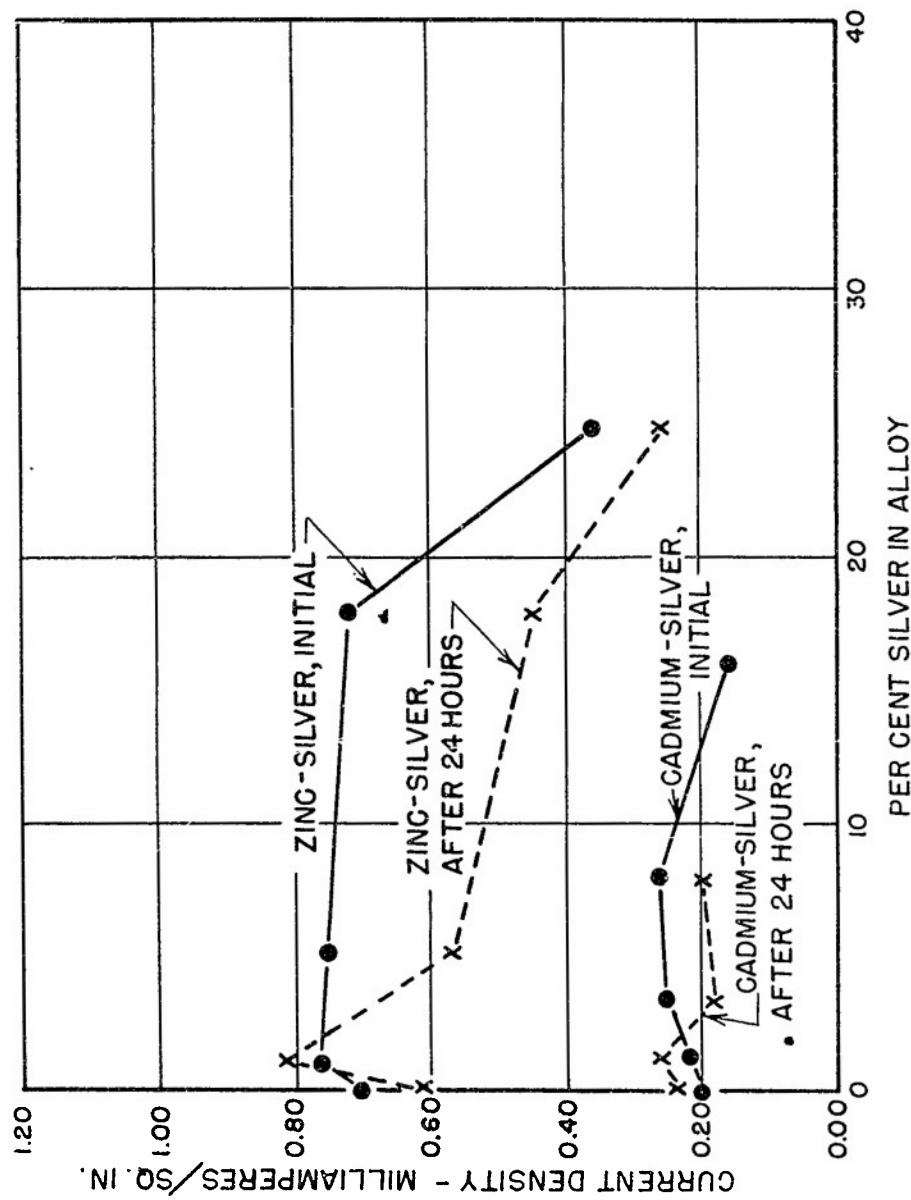


FIGURE 11. CORROSION CURRENT DENSITY IN CELLS CONSISTING OF ZINC-SILVER AND CADMIUM-SILVER ALLOYS COUPLED WITH STEEL IN 3% SODIUM CHLORIDE SOLUTION AT 90°F

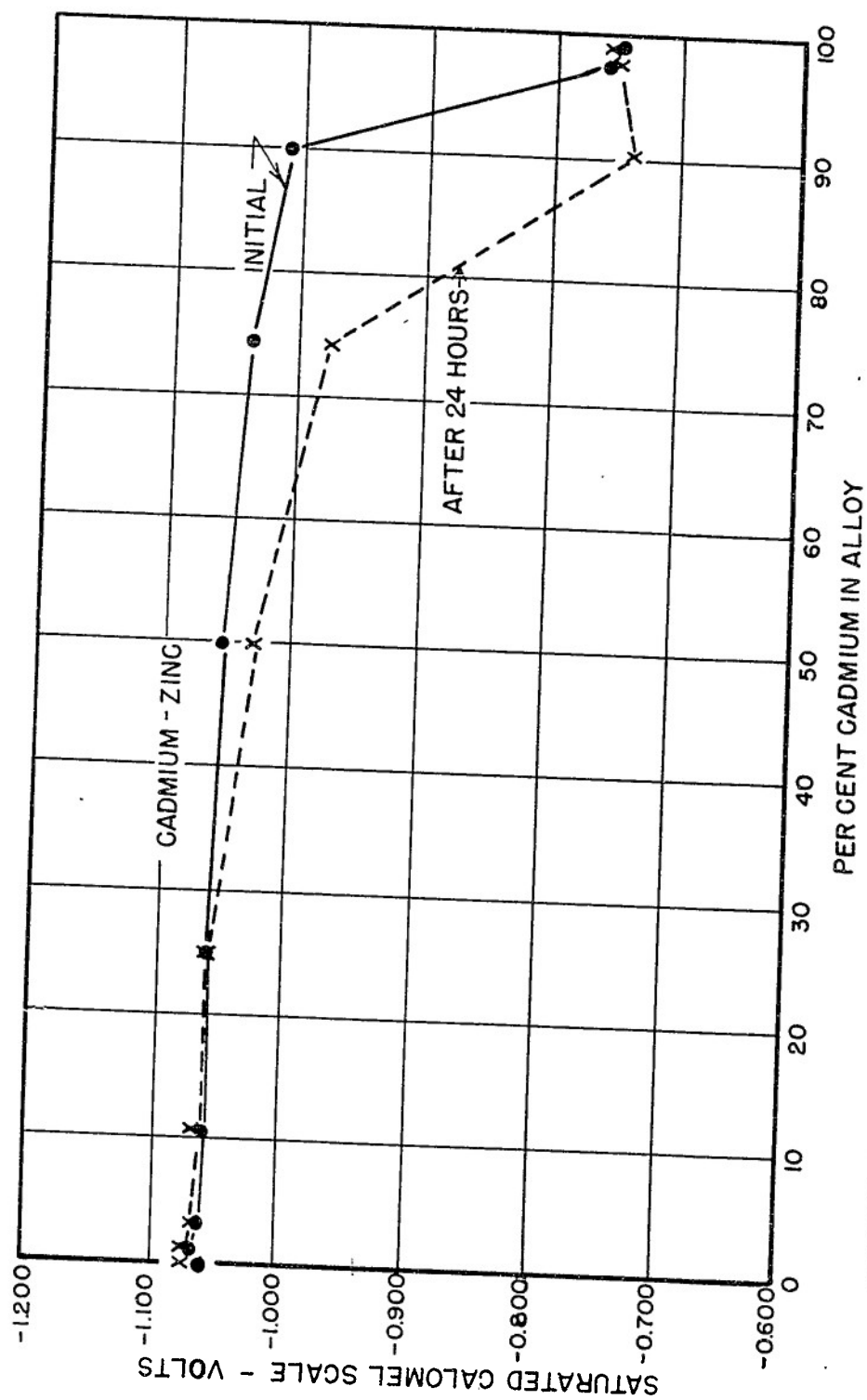


FIGURE 12. GRAPH SHOWING DYNAMIC ELECTRODE POTENTIALS OF CAST CADMIUM - ZINC ALLOYS COUPLED WITH STEEL IN 3% SODIUM CHLORIDE SOLUTION. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL, TEMPERATURE 90° F.

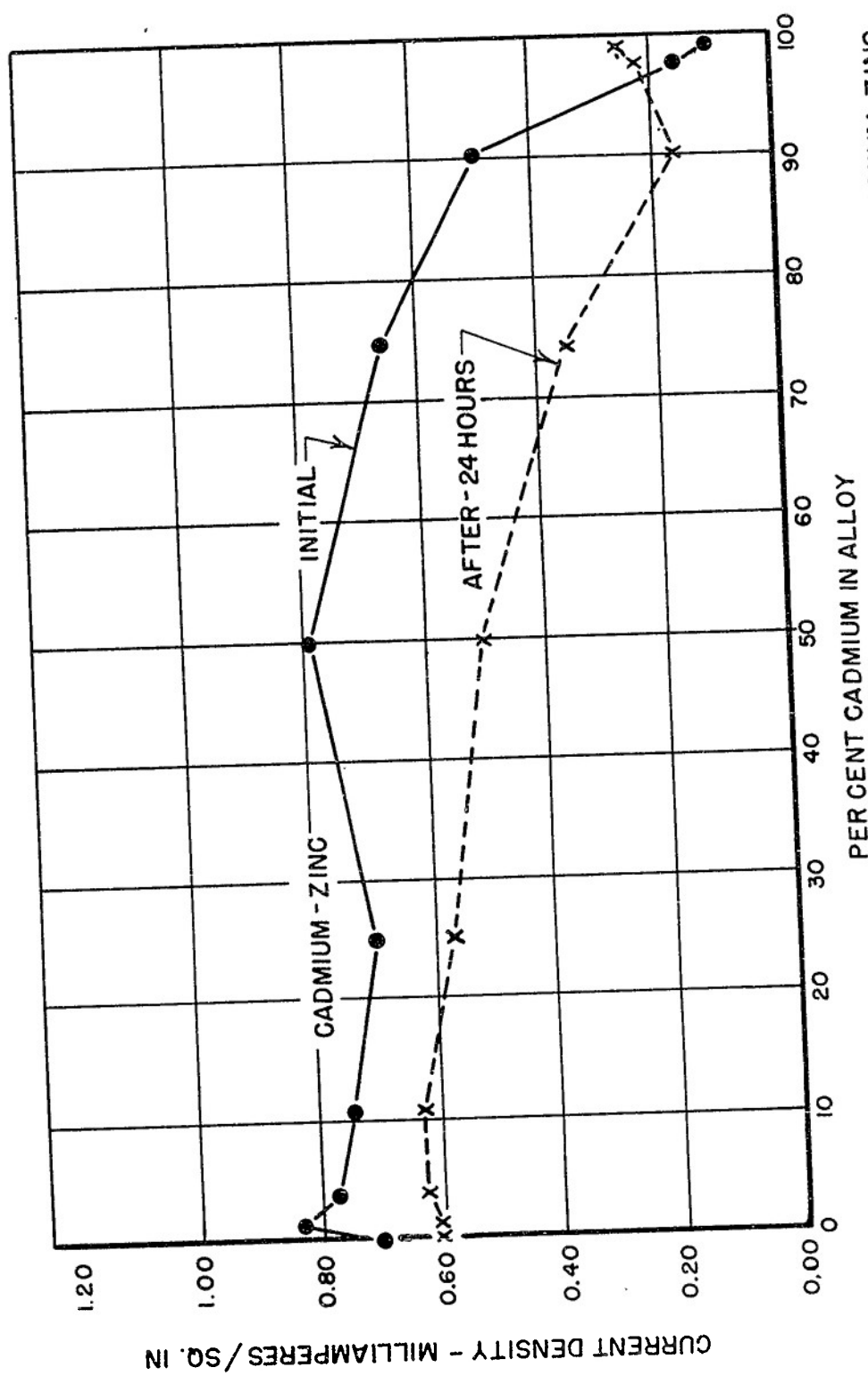


FIGURE 13. CORROSION CURRENT DENSITY IN CELLS CONSISTING OF CADMIUM-ZINC ALLOYS COUPLED WITH STEEL, IN 3% SODIUM CHLORIDE SOLUTION AT 90° F.

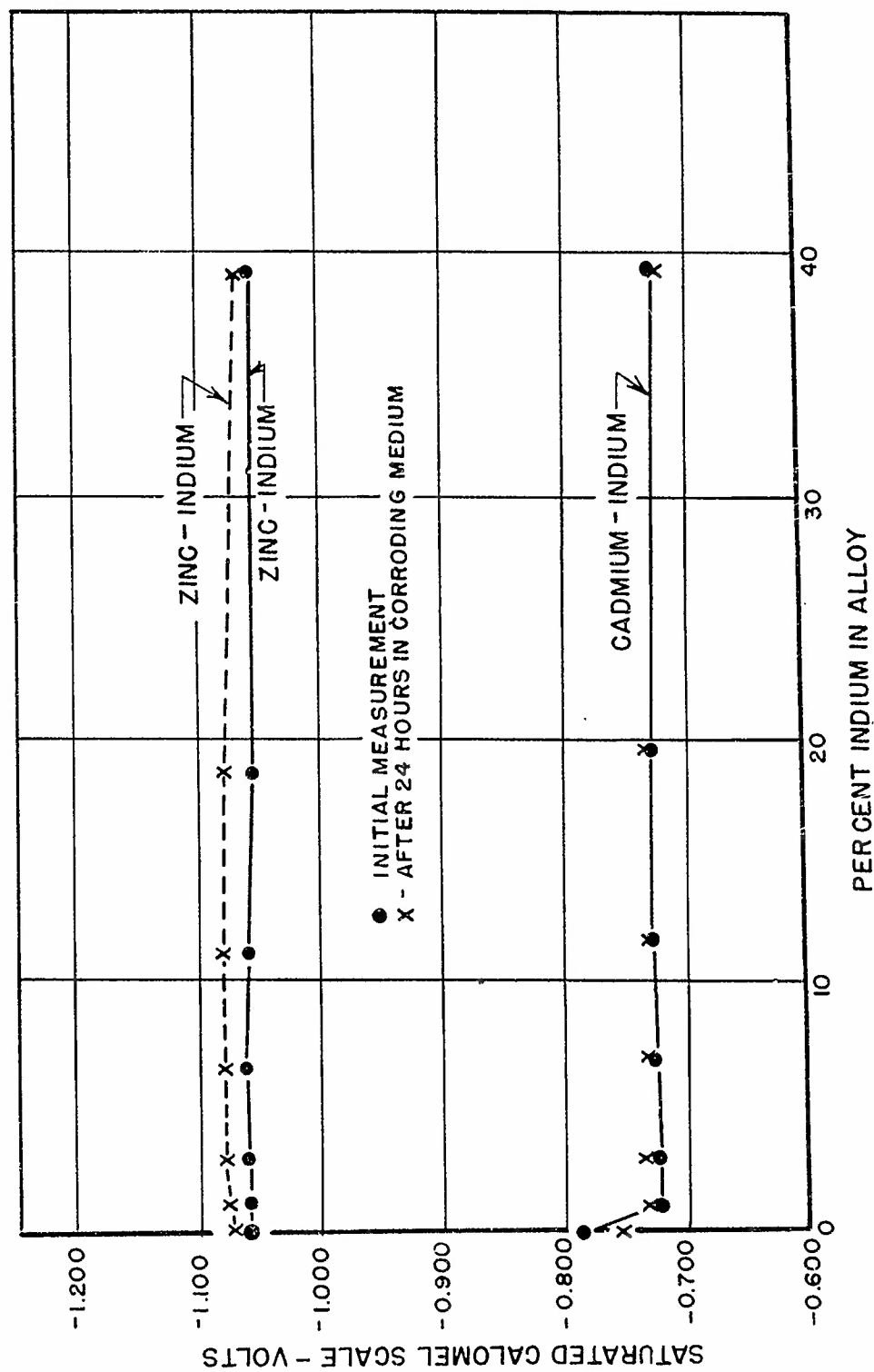


FIGURE 14. GRAPH SHOWING DYNAMIC ELECTRODE POTENTIALS OF CAST ZINC - INDIUM AND CADMIUM - INDIUM ALLOYS COUPLED WITH STEEL IN 3% SODIUM CHLORIDE SOLUTION. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90° F.

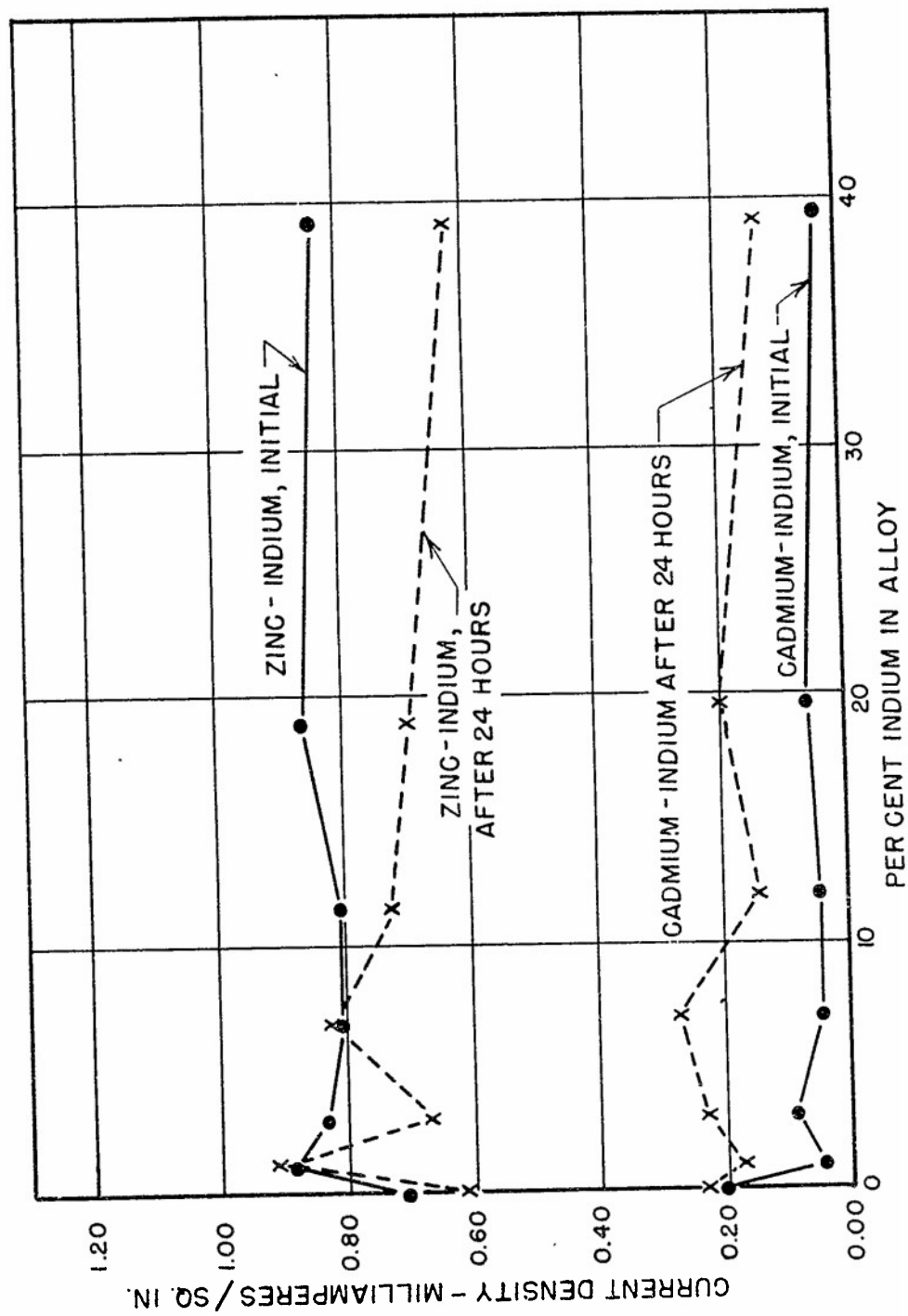


FIGURE 15. CORROSION CURRENT DENSITY IN CELLS CONSISTING OF ZINC - INDIUM AND CADMIUM - INDIUM ALLOYS COUPLED WITH STEEL, IN 3% SODIUM CHLORIDE SOLUTION AT 90° F.

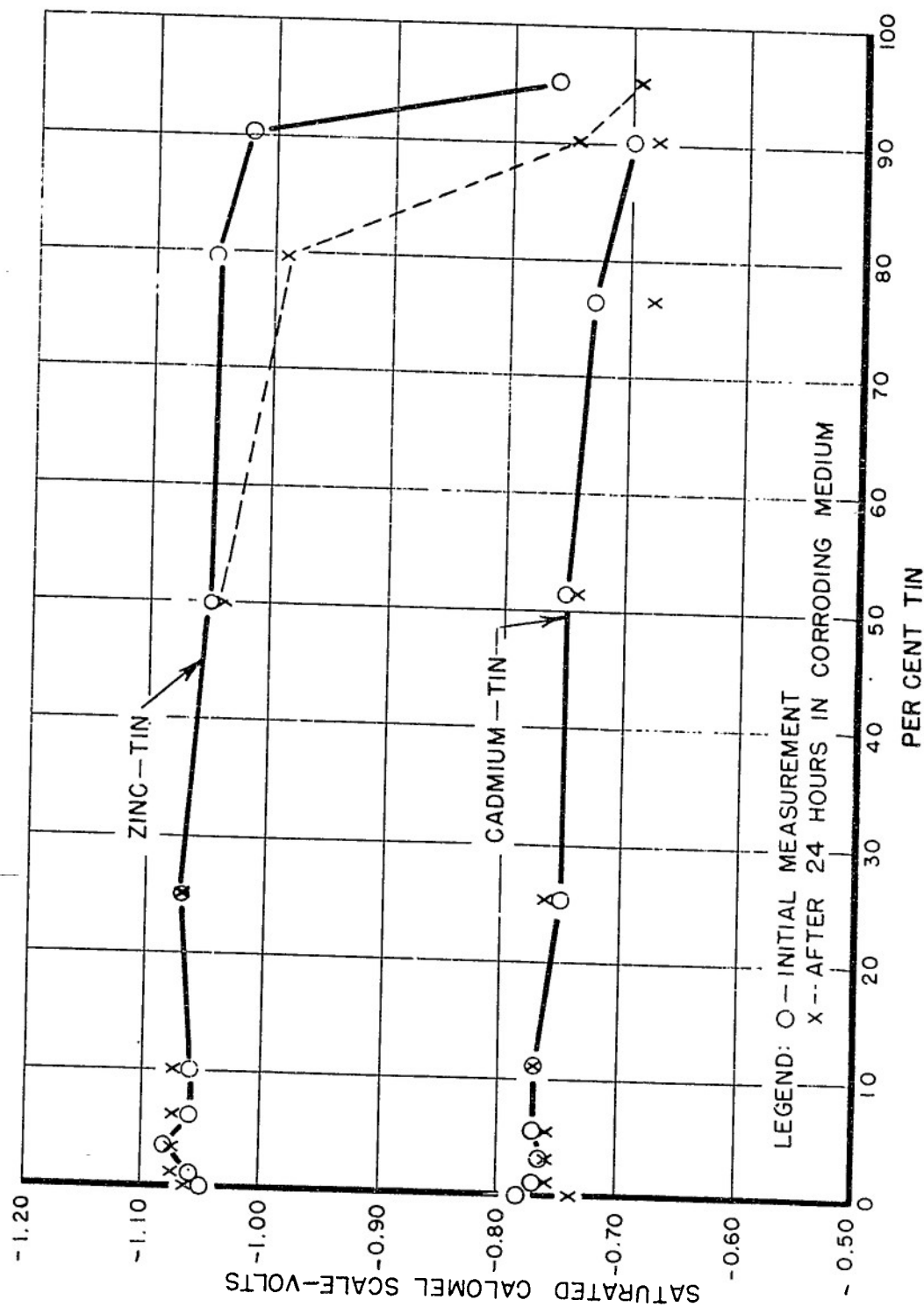


FIGURE 16. GRAPH SHOWING ELECTRODE POTENTIALS OF CAST ZINC-TIN AND CADMIUM-TIN ALLOYS COUPLED WITH STEEL IN 3% NaCl SOLUTION. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90°F. SAME GRAPH AS FIG. 5 OF PROGRESS REPORT NO. 3 WITH ADDITIONAL POINTS ADDED ON ZINC-TIN CURVES.

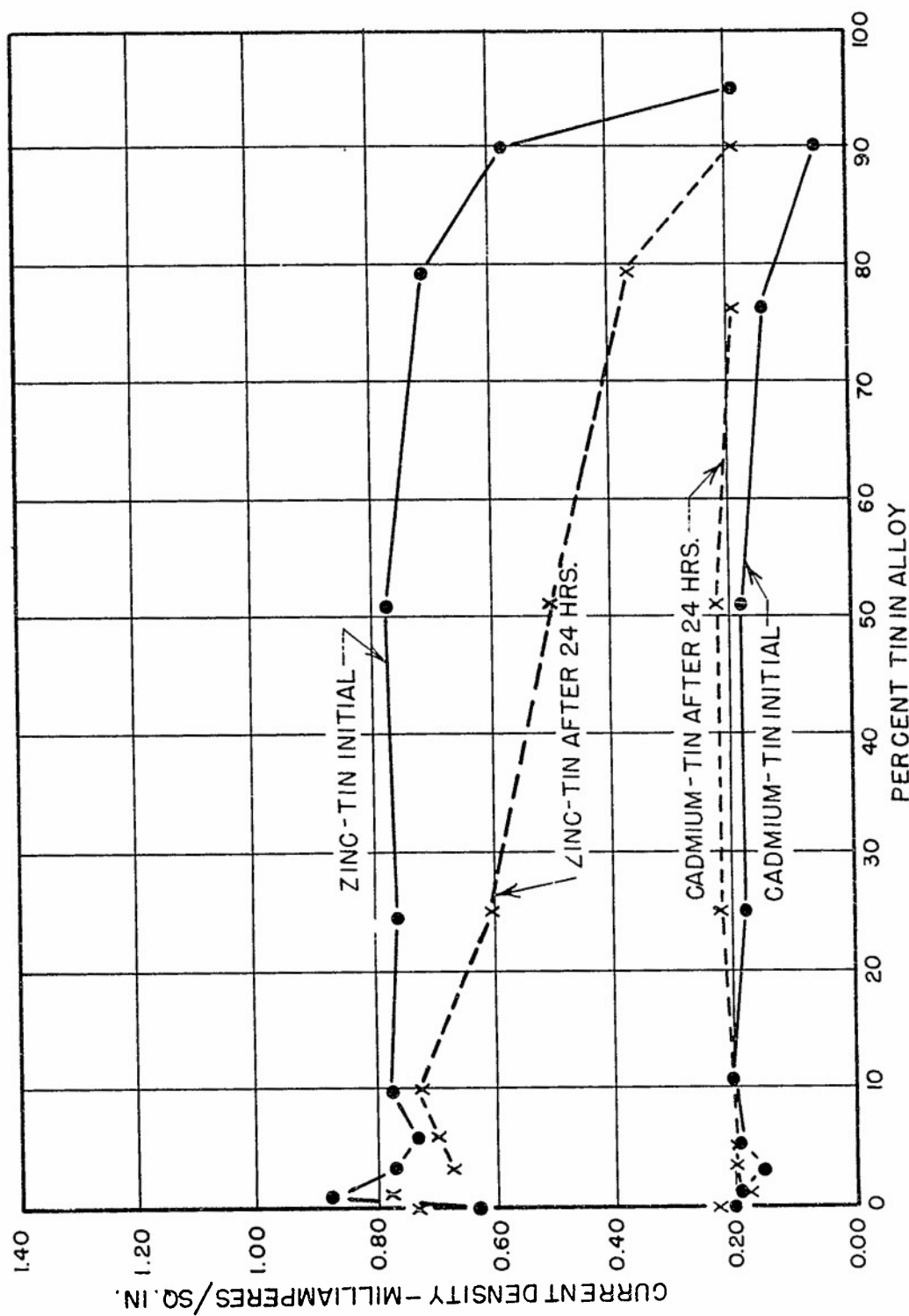


FIGURE 17. CORROSION CURRENT DENSITY IN CELLS CONSISTING OF Zn-Sn ALLOYS AND Cd-Sn ALLOYS COUPLED WITH STEEL, IN 3% SODIUM CHLORIDE SOLUTION AT 90° F. SAME GRAPH AS FIGURE 6 OF PROGRESS REPORT NO. 3 WITH ADDITIONAL POINTS ADDED ON ZINC-TIN CURVES.

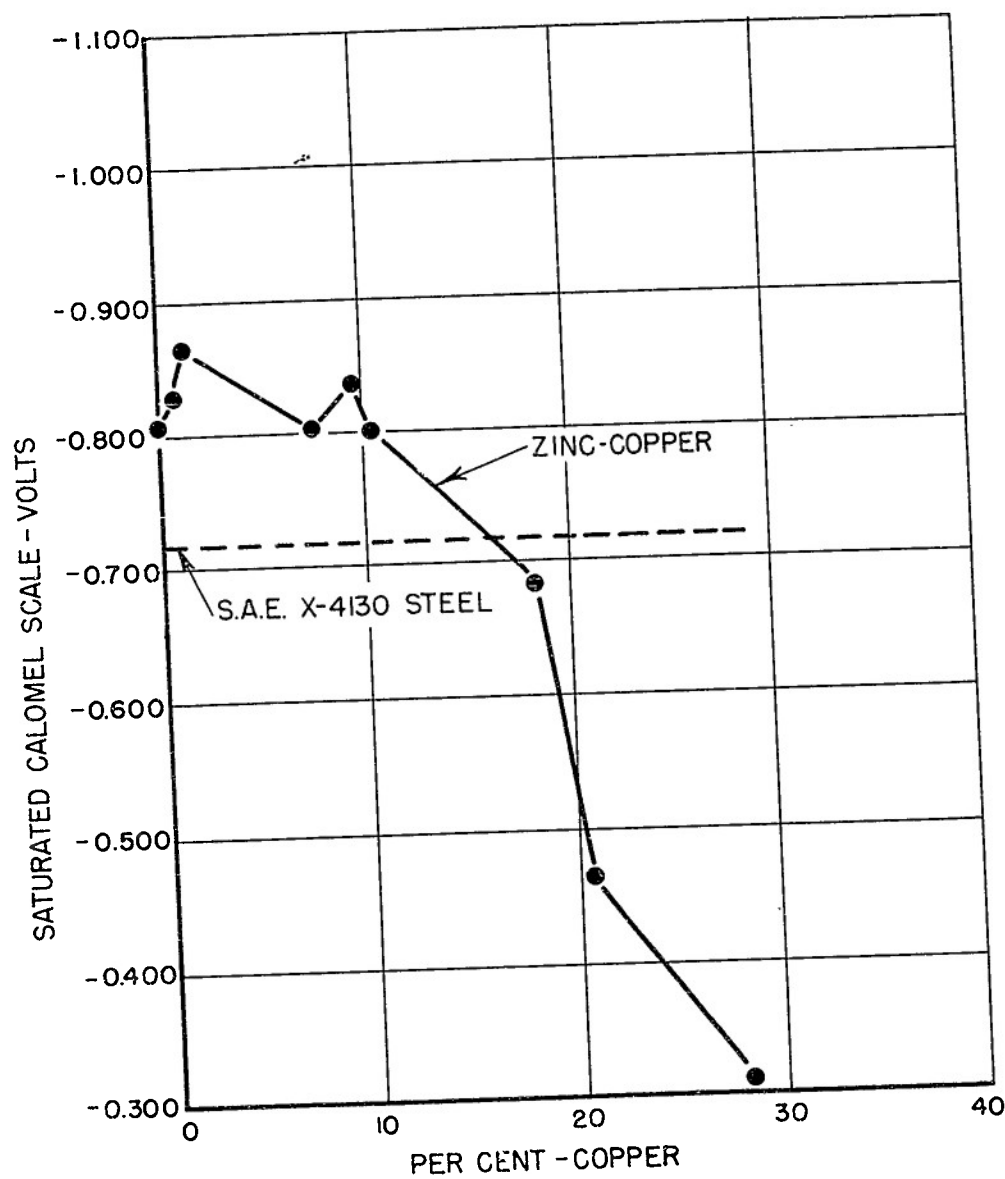


FIGURE 18. GRAPH SHOWING STATIC ELECTRODE POTENTIALS FOR CAST ZINC-COPPER ALLOYS IN DISTILLED WATER. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90°F. 60-MINUTE IMMERSION

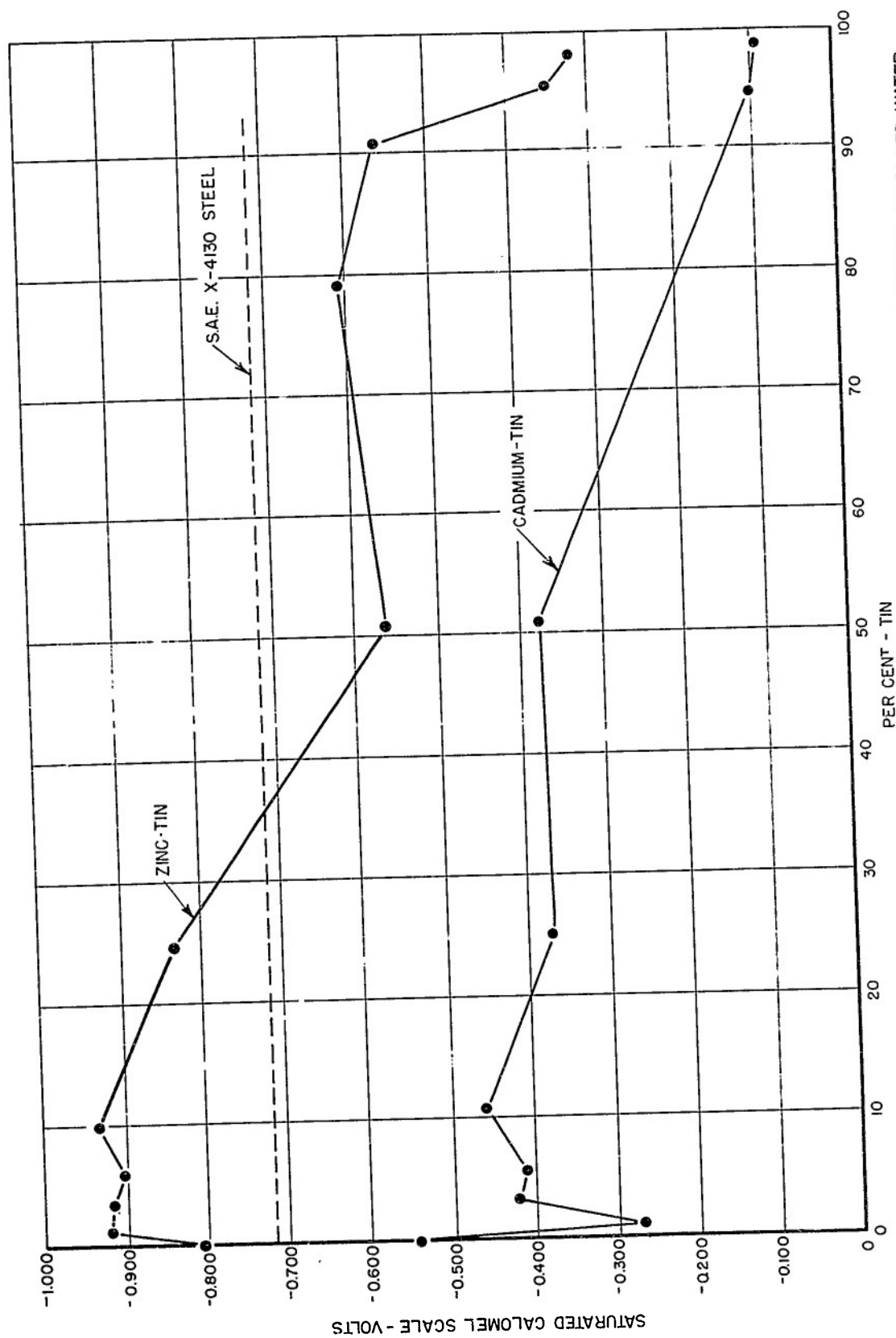
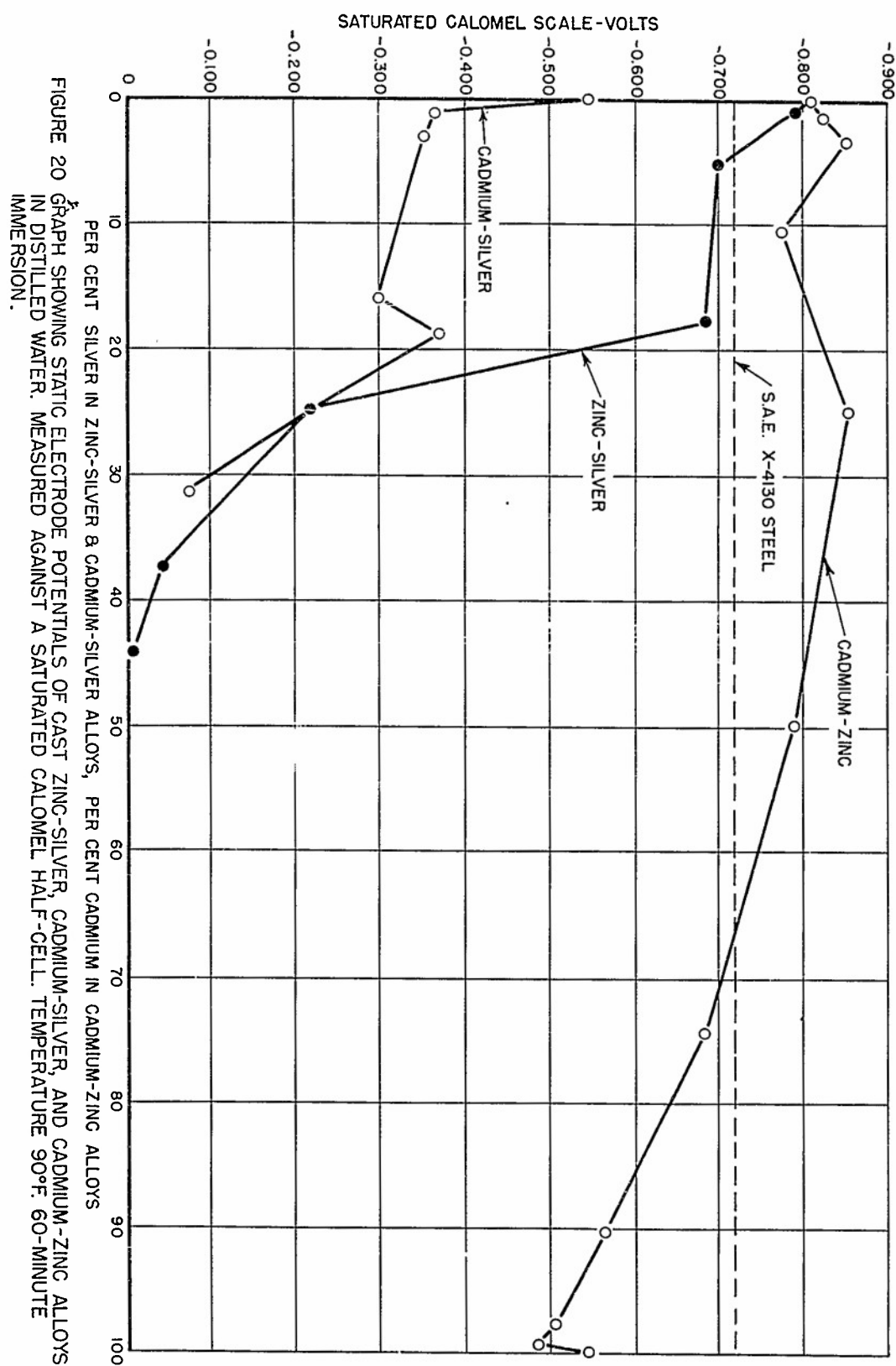


FIGURE 19. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST ZINC-TIN AND CADMIUM-TIN ALLOYS IN DISTILLED WATER. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90°F. 60-MINUTE IMMERSION



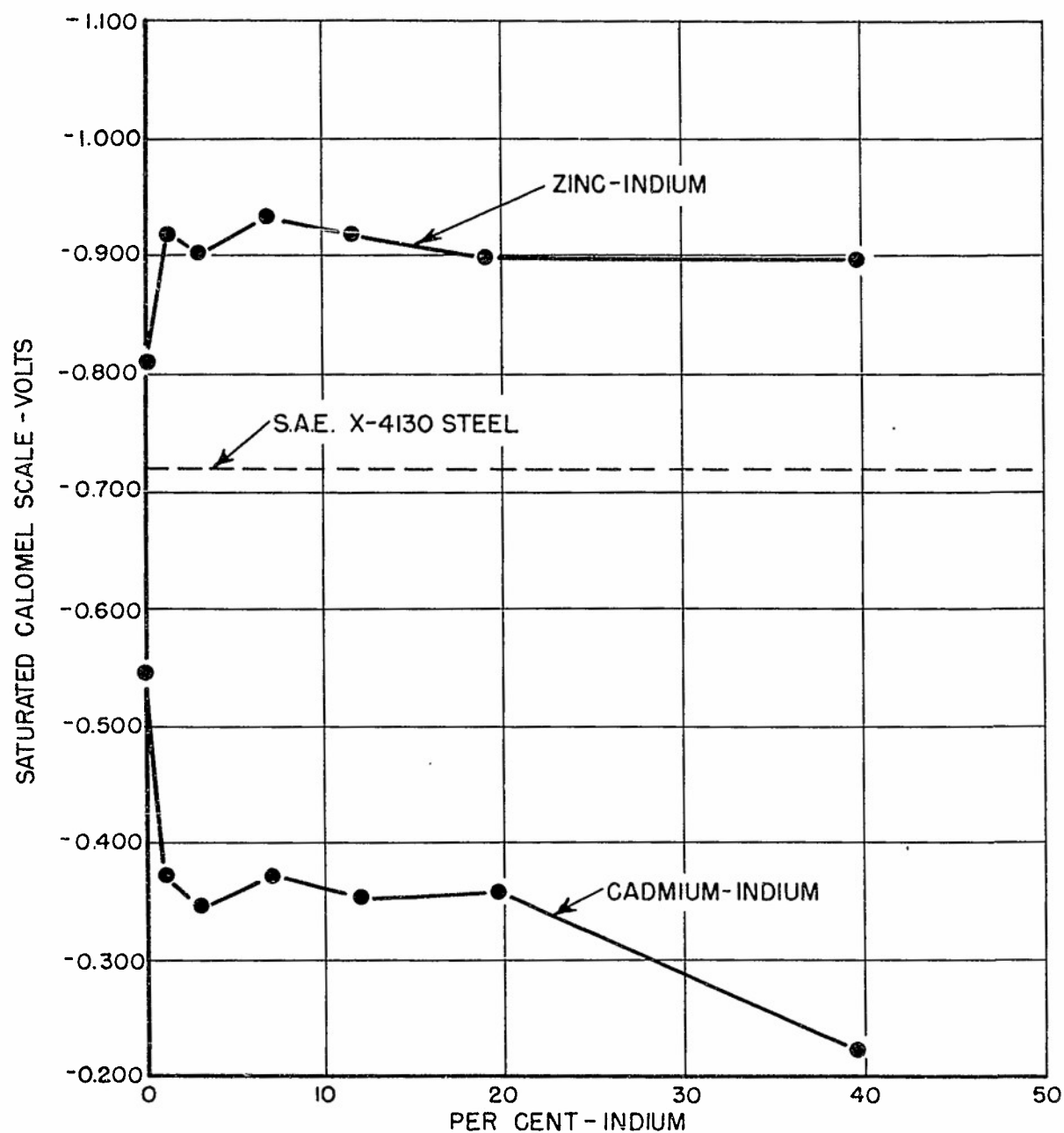


FIGURE 21. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST ZINC-INDIUM AND CADMIUM-INDIUM ALLOYS IN DISTILLED WATER. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90°F. 60-MINUTE IMMERSION

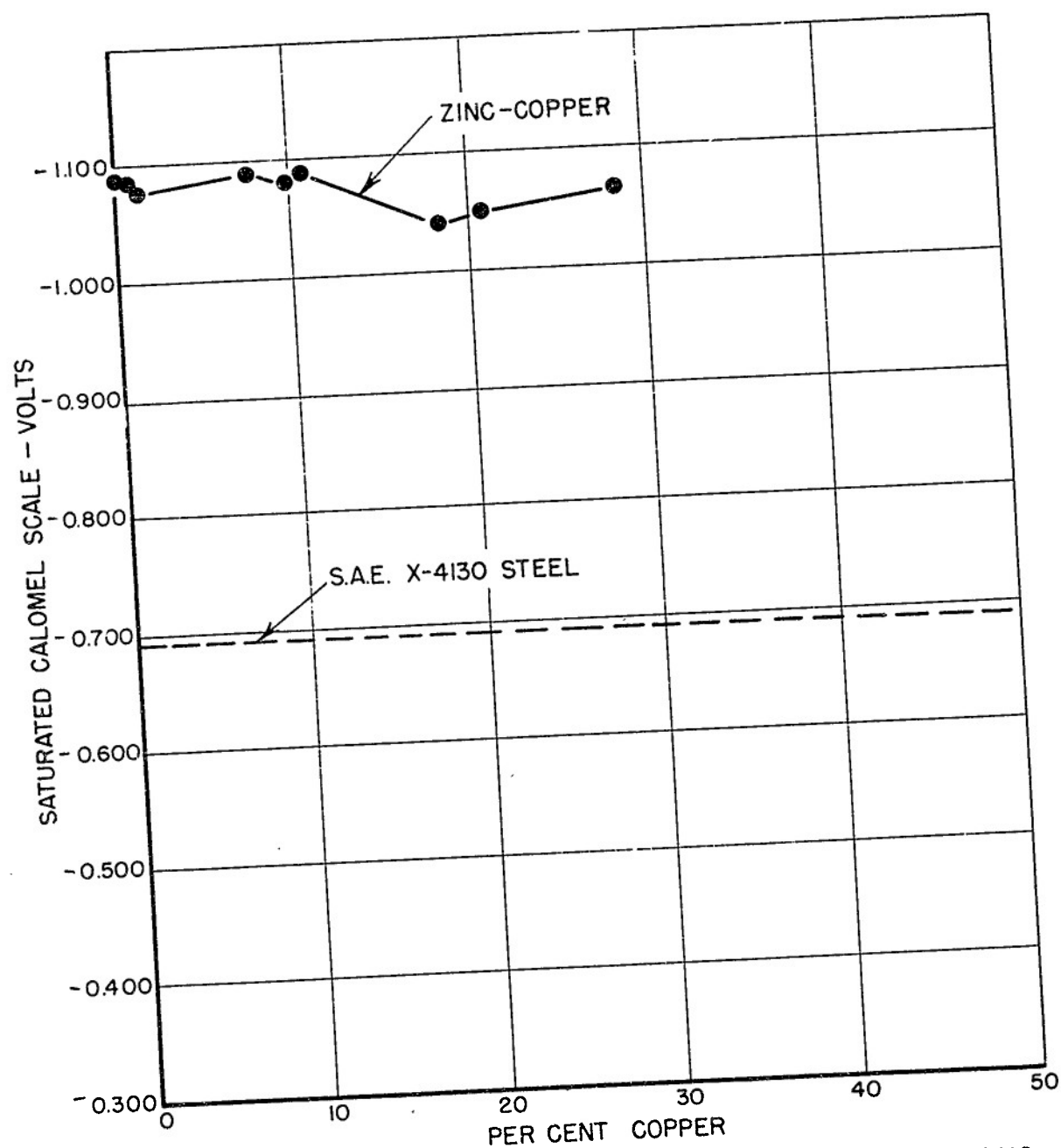


FIGURE 22. GRAPH SHOWING ELECTRODE POTENTIALS OF CAST ZINC-COPPER ALLOYS IN DISTILLED WATER SATURATED WITH CARBON DIOXIDE. TEMPERATURE 90°F. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. 60-MINUTE IMMERSION

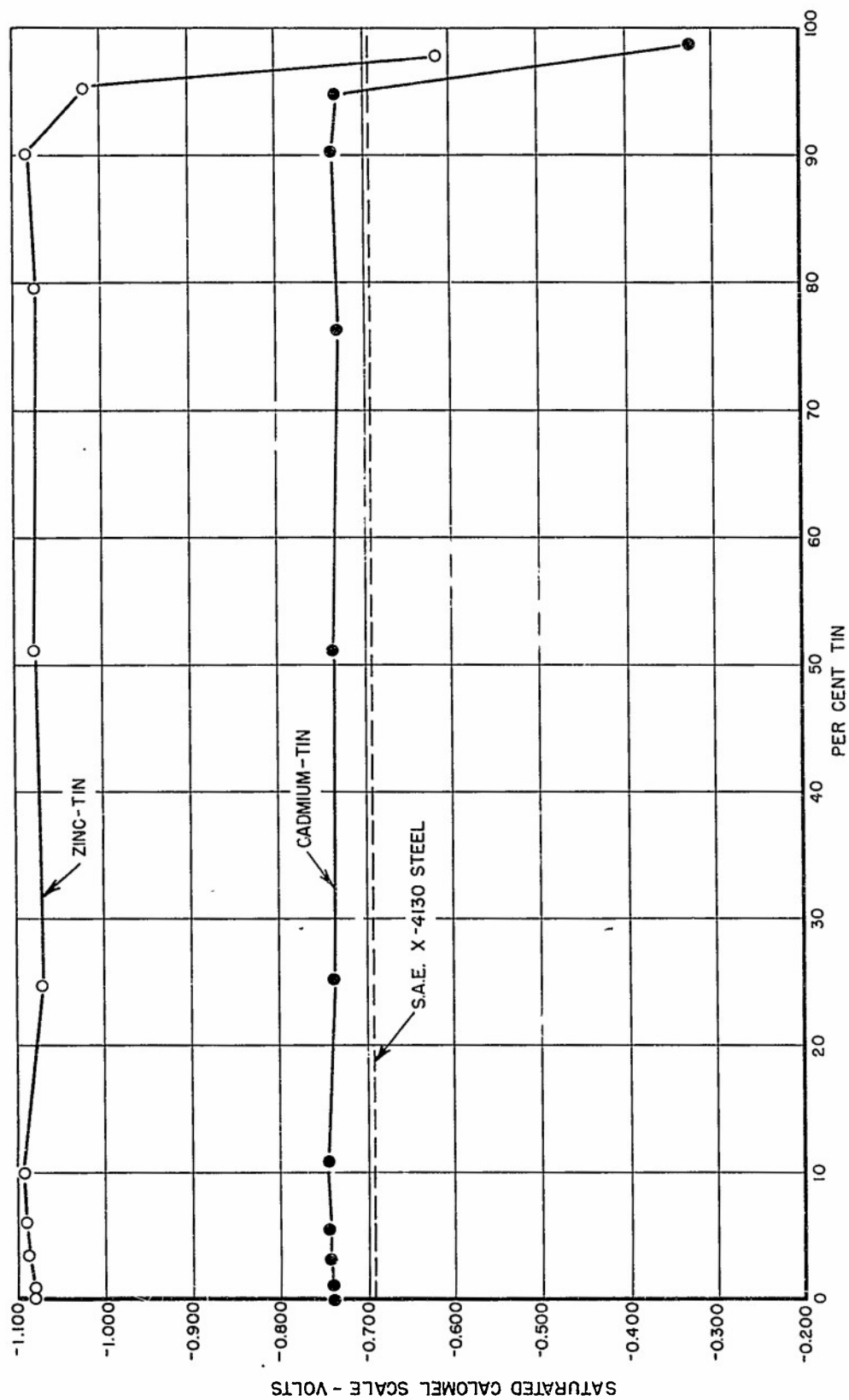


FIGURE 23. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST ZINC-TIN AND CADMIUM-TIN ALLOYS IN DISTILLED WATER SATURATED WITH CARBON DIOXIDE. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90°F. 60-MINUTE IMMERSION

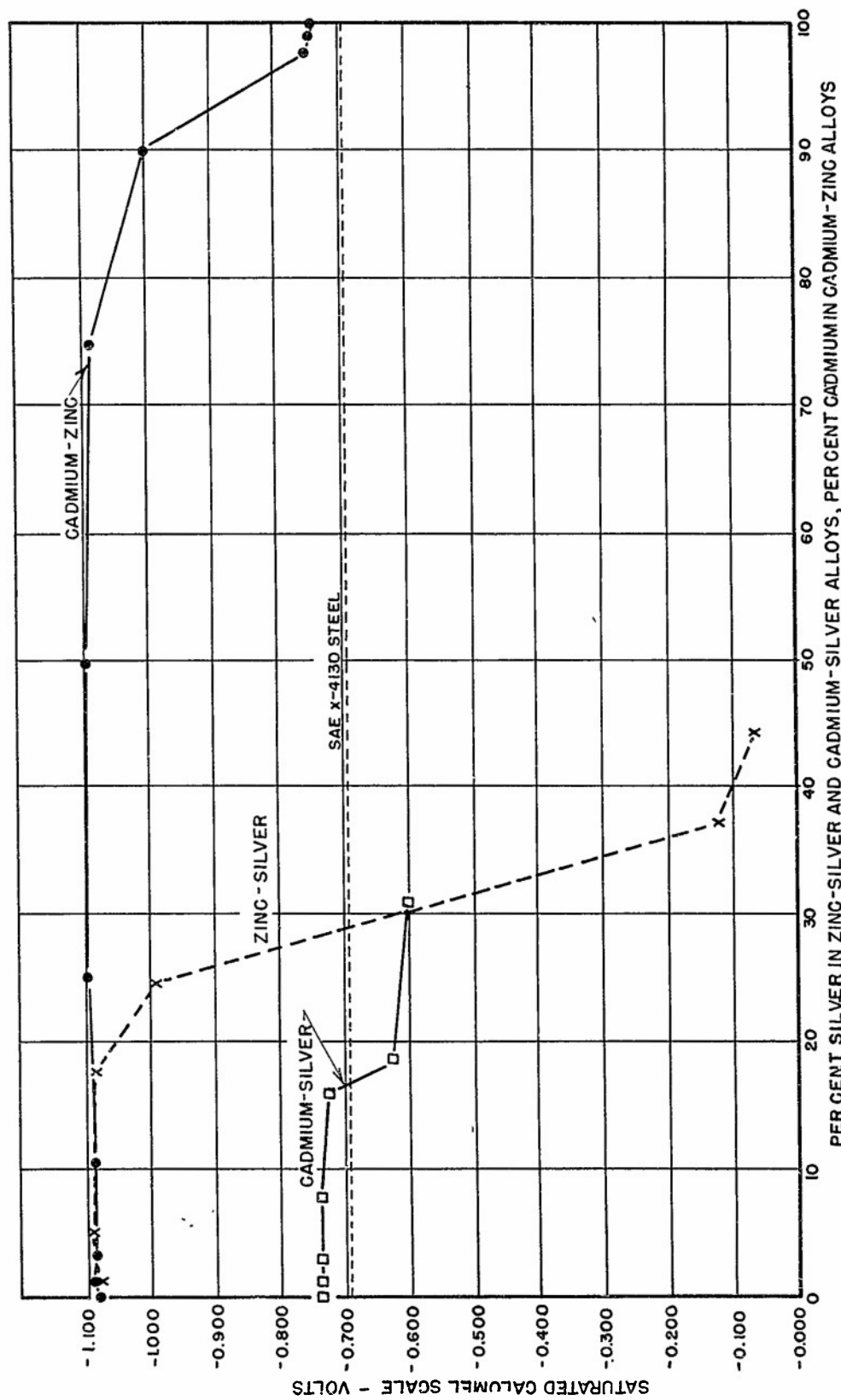


FIGURE 24. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST ZINC-SILVER, CADMIUM-SILVER AND CADMIUM-ZINC ALLOYS IN DISTILLED WATER SATURATED WITH CARBON DIOXIDE. MEASURED AGAINST A CALOMEL HALF-CELL. TEMPERATURE 90°F. 60-MINUTE IMMERSION.

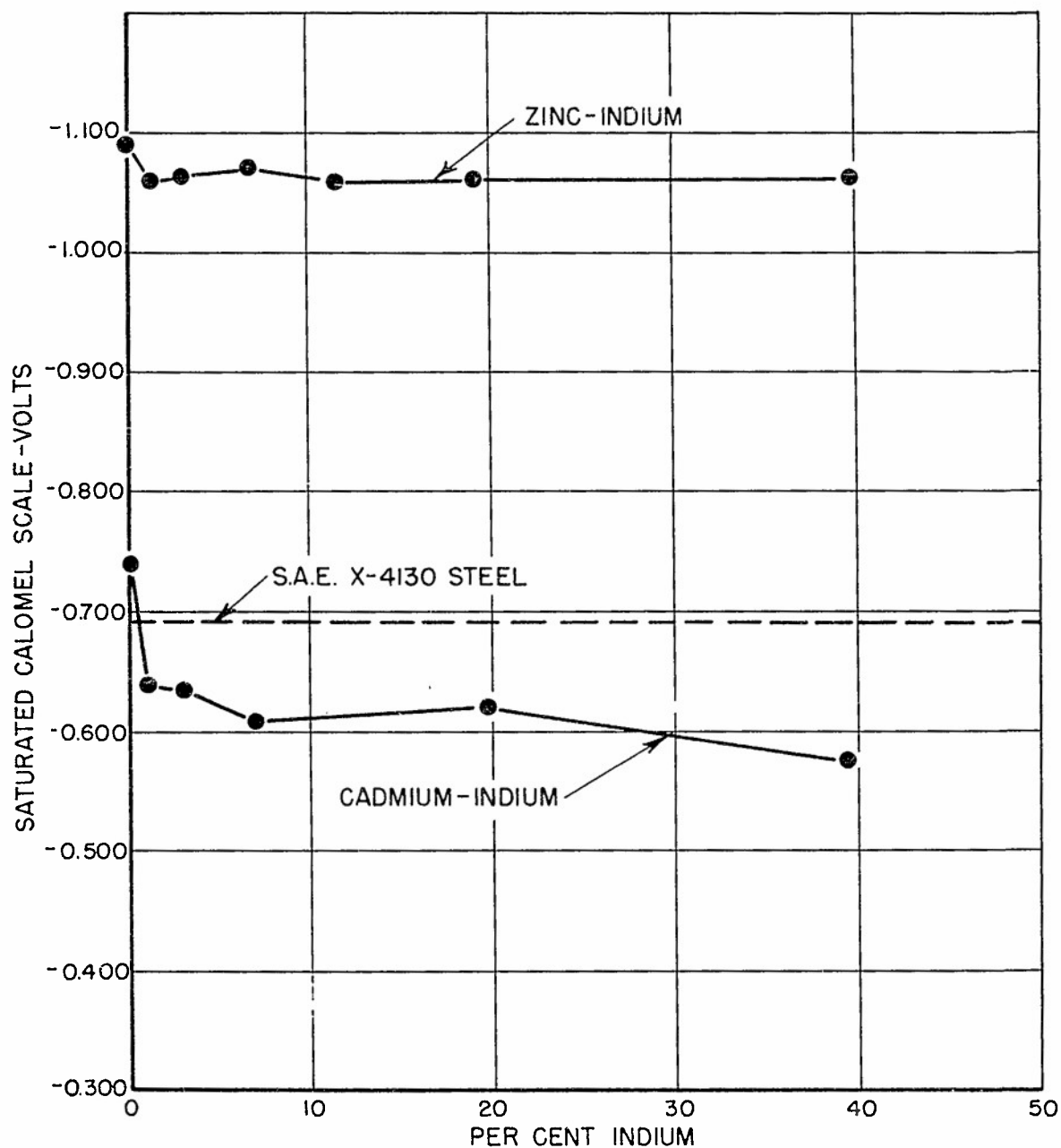


FIGURE 25. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST ZINC-INDIUM AND CADMIUM-INDIUM ALLOYS IN DISTILLED WATER SATURATED WITH CARBON DIOXIDE. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90°F. 60-MINUTE IMMERSION

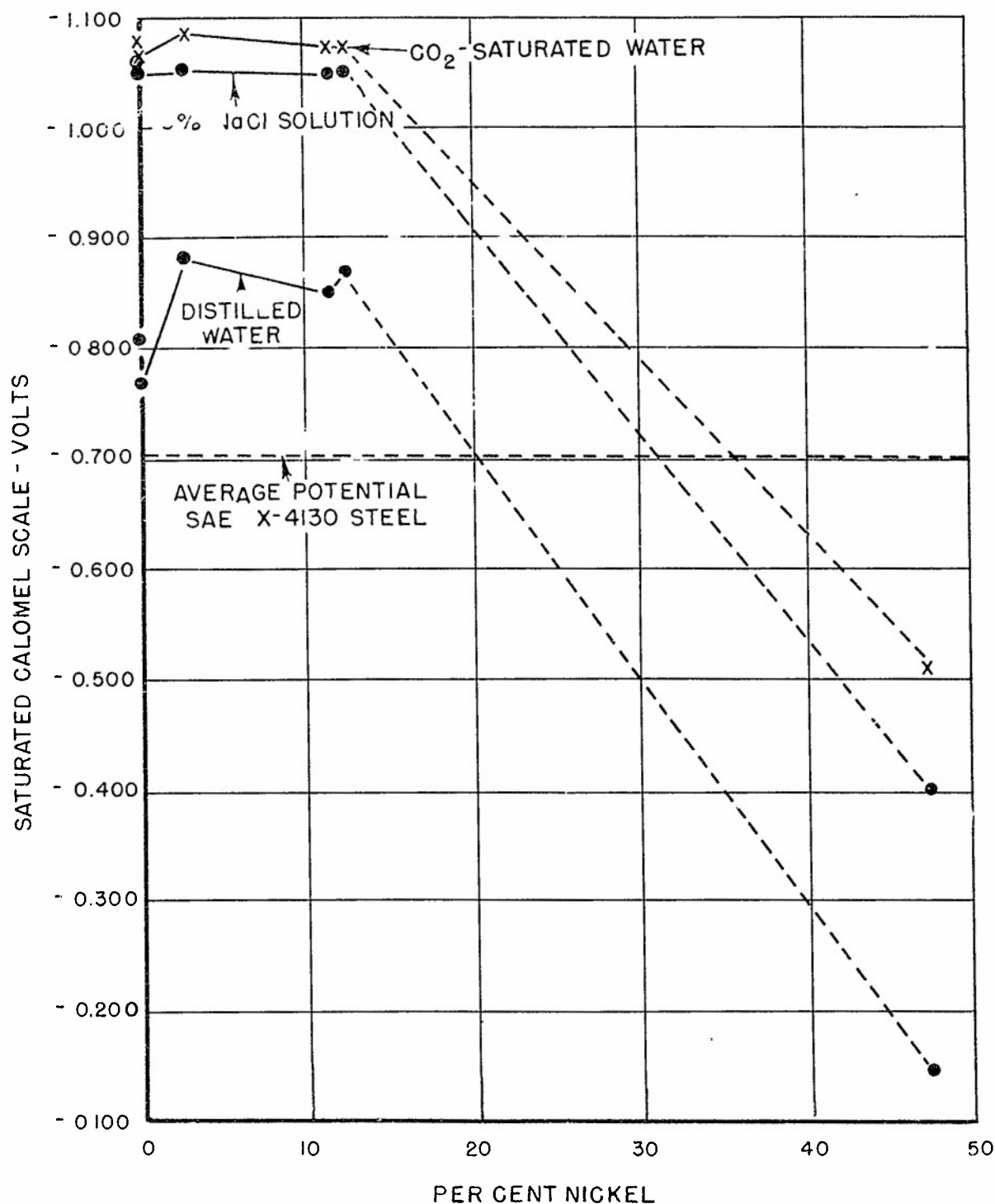


FIGURE 26 GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST ZINC-NICKEL ALLOYS IN 3% NaCl SOLUTION, CO₂-SATURATED WATER, AND DISTILLED WATER. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90° F. 60-MINUTE IMMERSION.

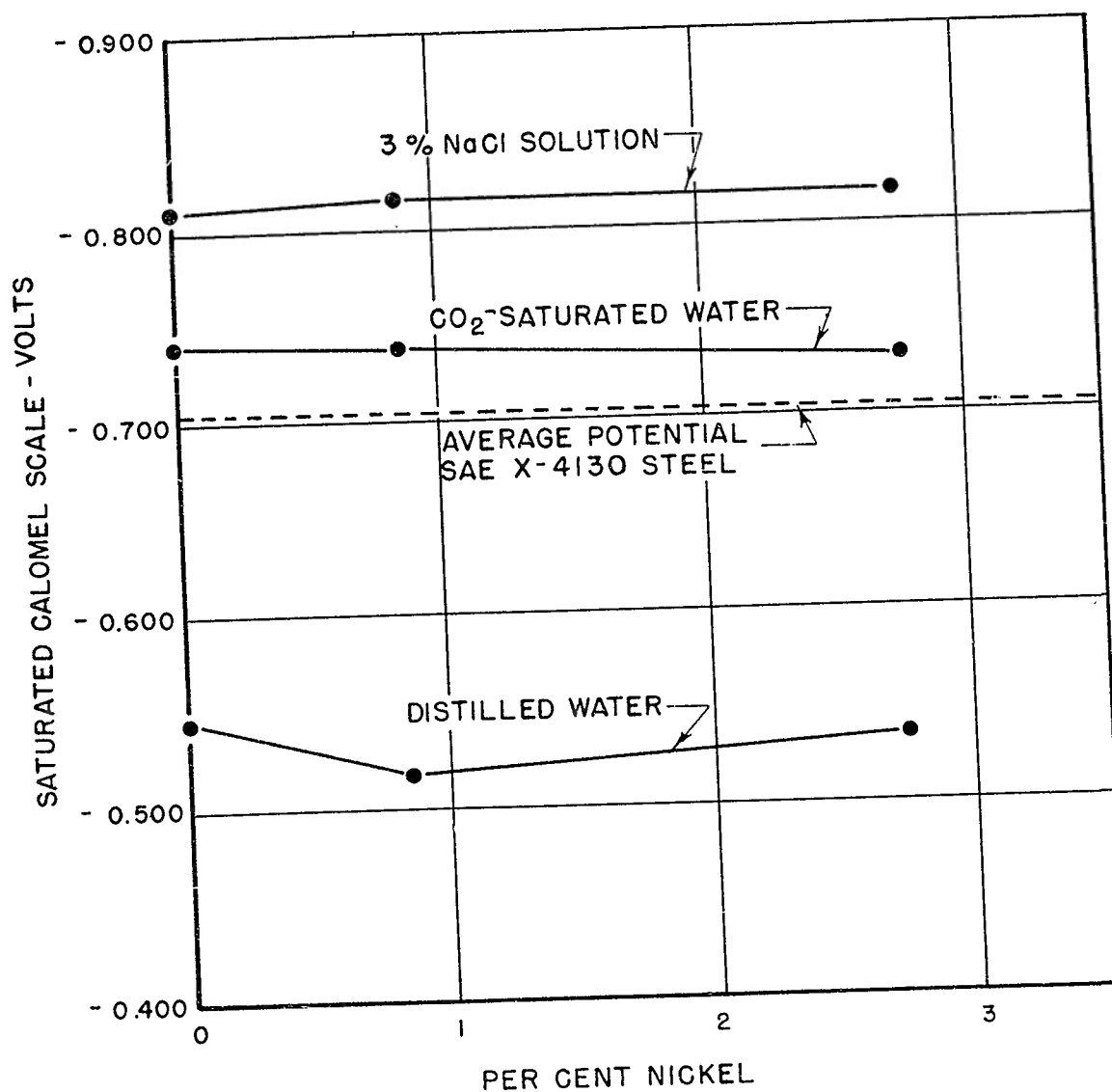


FIGURE 27. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST CADMIUM-NICKEL ALLOYS IN 3% NaCl SOLUTION, CO₂-SATURATED WATER, AND DISTILLED WATER. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90° F. 60-MINUTE IMMERSION.

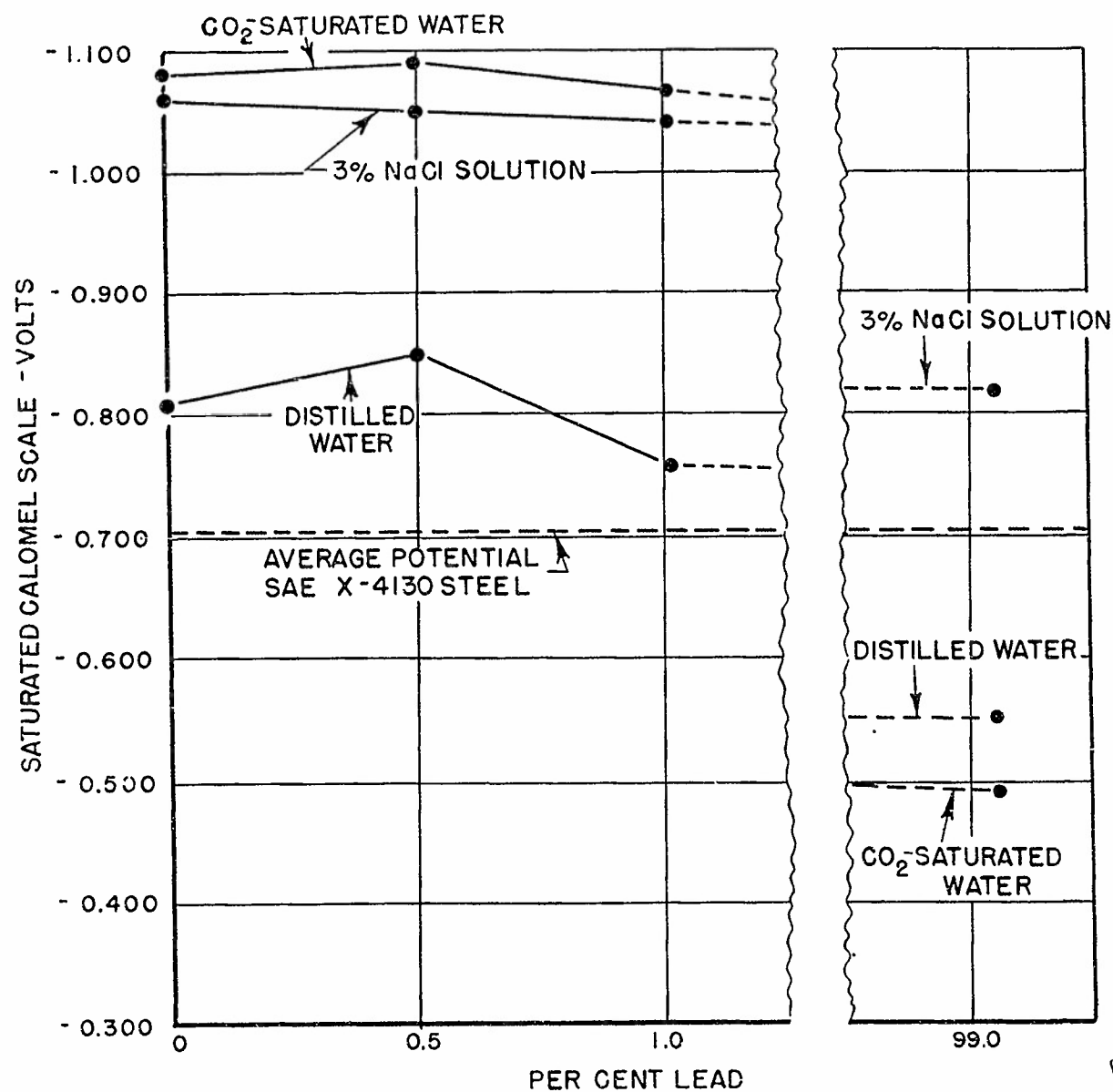


FIGURE 28. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST ZINC-LEAD ALLOYS IN 3% NaCl SOLUTION, CO₂-SATURATED WATER, AND DISTILLED WATER. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90° F. 60-MINUTE IMMERSION.

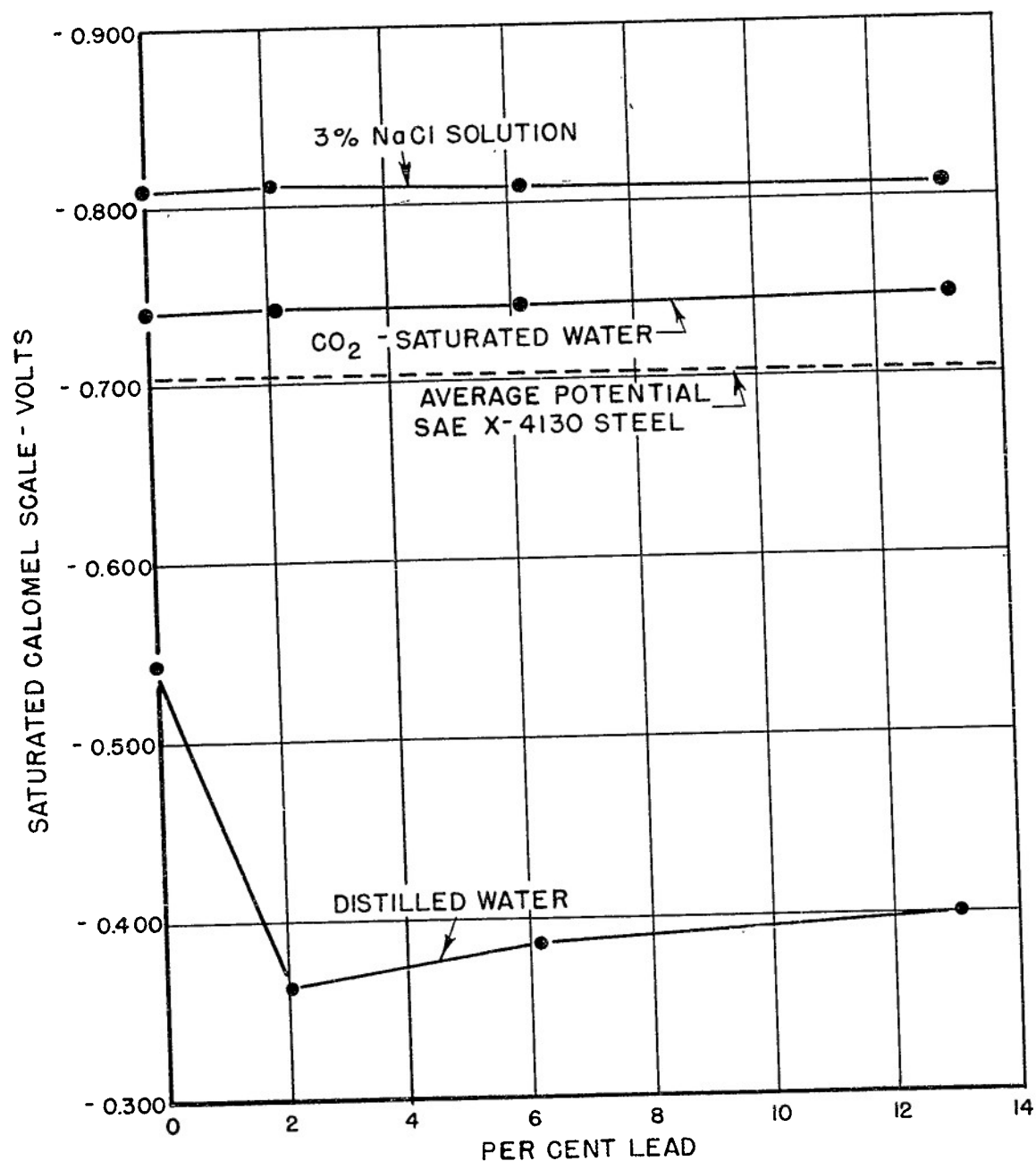


FIGURE 29. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST CADMIUM-LEAD ALLOYS IN 3% NaCl SOLUTION, CO₂-SATURATED WATER, AND DISTILLED WATER. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90° F. 60-MINUTE IMMERSION.

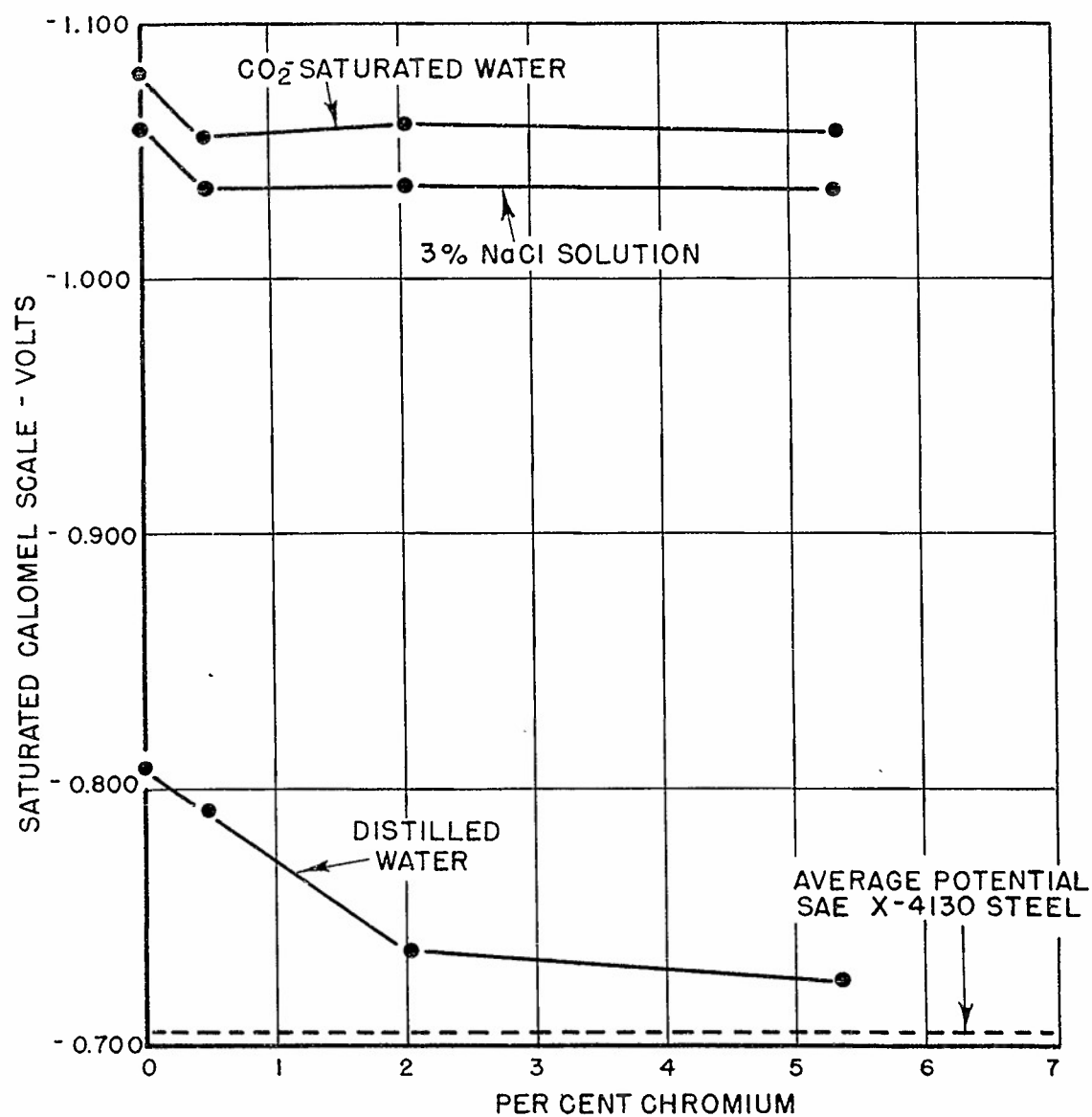


FIGURE 30. GRAPH SHOW STATIC ELECTRODE POTENTIALS OF CAST ZINC-CHROMIUM ALLOYS IN 3% NaCl SOLUTION, CO₂-SATURATED WATER AND DISTILLED WATER. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90°F. 60-MINUTE IMMERSION

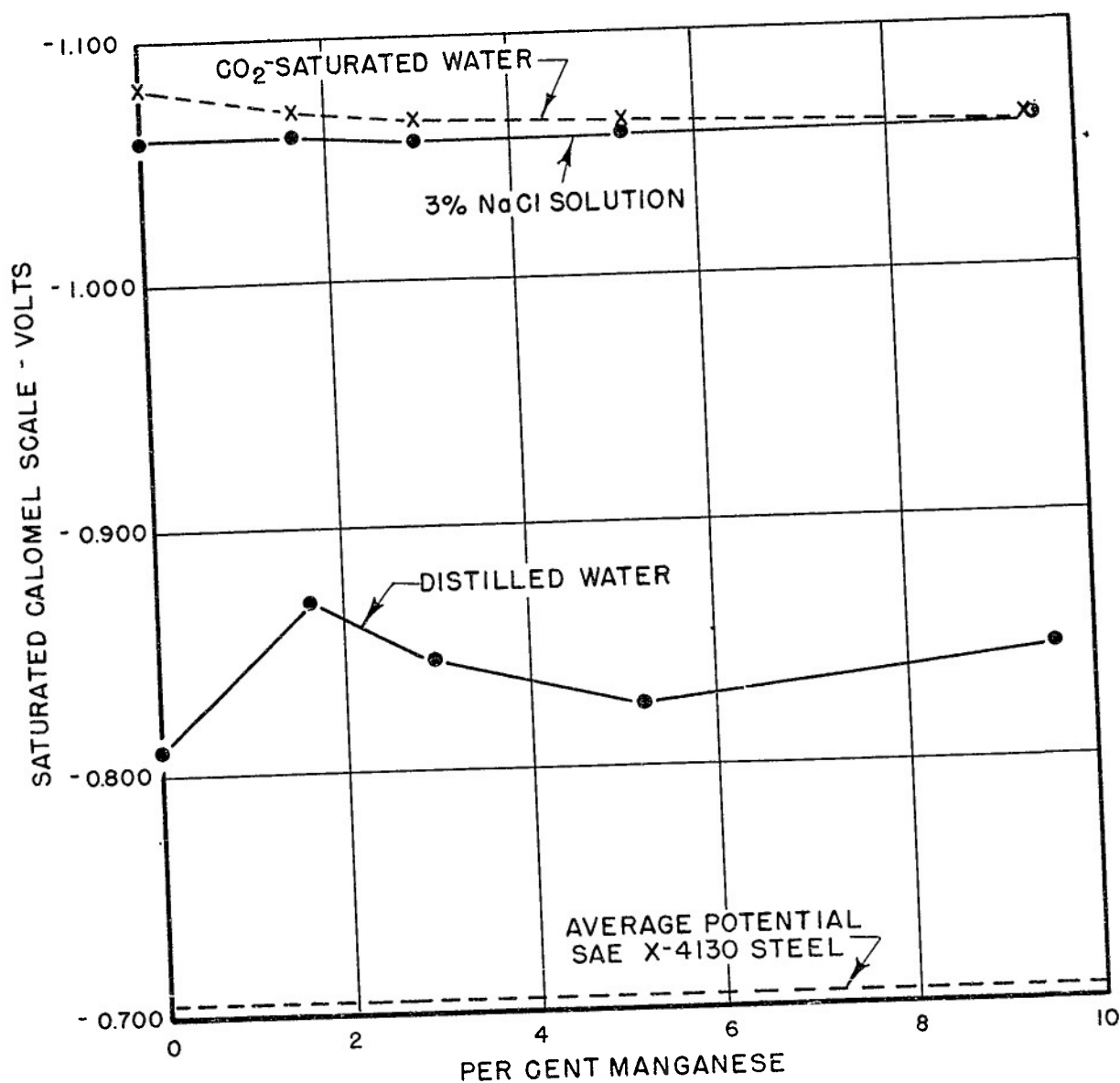


FIGURE 31. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST ZINC-MANGANESE ALLOYS IN 3% NaCl SOLUTION, CO₂-SATURATED WATER AND DISTILLED WATER. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90° F. 60-MINUTE IMMERSION.

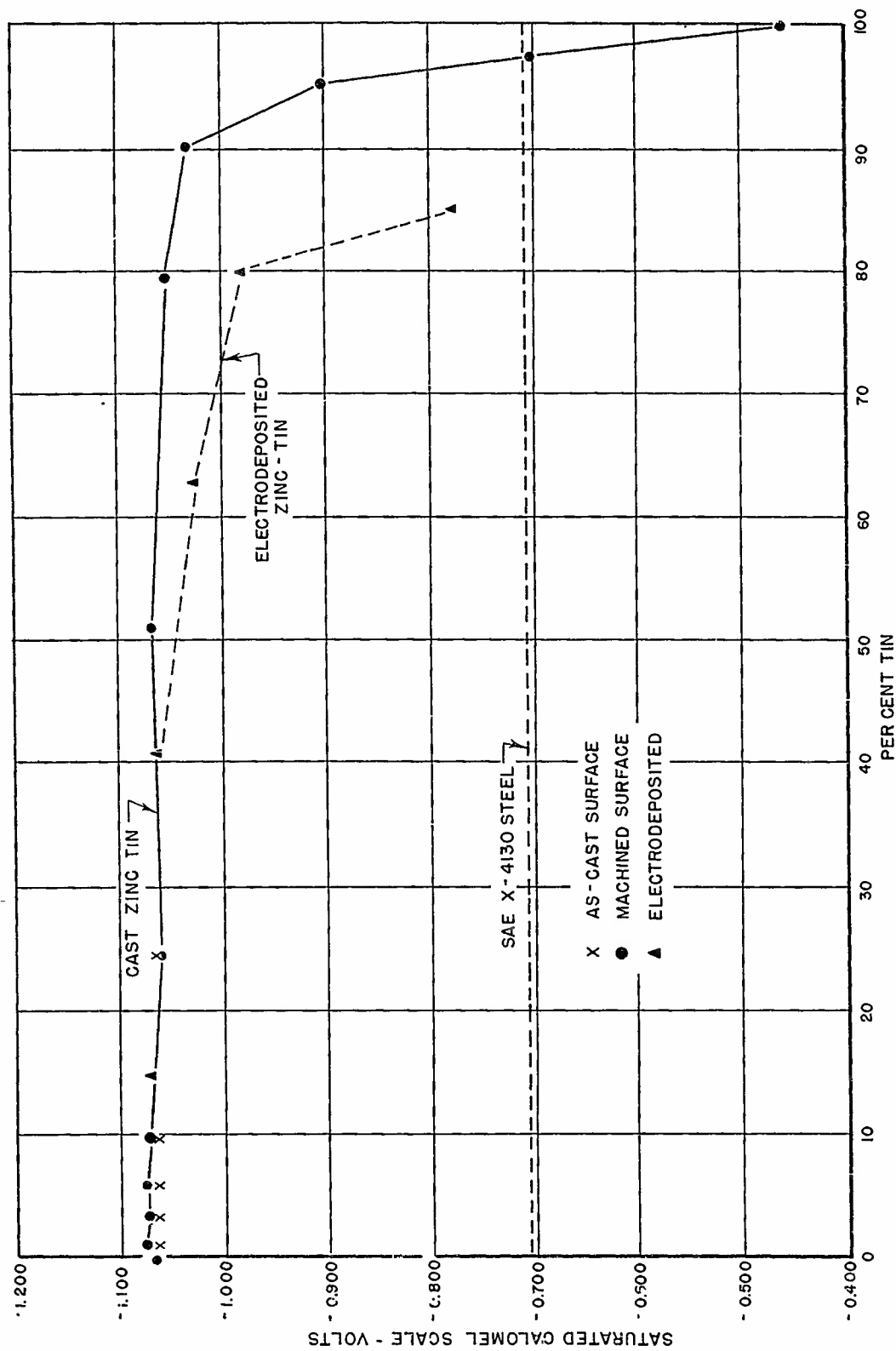


FIGURE 32. GRAPH SHOWING STATIC ELECTRODE POTENTIALS OF CAST AND ELECTRODEPOSITED ZINC-TIN ALLOYS IN 3% NaCl SOLUTION. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90° F. 60-MINUTE IMMERSION.

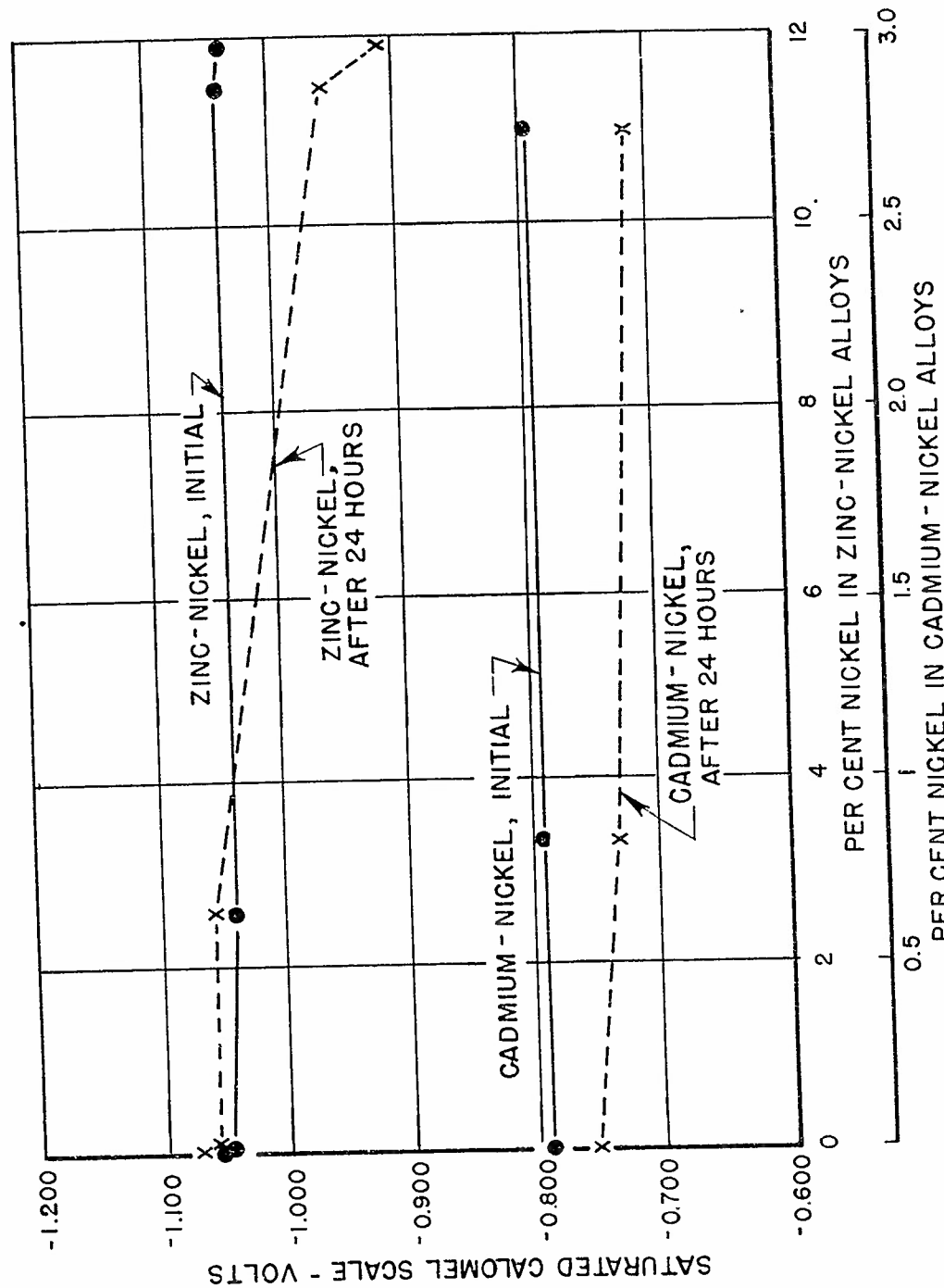


FIGURE 33. GRAPH SHOWING DYNAMIC ELECTRODE POTENTIALS OF CAST ZINC-NICKEL AND CADMIUM-NICKEL ALLOYS COUPLED WITH STEEL IN 3% SODIUM CHLORIDE SOLUTION. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL TEMPERATURE 90° F.

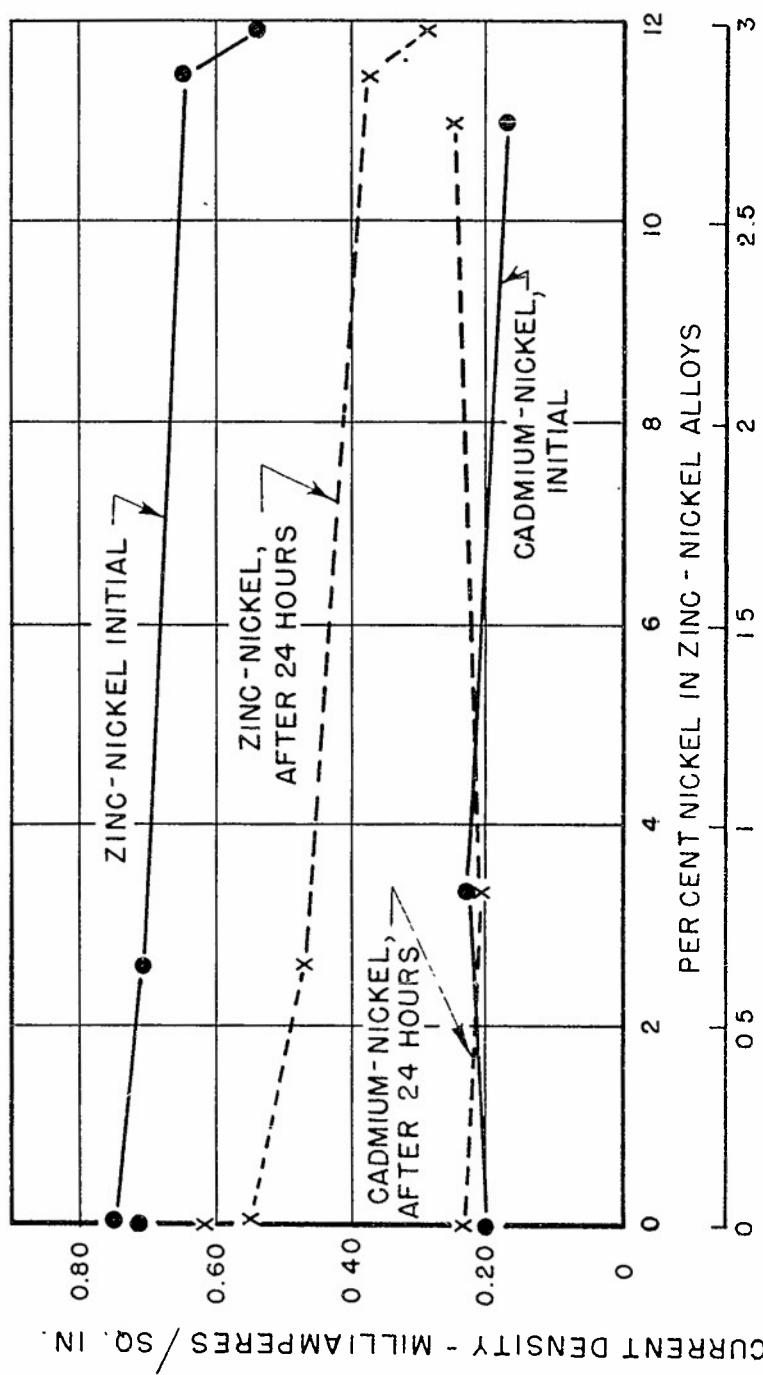


FIGURE 34 CORROSION CURRENT DENSITY IN CELLS CONSISTING OF CAST ZINC-NICKEL AND CADMIUM-NICKEL ALLOYS COUPLED WITH STEEL, IN 3% SODIUM CHLORIDE SOLUTION AT 90° F.

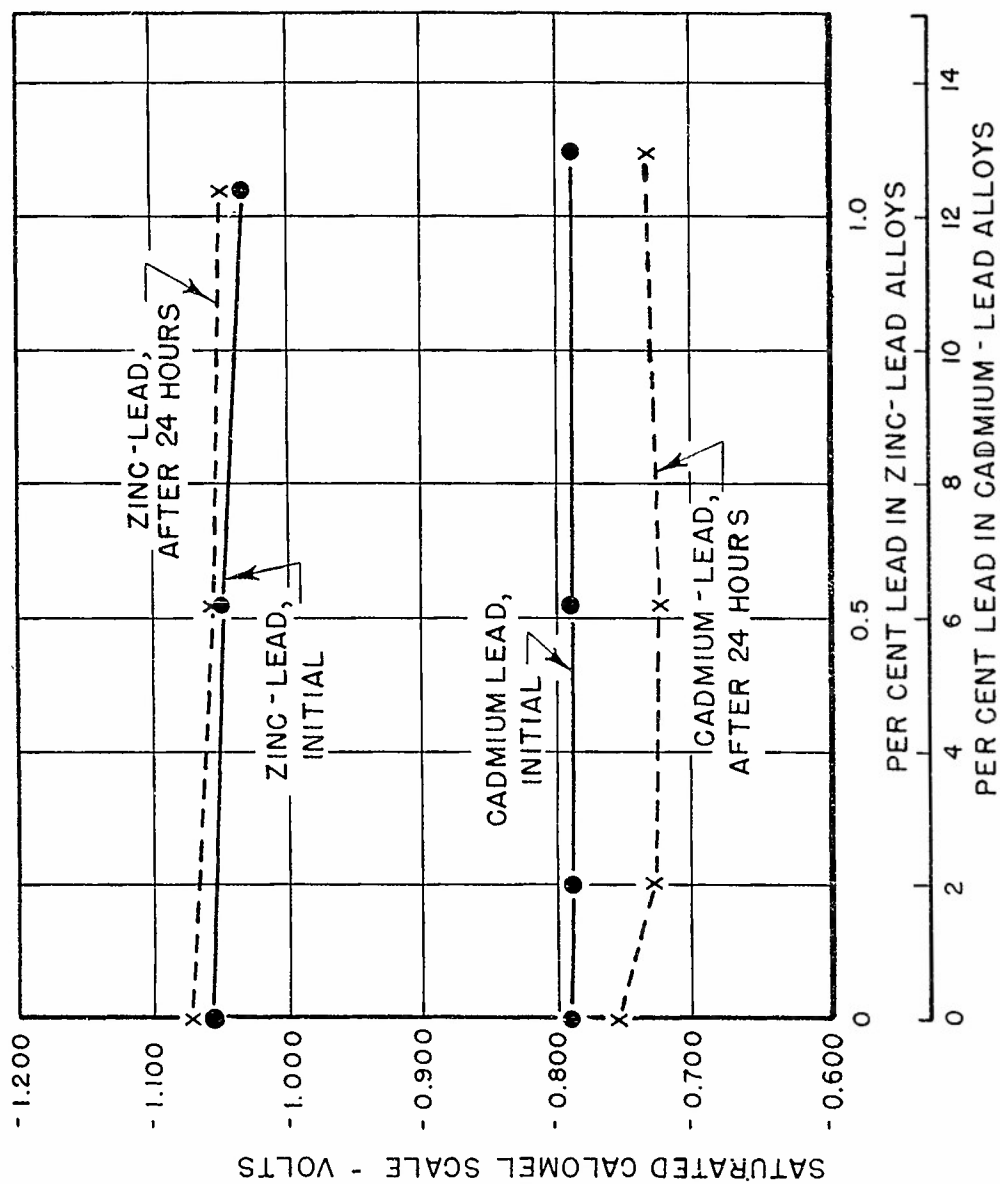


FIGURE 35. GRAPH SHOWING DYNAMIC ELECTRODE POTENTIALS OF CAST ZINC-LEAD AND CADMIUM LEAD ALLOYS COUPLED WITH STEEL IN 3% SODIUM CHLORIDE SOLUTION. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL. TEMPERATURE 90° F.

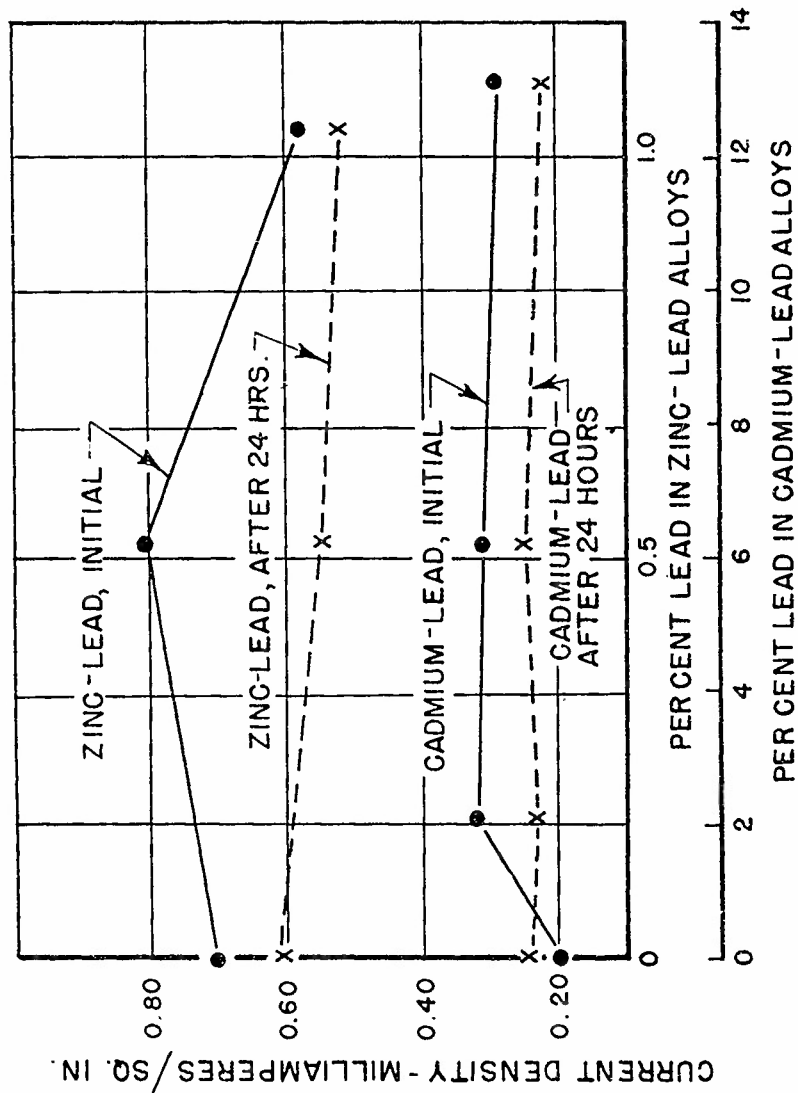


FIGURE 36. CORROSION CURRENT DENSITY IN CELLS CONSISTING OF CAST ZINC-LEAD AND CADMIUM-LEAD ALLOYS COUPLED WITH STEEL IN 3% SODIUM CHLORIDE SOLUTION AT 90° F.

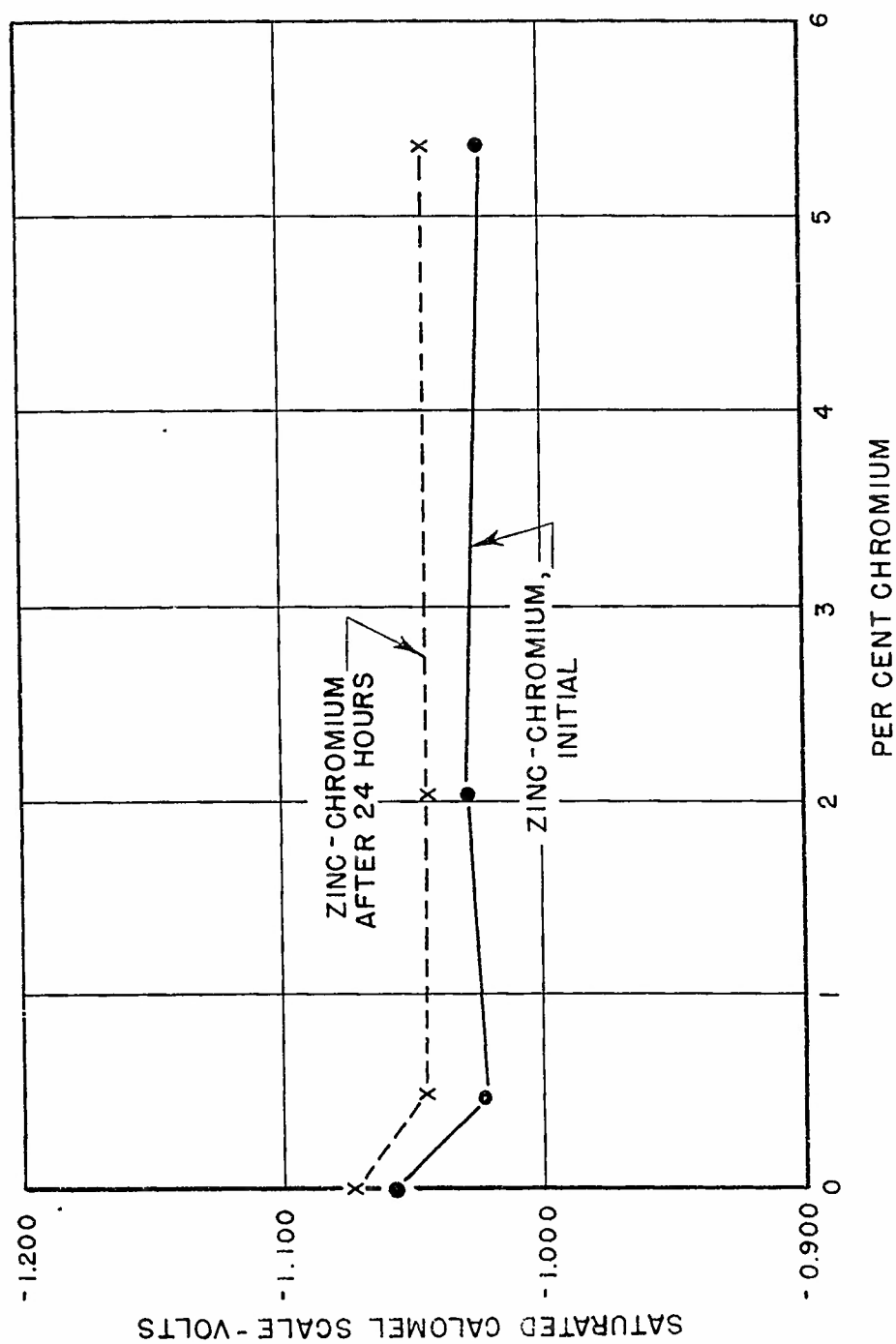


FIGURE 37. GRAPH SHOWING DYNAMIC ELECTRODE POTENTIALS OF CAST ZINC-CHROMIUM ALLOYS COUPLED WITH STEEL IN 3% SODIUM CHLORIDE SOLUTION. MEASURED AGAINST A SATURATED CALOMEL HALF-CELL, TEMPERATURE 90° F.

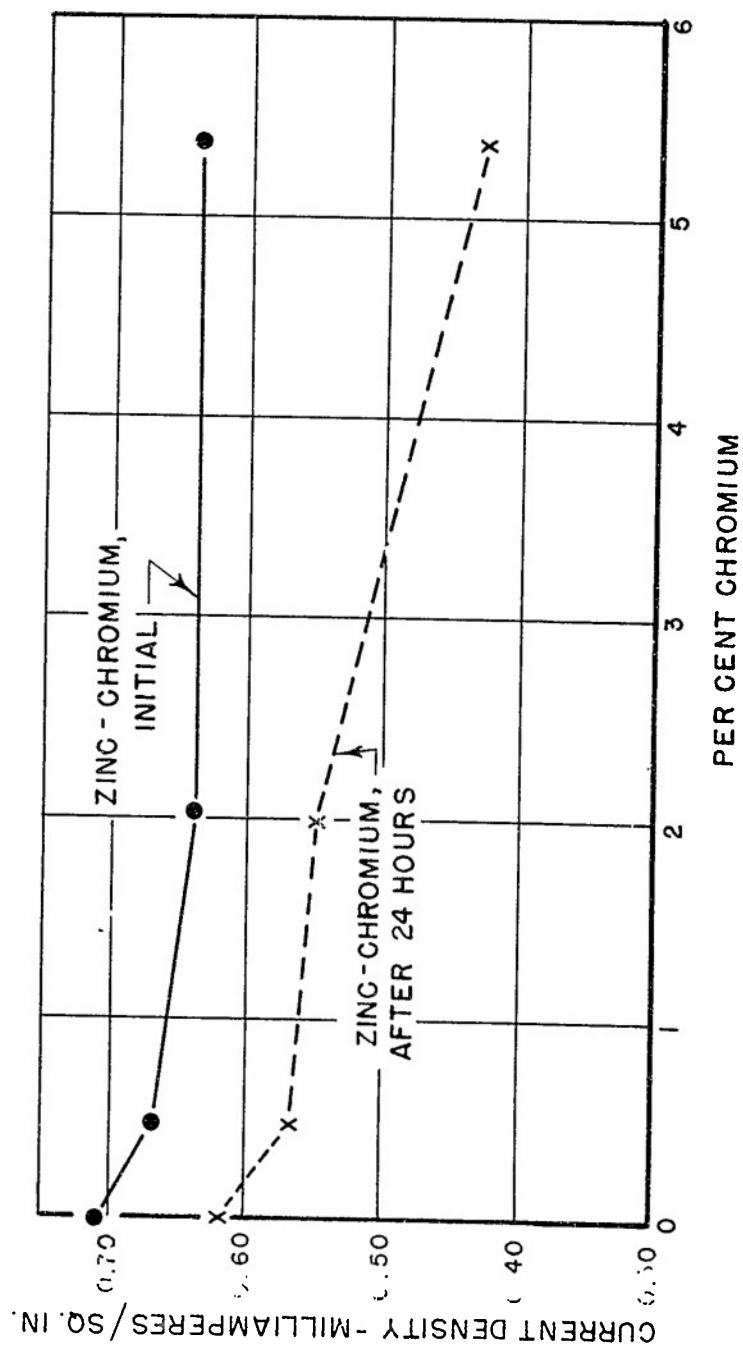


FIGURE 38. CORROSION CURRENT DENSITY IN CELLS CONSISTING OF CAST ZINC-CHROMIUM ALLOYS COUPLED WITH STEEL, IN 3% SODIUM CHLORIDE SOLUTION AT 90° F.

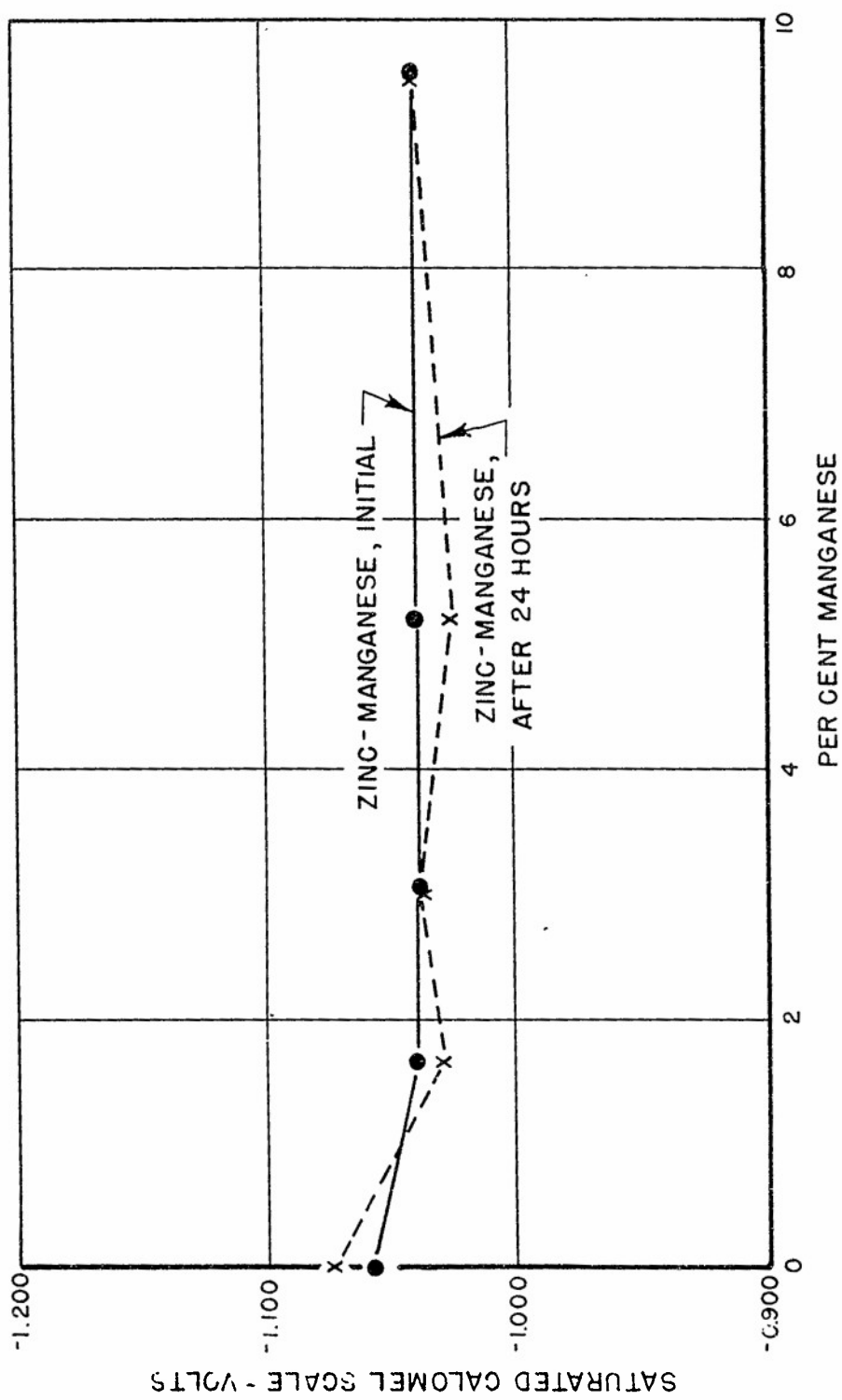


FIGURE 39. GRAPH SHOWING DYNAMIC ELECTRODE POTENTIALS OF CAST ZINC-MANGANESE ALLOYS COUPLED WITH STEEL IN 3% SODIUM CHLORIDE SOLUTION MEASURED AGAINST A SATURATED CALOMEL HALF-CELL, TEMPERATURE 90°F

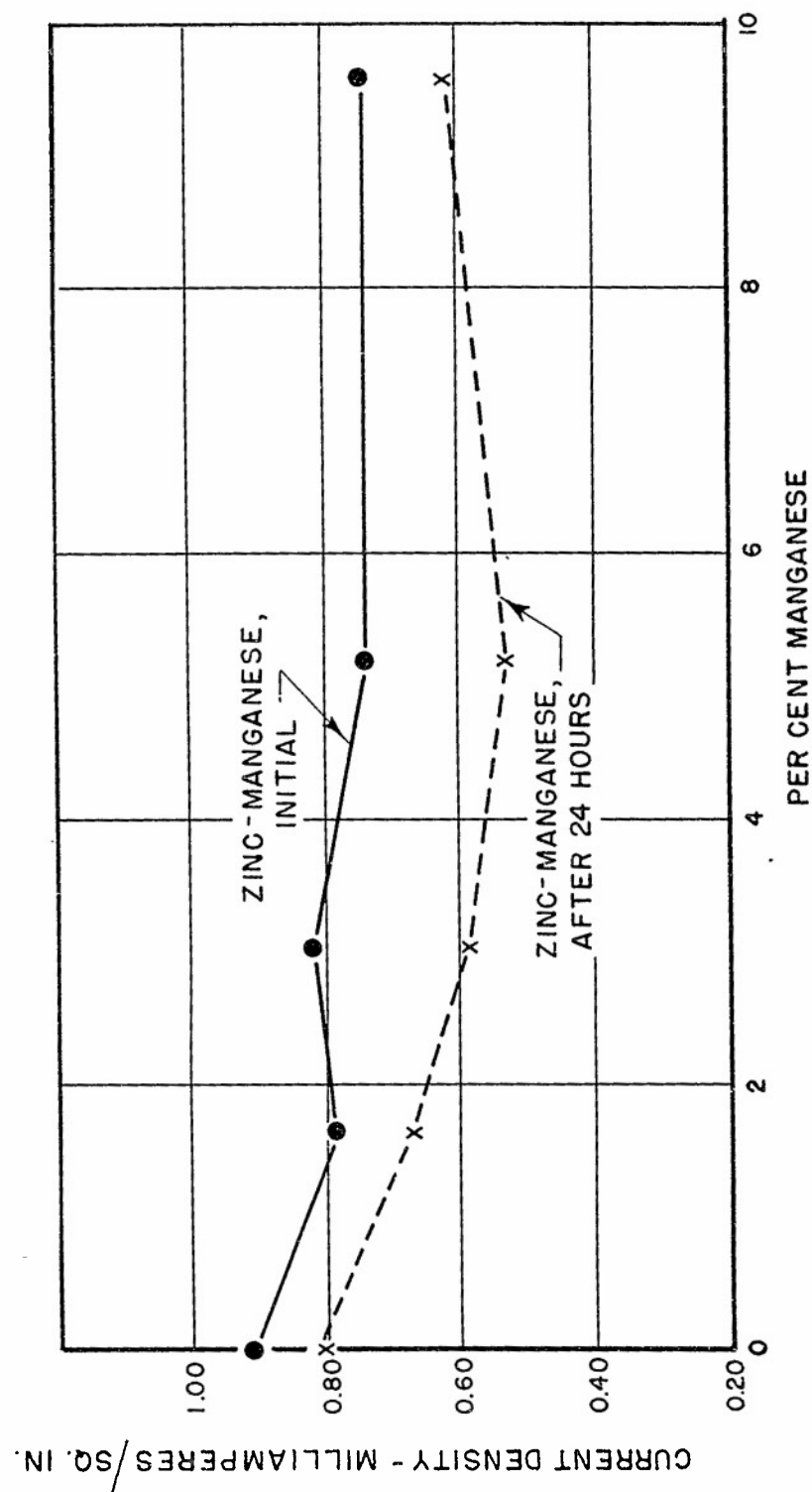


FIGURE 40. CORROSION CURRENT DENSITY IN CELLS CONSISTING OF CAST ZINC-MANGANESE ALLOYS COUPLED WITH STEEL IN 3% SODIUM CHLORIDE SOLUTION AT 90° F.

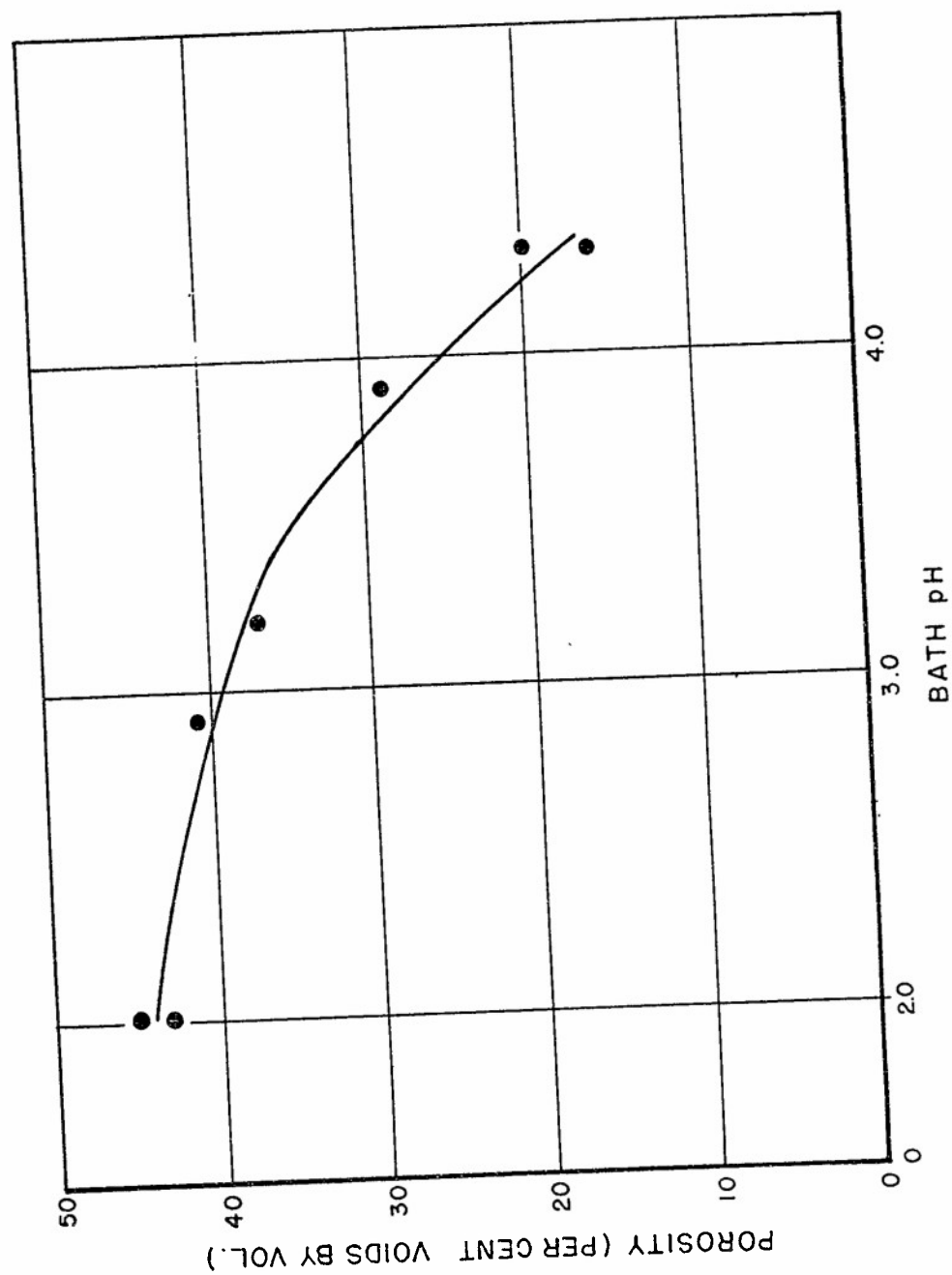


FIGURE 41. EFFECT OF BATH pH ON POROSITY OF ZINC PLATE.

APPENDIX III

This Appendix contains all data relative to potentials and corrosion current densities in tabulated form.

TABLE 1. POTENTIAL-TIME DATA FOR CAST ALLOYS BEFORE ANNEALING.
THREE PER CENT NaCl SOLUTION, 90°F., SATURATED CALOMEL
SCALE, VALUES IN VOLTS*

Elapsed Time (Min.)	Specimen Number and Per Cent Copper							
	1-A	12-D	12-B	12-C	13-A	11-A	36-B	38-B
	0.74	1.22	7.56	9.62	10.5	18.34	20.75	28.4
0	1.023	1.022	1.016	1.023	1.003	0.998		
1							0.935	0.900
5							0.914	0.919
7	1.027	1.031	1.026	1.027	1.005	1.002		
10							0.949	0.922
15	1.030	1.036	1.032	1.027	1.009	1.008		0.934
20							0.966	0.941
25	1.033	1.042	1.036	1.038	1.010	1.014	0.973	
30							0.979	0.950
35								0.954
40	1.039		1.042	1.043	1.013	1.019	0.984	0.955
50							0.991	0.958
55	1.045		1.046	1.042	1.019	1.024		
60			1.048				1.001	0.959
75							1.018	
90		1.056						
100					1.023			
115						1.021		
150							1.033	
160							1.033	

*. All values are negative

TABLE 2. POTENTIAL-TIME DATA FOR CAST ALLOYS AFTER ANNEALING AT
400°C. $\pm$ 10°C. FOR 17 HOURS. THREE PER CENT NaCl
SOLUTION, 90°F., SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Elapsed Time (Min.)	Specimen Number and Per Cent Copper					
	1-A 0.74	12-D 1.22	12-B 7.56	12-C 9.62	13-A 10.5	11-A 18.34
1	1.030	1.021	1.026	1.026	1.013	0.876
5	1.034	1.031	1.033	1.026	1.021	0.956
10	1.037		1.037	1.028	1.024	0.975
15	1.038	1.041	1.039	1.033	1.026	0.983
20	1.040	1.044	1.041	1.035	1.027	0.988
25	1.041	1.047	1.044	1.037	1.028	0.992
30	1.042	1.050	1.045	1.038	1.030	0.995
35	1.043	1.052	1.046	1.039	1.030	0.996
40	1.044	1.053	1.047		1.030	0.998
45	1.045	1.055	1.047	1.041	1.031	1.000
50	1.046		1.047	1.042	1.031	1.001
55		1.057	1.048	1.042	1.031	1.002
60	1.048	1.059	1.048	1.043	1.031	1.003

* All values are negative

TABLE 3. POTENTIAL-TIME DATA FOR ELECTRODEPOSITED ALLOYS. THREE PER CENT NaCl SOLUTION, 90°F., SATURATED CALOMEL SCALE, VALUES IN VOLTS.*

Elapsed Time (Min.)	Specimen Number and Per Cent Copper											
	18-A	17-B	14-C	13-C	22-D	29-E	36-C	29-B	38-A	8-A	40-A	22-B
	0.14	2.27	3.5	7.8	9.38	12.65	13.7	14.7	15.2	16.9	21.6	27.8
1	1.017	1.017	1.013	1.011	0.999	0.980	0.985	0.997	0.970	1.032	0.907	0.906
5	1.032	1.031	1.029	1.018	1.004	0.991	0.989	1.014	0.987	1.039	0.928	0.916
10	1.038	1.037	1.034	1.024	1.006	0.998	0.998	1.021	0.990	1.044	0.948	0.925
15	1.040	1.036	1.035	1.026	1.008	0.999	1.001	1.021	0.989	1.046	0.957	0.928
20		1.037	1.037	1.027	1.010	1.002	1.002	1.022		1.047	0.964	0.925
25	1.043	1.038	1.038	1.029	1.013	1.006	1.003	1.024	0.994	1.047		0.925
30	1.045	1.039	1.039	1.030	1.014	1.005	1.004	1.024	1.000	1.048	0.974	0.928
35	1.047	1.040	1.038	1.030	1.016	1.006			1.005			0.928
40	1.048	1.041	1.040	1.030	1.016	1.007	1.008	1.025		1.047	0.982	0.928
45	1.049	1.043	1.040		1.019	1.010	1.010	1.026	1.008		0.984	0.928
50	1.049	1.044	1.042		1.019	1.011		1.028	1.013		0.986	0.925
55	1.050	1.045			1.023	1.012	1.015	1.029				0.925
60	1.050	1.047			1.024	1.013	1.017	1.030	1.016		0.988	0.925

* All values are negative

TABLE 4. POLARIZATION AND CORROSION CELL CURRENT DATA FOR CAST AND ELECTRODEPOSITED ALLOYS. THREE PER CENT NaCl, 90°F., SPECIMENS 1 INCH APART, 1-1/2-INCH IMMERSION. VOLTAGES ON SATURATED CALOMEL SCALE.

	Specimen Number and Per Cent Copper			
	12-B	13-C	38-B	22-B
	Cast	Electro- deposited	Cast	Electro- deposited
	7.56	7.8	28.4	27.8
<u>No Current Flowing</u>				
1. X-4130 vs. calomel electrode	0.69 V.	0.68 V.	0.70 V.	0.675 V.
2. Alloy vs. calomel electrode	1.028 V.	1.01 V.	0.925 V.	0.92 V.
3. Calculated difference between 1 and 2.	0.338 V.	0.33 V.	0.225 V.	0.245 V.
4. X-4130 vs. alloy (measured)	0.334 V.	0.325 V.	0.225 V.	0.25 V.
<u>Cell Short-Circuited</u>				
5. X-4130 vs. alloy	0.00 V.	0.00 V.	0.00 V.	0.00 V.
6. Current	2.2 ma.	2.2 ma.	1.1 ma.	1.1 ma.
7. Current density	0.63 ma./sq.in.	0.7 ma./sq.in.	0.31 ma./sq.in.	0.35 ma./sq.in.
8. X-4130 vs. calomel electrode	1.025 V.	1.01 V.	0.925 V.	0.92 V.
9. Alloy vs. calomel electrode	1.025 V.	1.01 V.	0.925 V.	0.92 V.

TABLE 5. POTENTIAL-TIME DATA FOR CAST ZINC-TIN
ALLOYS IN 3% SODIUM CHLORIDE SOLUTION AT 90° F.
SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	% Sn	As-Cast Surfaces				V. at Elapsed Time of:				V. at Elapsed Time of:							
		1 Min.		30 Mins.		55 Mins.		60 Mins.		1 Min.		30 Mins.		55 Mins.		60 Mins.**	
50-B	0	-	-	-	-	-	-	-	-	1.045	1.049	1.076	1.074	1.077	1.074	1.075	1.071
53-A	1.08	1.054	1.062	1.065	1.065	1.066	1.065	1.066	1.065	1.053	1.073	1.073	1.073	1.070	1.061	1.066	1.051
53-B	3.44	1.065	1.062	1.065	1.064	1.065	1.066	1.065	1.065	1.045	1.056	1.063	1.065	1.060	1.065	1.065	1.051
53-C	6.01	1.063	1.058	1.065	1.065	1.065	1.067	1.067	1.067	1.048	1.063	1.063	1.065	1.060	1.065	1.065	1.051
53-D	9.98	1.058	1.061	1.065	1.065	1.065	1.067	1.067	1.067	1.040	1.047	1.047	1.051	1.051	1.051	1.051	1.051
53-E	24.7	1.052	1.062	1.065	1.067	1.067	1.067	1.067	1.067	1.040	1.047	1.047	1.051	1.051	1.051	1.051	1.051
53-F	51.1	1.060	1.063	1.065	1.067	1.067	1.067	1.067	1.067	1.040	1.047	1.047	1.051	1.051	1.051	1.051	1.051
53-G	79.5	1.041	1.051	1.050	1.051	1.051	1.051	1.051	1.051	1.040	1.047	1.047	1.051	1.051	1.051	1.051	1.051

connect to the saturated calomel cell.

* All the values given are negative with respect to the saturated calomel cell.

** Values plotted in Figure 9.

TABLE 6. POTENTIAL-TIME DATA FOR CAST CADMIUM-TIN ALLOYS
IN 3 PER CENT SODIUM CHLORIDE SOLUTION AT 90°F.,
SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	% Sn	V. at Elapsed Time of:**			
		1 Min.	30 Mins.	55 Mins.	60 Mins.
50-A	0.0	0.793	0.805	0.808	0.809
55-A	1.01	0.753	0.771	0.775	0.776
55-B	3.18	0.734	0.775	0.779	0.779
55-C	5.46	0.753	0.762	0.766	0.766
55-D	10.8	0.742	0.766	0.771	0.771
55-E	25.2	0.734	0.768	0.770	0.770
55-F	51.1	0.725	0.766	0.762	0.762
55-G	76.2	0.743	0.729	0.728	0.728
55-H	90.2	0.696	0.668	0.649	0.644
55-I	94.9	0.693	0.461	0.459	0.460
55-J	98.8	0.571	0.448	0.454	0.454

* All values are negative.

** Values plotted in Figure 9.

TABLE 7. INITIAL AND 24-HOUR DYNAMIC POTENTIAL AND CORROSION CURRENT DATA FOR CAST ZINC-TIN AND CADMIUM-TIN ALLOYS COUPLED WITH STEEL. COUPLES IMMERSSED IN 3 PERCENT SODIUM-CHLORIDE SOLUTION AT 90°F DURING MEASUREMENTS. SATURATED CALOMEL SCALE

Specimen No.	% Sn	Initial Measurements		24 Hour-Measurements	
		V.-Coupled Alloy	Corrosion Current Density in Ma./In. ²	V.-Coupled Alloy	Corrosion Current Density in Ma./In.
<u>Zinc-Tin Series</u>					
50-R	0.00	1.056	0.63	1.069	0.735
53-A	1.08	1.07	0.874	1.075	0.772
53-B	3.44	1.08	0.766	1.075	0.671
53-C	6.01	1.07	0.732	1.075	0.707
53-D	9.98	1.07	0.772	1.075	0.733
53-E	24.7	1.07	0.737	1.075	0.598
53-F	51.1	1.05	0.758	1.045	0.48
53-G	79.5	1.05	0.707	0.99	0.366
<u>Cadmium-Tin Series</u>					
50-A	0.00	0.784	0.20	0.752	0.23
55-A	1.01	0.775	0.19	0.768	0.178
55-B	3.18	0.763	0.148	0.766	0.197
55-C	5.46	0.773	0.185	0.759	0.197
55-D	10.8	0.771	0.20	0.776	0.20
55-E	25.2	0.759	0.172	0.757	0.224
55-F	51.1	0.755	0.178	0.741	0.216
55-G	76.2	0.734	0.132	0.682	0.185
55-H	90.2	0.705	0.049	0.677	*

*Steel corroded. No measurement possible.

TABLE 8. POTENTIAL-TIME DATA FOR CAST ZINC-SILVER AND
CADMIUM-SILVER ALLOYS IN 3 PER CENT SODIUM
CHLORIDE SOLUTION AT 90°F., SATURATED CALOMEL
SCALE, VALUES IN VOLTS*

Specimen No.	% Ag	Volts at Elapsed Time of:			
		1 Min.	30 Mins.	50 Mins.	60 Mins.
(Zinc-Silver System)					
2875-62-A-1	1.02	1.030	1.045	1.047	1.049
—62-B-1	5.14	1.025	1.040	1.042	1.043
—62-C-1	17.8	1.019	1.032	1.035	1.035
—62-D-1	24.8	0.945	0.925	0.924	0.924
—62-E-1	37.2	0.416	0.267	0.281	0.279
—62-F-1	44.2	0.332	0.227	0.218	0.217
(Cadmium-Silver System)					
2875-60-A-1	1.24	0.803	0.800	0.800	0.800
—60-B-1	3.04	0.805	0.810	0.807	0.806
—60-C-1	7.95	0.808	0.809	0.806	0.804
—60-D-1	16.0	0.789	0.795	0.769	0.757
—60-E-2	18.65	0.758	0.679	0.705	0.708
—60-F-1	31.2	0.724	0.571	0.539	0.523

* All values are negative.

** Values plotted in Figure 7.

TABLE 9. POTENTIAL-TIME DATA FOR CAST CADMIUM-ZINC ALLOYS
IN 3 PER CENT SODIUM CHLORIDE SOLUTION AT 90°F.,
SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	% Zn	Volts at Elapsed Time of:			
		1 Min.	30 Mins.	50 Mins.	60 Mins.**
2875-57-A-1	0.91	0.740	0.737	0.739	0.740
-57-B-1	2.35	0.816	0.728	0.730	0.733
-57-C-1	9.83	0.993	0.988	0.991	0.982
-57-D-1	25.6	1.033	1.042	1.041	1.040
-57-E-1	50.2	1.047	1.062	1.062	1.058
-57-F-1	74.9	1.050	1.063	1.065	1.063
-57-G-1	89.5	1.050	1.062	1.063	1.062
-57-H-1	96.7	1.050	1.063	1.066	1.066
-57-I-1	98.7	1.053	1.070	1.067	1.069

* All values are negative.

** Values plotted in Figure 7.

TABLE 10. POTENTIAL-TIME DATA FOR CAST ZINC-INDIUM AND
CADMIUM-INDIUM ALLOYS IN 3 PER CENT SODIUM
CHLORIDE SOLUTION AT 90°F., SATURATED CALOMEL
SCALE, VALUES IN VOLTS*

Specimen No.	% In	Volts at Elapsed Time of:			
		1 Min.	30 Mins.	50 Mins.	60 Mins.
(Zinc-Indium System)					
2875-71-A-1	1.2	1.056	1.072	1.075	1.077
--71-B-1	3.0	1.057	1.068	1.072	1.072
--71-C-1	6.8	1.051	1.069	1.073	1.074
--71-D-1	11.5	1.049	1.067	1.071	1.071
--71-E-1	19.0	1.045	1.060	1.062	1.064
--71-F-1	39.6	1.052	1.062	1.064	1.063
(Cadmium-Indium System)					
2875-70-A-1	1.1	0.726	0.735	0.736	0.737
--70-B-1	3.0	0.720	0.717	0.718	0.718
--70-C-1	7.0	0.711	0.714	0.716	0.717
--70-D-1	11.9	0.715	0.718	0.720	0.720
--70-E-1	19.7	0.717	0.713	0.714	0.715
--70-F-1	39.5	0.718	0.708	0.712	0.713

* All values are negative.

** Values for 60 minutes plotted in Figure 8.

TABLE 11. POTENTIAL-TIME DATA FOR SOME ADDITIONAL
ZINC-TIN ALLOYS IN 3 PER CENT SODIUM
CHLORIDE SOLUTION AT 90°F., SATURATED
CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	% Sn	Volts at Elapsed Time of:			
		1 Min.	30 Mins.	50 Mins.	60 Mins**
2875--87-A-1	90.13	1.032	1.018	1.011	1.008
--87-B-1	95.30	0.902	0.664	0.641	0.631
--87-C-1	97.80	0.700	0.599	0.591	0.588

* All values are negative.

** Sixty-minute values plotted in Figure 9.

TABLE 12. INITIAL AND 24-HOUR DYNAMIC POTENTIAL AND CORROSION CURRENT DATA FOR CAST ZINC-SILVER AND CADMIUM-SILVER ALLOYS COUPLED WITH STEEL. COUPLES IMMersed IN 3 PER CENT NaCl at 90°F. FOR THE 24-HOUR PERIOD SATURATED CALOMEL SCALE.

Specimen No.	% Ag	Initial Measurements		24-Hour Measurements	
		Coupled Alloy (Volts)	Corrosion Current Density (Ma./In. ²)	Coupled Alloy (Volts)	Corrosion Current Density (Ma./In. ²)
(Zinc-Silver System)					
2875--62-A-1	1.02	1.038	0.76	1.063	0.82
--62-B-1	5.14	1.036	0.75	1.049	0.57
--62-C-1	17.8	1.027	0.72	0.976	0.45
--62-D-1	24.8	0.865	0.36	0.916	0.26
--62-E-1	37.2	*	*	*	*
--62-F-1	44.2	*	*	*	*
(Cadmium-Silver System)					
2875--60-A-1	1.24	0.789	0.22	0.717	0.26
--60-B-1	3.04	0.788	0.25	0.736	0.17
--60-C-1	7.95	0.786	0.26	0.723	0.20
--60-D-1	16.0	0.727	0.16	*	*
--60-E-2	18.65	*	*	*	*
--60-F-1	31.2	*	*	*	*

* Alloy was more noble than steel. No dynamic measurements were made.

TABLE 13. INITIAL AND 24-HOUR DYNAMIC POTENTIAL AND CORROSION CURRENT DATA FOR CAST CADMIUM-ZINC ALLOYS AND THREE ADDITIONAL ZINC-TIN ALLOYS COUPLED WITH STEEL. COUPLES IMMERSSED IN 3 PER CENT NaCl at 90°F. FOR THE 24-HOUR PERIOD. SATURATED CALOMEL SCALE

		Initial Measurements		24-Hour Measurements	
Specimen No.	% Cd	Coupled Alloy	Corrosion Current Density	Coupled Alloy	Corrosion Current Density
		(Volts)	(Ma./In. ²)	(Volts)	(Ma./In. ²)
(Cadmium-Zinc System)					
2875—57-A-1	99.09	0.745	0.11	0.781	0.26
—57-B-1	97.65	0.757	0.16	0.751	0.23
—57-C-1	90.17	1.007	0.50	0.736	0.17
—57-D-1	74.4	1.036	0.66	0.976	0.36
—57-E-1	49.8	1.052	0.79	1.029	0.51
—57-F-1	25.1	1.060	0.70	1.058	0.57
—57-G-1	10.5	1.059	0.74	1.062	0.63
—57-H-1	3.3	1.061	0.77	1.066	0.63
—57-I-1	1.3	1.067	0.83	1.073	0.61
(Zinc-Tin System)					
	% Sn				
2875—87-A-1	90.13	1.016	0.57	0.745	0.18
—87-B-1	95.3	0.761	0.18	0.689	*
—87-C-1	97.8	*	*	*	*

* Alloy was more noble than steel. No dynamic measurements were made.

TABLE 14. INITIAL AND 24-HOUR DYNAMIC POTENTIAL AND CORROSION CURRENT DATA FOR CAST ZINC-INDIUM AND CADMIUM-INDIUM ALLOYS COUPLED WITH STEEL. COUPLES IMMERSSED IN 3 PER CENT NaCl AT 90°F. FOR THE 24-HOUR PERIOD. SATURATED CALOMEL SCALE.

		Initial Measurements		24-Hour Measurements	
		Corrosion		Corrosion	
Specimen		Coupled	Current	Coupled	Current
No.	% In	Alloy	Density	Alloy	Density
		(Volts)	(Ma./In. ²)	(Volts)	(Ma./In. ²)
(Zinc-Indium System)					
2875-71-A-1	1.2	1.055	0.88	1.073	0.91
--71-B-1	3.0	1.056	0.83	1.076	0.66
--71-C-1	6.8	1.059	0.80	1.078	0.82
--71-D-1	11.5	1.054	0.80	1.075	0.72
--71-E-1	19.0	1.051	0.86	1.074	0.69
--71-F-1	39.6	1.048	0.83	1.061	0.61
(Cadmium-Indium System)					
2875-70-A-1	1.1	0.721	0.043	0.730	0.17
--70-B-1	3.0	0.720	0.086	0.732	0.23
--70-C-1	7.0	0.722	0.043	0.728	0.27
--70-D-1	11.9	0.724	0.043	0.727	0.14
--70-E-1	19.7	0.723	0.057	0.726	0.19
--70-F-1	39.5	0.719	0.029	0.715	0.12

TABLE 15. POTENTIAL-TIME DATA FOR CAST ZINC-COPPER ALLOYS IN DISTILLED WATER AT 90°F., SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	% Cu	Volts at Elapsed Time of:		
		60 Mins.**	75 Mins.	90 Mins.
2875-1-A	0.74	0.833	0.835	0.830
—12-D	1.22	0.866	0.875	0.880
—12-B	7.56	0.805	0.799	0.806
—12-C	9.62	0.839	0.860	0.880
—13-A	10.5	0.800	0.765	0.763
—11-A	18.34	0.685	0.685	0.715
—36-B	20.75	0.464	0.491	0.537
—38-B	28.4	0.311	0.249	0.255

* All values are negative.

** Sixty-minute values are plotted in Figure 18.

TABLE 16. POTENTIAL-TIME DATA FOR CAST ZINC-TIN
ALLOYS IN DISTILLED WATER AT 90°F.,
SATURATED CALOMEL SCALE, VALUES IN
VOLTS*

Specimen No.	% Sn	Volts at Elapsed Time of:		
		60 Mins.**	75 Mins.	90 Mins.
2875-53-A-1	1.08	0.919	0.910	0.900
--53-B-1	3.44	0.915	0.936	0.937
--53-C-1	6.01	0.903	0.947	0.947
--53-D-1	9.48	0.933	0.951	0.985
--53-E-1	24.7	0.832	0.872	0.877
--53-F-1	51.1	0.565	0.578	0.575
--53-G-1	79.5	0.610	0.633	0.642
--87-A-1	90.13	0.562	0.590	0.675
--87-B-1	95.3	0.385	0.360	0.352
--87-C-1	97.8	0.332	0.329	0.322

* All values are negative.

** Sixty-minute values plotted in Figure 19.

TABLE 17. POTENTIAL-TIME DATA FOR CAST CADMIUM-TIN
ALLOYS IN DISTILLED WATER AT 90°F,
SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	% Sn	Volts at Elapsed Time of:		
		60 Mins.**	75 Mins.	90 Mins.
2875--50-A	0.00	0.545	0.505	0.450
--55-A-1	1.01	0.268	0.286	0.301
--55-B-1	3.18	0.423	0.407	0.407
--55-C-1	5.46	0.412	0.426	0.436
--55-D-1	10.8	0.459	0.446	0.456
--55-E-1	25.2	0.371	0.367	0.364
--55-F-1	51.1	0.377	0.350	0.355
--55-G-1	76.2	—	—	0.288
--55-H-1	90.2	—	—	0.294
--55-I-1	94.9	0.103	0.105	0.108
--55-J-2	98.8	0.095	0.130	0.165

* All values are negative.

** Sixty-minute values are plotted in Figure 19.

TABLE 18. POTENTIAL-TIME DATA FOR CAST ZINC-SILVER AND CADMIUM-SILVER ALLOYS IN DISTILLED WATER AT 90°F., SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	% Ag	Volts at Elapsed Time of:		
		60 Mins.**	75 Mins.	90 Mins.
(Zinc-Silver System)				
2875-62-A-1	1.02	0.793	0.810	0.825
--62-B-1	5.14	0.700	0.822	0.808
--62-C-1	17.8	0.685	0.746	0.680
--62-D-1	24.8	0.220	0.227	0.230
--62-E-1	37.2	0.043	0.046	0.040
--62-F-1	44.2	0.008	0.005	0.000
(Cadmium-Silver System)				
2875-60-A-1	1.24	0.365	0.371	0.364
--60-B-1	3.04	0.383	0.375	0.384
--60-C-1	7.95	0.355	0.335	0.339
--60-D-1	16.0	0.300	0.276	0.302
--60-E-2	18.65	0.373	0.358	0.355
--60-F-1	31.2	0.072	0.065	0.065

* All values are negative.

** Values for 60 mins. plotted in Figure 20.

TABLE 19. POTENTIAL-TIME DATA FOR CAST CADMIUM-ZINC ALLOYS IN DISTILLED WATER AT 90°F., SATURATED CALOMEL SCALE, VALUES IN VOLTS. *

Specimen No.	% Cd	Volts at Elapsed Time of:		
		60 Mins.**	75 Mins.	90 Mins.
2875-57-A-1	99.09	0.454	0.476	0.485
—57-B-1	97.65	0.486	0.491	0.504
—57-C-1	90.17	0.544	0.549	0.565
—57-D-1	74.4	0.673	0.682	0.684
—57-E-1	49.8	0.792	0.785	0.790
—57-F-1	25.1	0.847	0.854	0.855
—57-G-1	10.5	0.785	0.784	0.778
—57-H-1	3.3	0.832	0.837	0.847
—57-I-1	1.3	0.808	0.813	0.825

* All values are negative.

** Values for 60 mins. plotted in Fig. 20.

TABLE 20. POTENTIAL-TIME DATA FOR CAST ZINC-INDIUM AND
CADMIUM-INDIUM ALLOYS IN DISTILLED WATER AT
90°F., SATURATED CALOMEL SCALE, VALUES IN
VOLTS *

Specimen No.	% In	Volts at Elapsed Time of:		
		60 Mins.**	75 Mins.	90 Mins.
(Zinc-Indium System)				
2875--71-A-1	1.2	0.918	0.931	0.910
--71-B-1	3.0	0.900	0.888	0.878
--71-C-1	6.8	0.932	0.933	0.941
--71-D-1	11.5	0.917	0.914	0.915
--71-E-1	19.0	0.898	0.935	0.922
--71-F-1	39.0	0.895	0.889	0.882
(Cadmium-Indium System)				
2875--70-A-1	1.1	0.372	0.382	0.389
--70-B-1	3.0	0.347	0.368	0.373
--70-C-1	7.0	0.373	0.398	0.408
--70-D-1	11.9	0.353	0.358	0.362
--70-E-1	19.7	0.358	0.365	0.396
--70-F-1	39.5	0.224	0.240	0.237

* All values are negative.

** Values for 60 mins. plotted in Fig. 21.

TABLE 21. POTENTIAL-TIME DATA FOR CAST ZINC-COPPER ALLOYS,
MEASURED AT 90°F IN DISTILLED WATER SATURATED
WITH CARBON DIOXIDE, SATURATED CALOMEL SCALE,
VALUES IN VOLTS*

Specimen No.	% Cu	Volts at Elapsed Time of:			
		1 Min.	30 Mins.	50 Mins.	60 Mins.**
2875-1-A	0.74	1.077	1.063	1.085	1.085
-12-D	1.22	1.074	1.075	1.077	1.078
-12-B	7.56	1.076	1.088	1.088	1.090
-12-C	9.62	1.072	1.083	1.083	1.082
-13-A	10.5	1.083	1.068	1.086	1.087
-11-A	18.34	0.920	1.029	1.037	1.039
-36-E	20.75	1.035	1.047	1.047	1.048
-38-E	28.4	1.035	1.069	1.067	1.065

* All values are negative.

** Sixty-minute values plotted in Figure 22.

TABLE 22. POTENTIAL-TIME DATA FOR ZINC-TIN ALLOYS,
MEASURED AT 90°F. IN DISTILLED WATER
SATURATED WITH CARBON DIOXIDE, SATURATED
CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	% Sn	Volts at Elapsed Time of:			
		1 Min.	30 Mins.	50 Mins.	60 Mins.**
2875--53-A-1	1.06	1.060	1.071	1.077	1.080
--53-B-1	3.44	1.061	1.076	1.084	1.086
--53-C-1	6.01	1.063	1.083	1.089	1.091
--53-D-1	9.98	1.068	1.091	1.093	1.093
--53-E-1	24.7	1.050	1.063	- -	1.070
--53-F-1	51.1	1.056	1.069	- -	1.078
--53-G-1	79.5	1.064	1.074	- -	1.076
--87-A-1	90.13	1.069	1.082	1.085	1.084
--87-B-1	95.3	1.061	1.061	1.046	1.019
--87-C-1	97.8	1.059	0.586	0.616	0.616

* All values are negative.

** Values at 60 minutes plotted in Figure 23.

TABLE 23. POTENTIAL-TIME DATA FOR CADMIUM-TIN ALLOYS,
AT 90°F., IN DISTILLED WATER SATURATED WITH
CARBON DIOXIDE, SATURATED CALOMEL SCALE,
VALUES IN VOLTS*

Specimen No.	% Sn	Volts at Elapsed Time of:			
		1 Min.	30 Mins.	50 Mins.	60 Mins.**
2875-55-A-1	1.01	0.708	0.733	0.739	0.740
-55-B-1	3.18	0.714	0.739	0.743	0.743
-55-C-1	5.46	0.708	0.739	0.742	0.743
-55-D-1	10.8	0.716	0.741	0.744	0.744
-55-E-1	25.2	0.711	0.734	0.737	0.738
-55-F-1	51.1	0.703	0.728	0.735	0.736
-55-G-1	75.2	0.695	0.724	0.729	0.729
-55-H-1	90.2	0.709	0.738	0.738	0.737
-55-I-1	94.9	0.711	0.731	0.731	0.729
-55-J-2	98.8	0.700	0.571	0.396	0.324

* All values are negative.

** Sixty-minute values are plotted in Figure 23.

TABLE 24. POTENTIAL-TIME DATA FOR CAST ZINC-SILVER AND
CADMIUM-SILVER ALLOYS, MEASURED AT 90°F. IN
DISTILLED WATER SATURATED WITH CARBON DIOXIDE,
SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	% Ag	Volts at Elapsed Time of:			
		1 Min.	30 Mins.	50 Mins.	60 Mins.**
(Zinc-Silver System)					
2875-62-A-1	1.02	1.066	1.082	1.082	1.082
--62-B-1	5.14	1.060	1.084	1.090	1.091
--62-C-1	17.8	1.074	1.085	1.088	1.089
--62-D-1	24.3	1.052	1.054	1.021	0.994
--62-E-1	37.2	0.996	0.139	0.119	0.123
--62-F-1	44.2	0.882	0.064	0.062	0.062
(Cadmium-Silver System)					
2875-60-A-1	1.24	0.711	0.736	0.739	0.740
--60-B-1	3.04	0.706	0.734	0.737	0.737
--60-C-1	7.95	0.702	0.731	0.740	0.741
--60-D-1	16.0	0.709	0.721	0.726	0.726
--60-E-2	18.65	0.661	0.625	0.622	0.618
--60-F-1	31.2	0.631	0.611	0.604	0.603

* All values are negative.

** Values for 60 minutes are plotted in Figure 24.

TABLE 25. POTENTIAL-TIME DATA FOR CAST CADMIUM-ZINC ALLOYS,
MEASURED AT 90°F. IN DISTILLED WATER SATURATED WITH
CARBON DIOXIDE, SATURATED CALOMEL SCALE, VALUES
IN VOLTS*

Specimen No.	% Cd	Volts at Elapsed Time of:			
		1 Min.	30 Mins.	50 Mins.	60 Mins.**
2875-57-A-1	99.09	1.015	- -	0.745	0.745
-57-F-1	97.65	1.045	0.727	0.758	0.755
-57-J-1	90.17	1.063	1.059	1.018	0.999
-57-D-1	74.4	1.066	1.089	1.088	1.087
-57-E-1	49.8	1.063	1.088	1.092	1.092
-57-F-1	25.1	1.072	1.090	1.095	1.095
-57-G-1	10.5	1.061	1.084	1.088	1.088
-57-H-1	3.3	1.061	1.081	1.087	1.088
-57-I-1	1.3	1.064	1.085	1.089	1.089

* All values are negative.

** Values for 60 minutes plotted in Figure 24.

TABLE 26. POTENTIAL-TIME DATA FOR CAST ZINC-INDIUM AND CADMIUM-INDIUM ALLOYS, MEASURED AT 90°F. IN DISTILLED WATER SATURATED WITH CARBON DIOXIDE, SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	In	Volts at Elapsed Time of:			
		1 Min.	30 Mins.	50 Mins.	60 Mins.**
(Zinc-Indium System)					
2875-71-A-1	1.2	1.058	1.085	1.091	1.093
-71-B-1	3.0	1.064	1.085	1.090	1.091
-71-C-1	6.8	1.069	1.085	1.089	1.090
-71-D-1	12.5	1.058	1.078	1.086	1.088
-71-E-1	19.0	1.061	1.084	1.092	1.093
-71-F-1	39.6	1.062	1.095	1.097	1.098
(Cadmium-Indium System)					
2875-70-A-1	1.1	0.638	0.667	0.684	0.692
-70-B-1	3.0	0.634	0.659	0.677	0.683
-70-C-1	7.0	0.610	0.641	0.654	0.660
-70-D-1	11.9	0.610	0.646	0.654	0.660
-70-E-1	19.7	0.620	0.640	0.651	0.656
-70-F-1	39.5	0.578	0.573	0.581	0.589

* All values are negative.

** Values for 60 minutes plotted in Figure 25.

TABLE 27. POTENTIAL-TIME DATA FOR CAST PURE METALS AND SAE
X-4130 STEEL IN 3 PER CENT SODIUM CHLORIDE SOLUTION
AT 90°F., SATURATED CALOMEL SCALE, VALUES IN VOLTS

Metal	Specimen No.	Volts at Elapsed Time of:				
		1 Min.	30 Mins.	50 Mins.	60 Mins.	160 Mins.
Zinc	2875-50-B	-1.048	-1.056	-1.060	-1.061	—
Zinc	—50-B	-1.045	-1.050	—	-1.055	—
Zinc	—88-A	-1.039	-1.059	-1.062	-1.064	—
Cadmium	—50-A	-0.793	-0.805	-0.808	-0.809	—
Tin	—73-B-1	-0.631	-0.458	-0.458	-0.457	—
Indium	—73-A	-0.721	-0.678	-0.685	-0.687	—
Titanium	3180-37-A	-0.373	-0.084	-0.006	+0.023	+0.091
Zirconium	—37-B	-0.210	+0.020	+0.083	+0.095	+0.140
Manganese	—37-C	-1.390	-1.317	-1.315	-1.316	-1.301
X-4130 steel	2875-33-A	-0.617	-0.713	-0.711	-0.711	—
Ditto	—33-B	-0.619	-0.709	-0.708	-0.707	—
"	—72-A	-0.609	-0.701	-0.698	-0.697	-0.707
"	—72-B	-0.590	-0.710	-0.707	-0.707	-0.707

TABLE 28. POTENTIAL-TIME DATA FOR PURE METALS, MEASURED
AT 90°F, IN DISTILLED WATER AND CARBON
DIOXIDE SATURATED WATER, SATURATED CALOMEL
SCALE, VALUES IN VOLTS*

Metal	Specimen No.	Volts at Elapsed Time of:					
		1 Min.	30 Mins.	50 Mins.	60 Mins.	75 Mins.	90 Mins.
(Distilled Water)							
Zinc	3180-5-B**				0.809	0.865	0.873
Cadmium	2875-50-A				0.545	0.505	0.450
Y-4130 steel	2875-99-A				0.718	0.719	0.712
X-4130 steel	2875-99-B				0.718	0.720	0.721
(Distilled Water Saturated With Carbon Dioxide)							
Zinc	2875-50-B	1.070	1.076	- -	1.079	- -	- -
Cadmium	2875-50-A	0.724	0.739	0.740	0.741	- -	- -
X-4130 steel	3180-18-A	0.610	0.677	0.686	0.690	- -	0.695
X-4130 steel	3180-18-B	0.630	0.683	0.691	0.693	- -	0.698

* All values are negative.

** Unmachined.

TABLE 29. POTENTIAL-TIME DATA FOR CAST ZINC AND CADMIUM SPECIMENS TREATED WITH THE CRONAK OR IRIDITE PROCESSES, IN 3 PER CENT SODIUM CHLORIDE SOLUTION AT 20°F., SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	Metal	Treatment	Volts at Elapsed Time of:					
			1 Min.	30 Mins.	50 Mins.	60 Mins.	24 Hrs.	48 Hrs.
3180-16-A	Zn	Cronak	1.063	1.055	1.048	1.045	--	--
--16-C	Zn	Iridite	1.064	1.074	1.075	1.075	--	--
--19-A	Cd	Cronak	0.786	0.762	0.737	0.733	--	--
--19-C	Cd	Iridite	0.786	0.778	0.776	0.774	--	--
--16-E	Zn	Cronak	1.080	1.053	1.053	1.052	1.052	1.069
--16-F	Zn	Iridite	1.067	1.051	1.048	1.050	1.062	1.065
--19-E	Cd	Cronak	0.788	0.789	0.776	0.770	0.768	0.779
--19-F	Cd	Iridite	0.790	0.787	0.778	0.779	0.774	0.777

* All values are negative.

TABLE 30. INITIAL AND 24-HOUR DYNAMIC POTENTIAL AND CORROSION CURRENT DATA FOR CAST ZINC AND CADMIUM SPECIMENS TREATED BY THE CRONAK OR IRIDITE PROCESSES. THESE SPECIMENS WERE COUPLED WITH STEEL AND IMMersed IN 3 PER CENT SODIUM CHLORIDE SOLUTION FOR 24 HOURS AT 90°F., SATURATED CALOMEL SCALE

Specimen No.	Metal	Treatment	Initial Measurements		24-Hour Measurements	
			Coupled Alloy (Volts)	Corrosion Current Density (Ma./In. ²)	Coupled Alloy (Volts)	Corrosion Current Density (Ma./In. ²)
3180-16-B	Zn	Cronak	1.043	0.69	1.055	0.65
-16-D	Zn	Iridite	1.034	0.72	1.052	0.55
-19-B	Cd	Cronak	0.743	0.13	0.729	0.26
-19-D	Cd	Iridite	0.758	0.22	0.737	0.25

TABLE 31. BATH COMPOSITIONS AND PLATING DATA
FOR ELECTRODEPOSITED ZINC-TIN ALLOYS

Alloy Composition, (Per Cent)	85 Zn- 15 Sn	59 Zn- 41 Sn	37 Zn- 63 Sn	20 Zn- 80 Sn	15 Zn- 85 Sn
Sn (as Na_2SnO_3) (g./l.)	7.5	30	30	30	30
Zn [as $\text{Zn}(\text{CH})_2$] (g./l.)	60	26	12	5	3
Total NaCN (g./l.)	197	101	53	32	26
Free NaOH (g./l.)	6	6	6	6	6
Temperature ($^{\circ}\text{F.}$)	160	160	160	160	160
Current density (Amps./sq. Ft.)	20	20	20	20	20
Minutes to Plate 0.001 inch	60	52	60	60	60

TABLE 32. BATH COMPOSITIONS AND PLATING DATA
FOR ELECTRODEPOSITED CADMIUM-SILVER
ALLOYS

Alloy Composition (Per Cent)	94 Cd-6 Ag	97 Cd-3 Ag
Cd/as Cd(CN) ₂ (g/l)	28	28
Ag(as Ag CN) (g/l)	1	0.5
Free NaCN	55	55
Total Na ₂ CO ₃	5	5
Total NaOH	3.75	3.75
Temperature (°F.)	90	90
Current density (Amps./Sq. Ft.)	15	15
Minutes to plate 0.001 inch	40	45

TABLE 33. POTENTIAL-TIME DATA FOR CAST ZINC-NICKEL ALLOYS,
MEASURED AT 90°F., IN 3 PER CENT SODIUM CHLORIDE
SOLUTION, DISTILLED WATER, AND DISTILLED WATER
SATURATED WITH CARBON DIOXIDE, SATURATED CALOMEL
SCALE, VALUES IN VOLTS*

Specimen No.	% Ni	Volts at Elapsed Time of:					
		1 Min.	30 Mins.	50 Mins.	60** Mins.	75 Mins.	90 Mins.
(3 Per Cent Sodium Chloride Solution)							
2875--83-A-1	0.03	1.032	1.047	1.050	1.050	--	--
--83-B-1	2.58	1.039	1.049	1.051	1.052	--	--
--83-D-1	11.44	1.027	1.048	1.049	1.049	--	--
--83-E-1	11.9	1.035	1.051	1.051	1.052	--	--
--83-G-1	47.2	0.334	0.398	0.401	0.402	--	--
(Distilled Water)							
2875--83-A-1	0.03				0.770	0.769	0.780
--83-B-1	2.58				0.882	0.885	0.905
--83-D-1	11.44				0.852	0.807	0.775
--83-E-1	11.9				0.870	0.901	0.875
--83-G-1	47.2				0.145	0.134	0.125
(Distilled Water Saturated With Carbon Dioxide)							
2875--83-A-1	0.03	1.055	1.061	1.060	1.063		
--83-B-1	2.58	1.068	1.093	1.091	1.088		
--83-D-1	11.44	1.053	1.073	1.076	1.077		
--83-E-1	11.9	1.062	1.072	1.073	1.074		
--83-G-1	47.2	0.473	0.501	0.511	0.514		

* All values are negative.

** 60-minute values plotted in Figure 26.

TABLE 34. POTENTIAL-TIME DATA FOR CAST CADMIUM-NICKEL ALLOYS, MEASURED AT 90°F, IN 3 PERCENT SODIUM CHLORIDE SOLUTION, DISTILLED WATER, AND DISTILLED WATER SATURATED WITH CARBON DIOXIDE, SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	% Ni	Volts at Elapsed Time of:					
		1 Min.	30 Mins.	50 Mins.	60** Mins.	75 Mins.	90 Mins.
(3 Per Cent Sodium Chloride Solution)							
3180-14-A	0.84	0.814	0.817	0.816	0.815	-	0.810
-14-B	2.75	0.813	0.813	0.816	0.815	-	0.808
(Distilled Water)							
3180-14-A	0.84				0.516	0.490	0.474
-14-B	2.75				0.534	0.514	0.488
(Distilled Water Saturated With Carbon Dioxide)							
3180-14-A	0.84	0.723	0.734	0.737	0.737		
-14-B	2.75	0.712	0.722	0.727	0.729		

* All values are negative.

** 60-minute values plotted in Figure 27.

TABLE 35. POTENTIAL-TIME DATA FOR CAST ZINC-LEAD ALLOYS. MEASURED AT 90°F., IN 3 PER CENT SODIUM CHLORIDE SOLUTION, DISTILLED WATER, AND DISTILLED WATER SATURATED WITH CARBON DIOXIDE. SATURATED CALOMEL SCALE, VALUES IN VOLTS.*

Specimen No.	% Pb	Volts at Elapsed Time of:					
		1 Min.	30 Mins.	50 Mins.	60 Mins.**	75 Mins.	90 Mins.
(3 Per Cent Sodium Chloride Solution)							
3180—29-D-1	0.52	1.038	1.049	1.051	1.051	—	1.054
2875—86-A-1	1.04	1.030	1.045	1.040	1.039	—	1.039
—86-I-1	99.05	0.929	0.848	0.830	0.820	—	0.794
(Distilled Water)							
3180—29-D-1	0.52				0.852	0.892	0.872
2875—86-A-1	1.04				0.761	0.788	0.811
—86-I-1	99.05				0.549	0.550	0.553
(Distilled Water Saturated With Carbon Dioxide)							
3180—29-D-1	0.52	1.067	1.090	1.089	1.089	—	—
2875—86-A-1	1.04	1.060	1.071	1.062	1.057	—	—
—86-I-1	99.05	0.575	0.501	0.492	0.489	—	—

* All values are negative.

** 60-minute values plotted in Figure 28.

TABLE 36. POTENTIAL-TIME DATA FOR CAST CADMIUM-LEAD ALLOYS, MEASURED AT 90°F., IN 3 PER CENT SODIUM CHLORIDE SOLUTION, DISTILLED WATER, AND DISTILLED WATER SATURATED WITH CARBON DIOXIDE. SATURATED CALOMEL SCALE, VALUES IN VOLTS.*

Specimen No.	% Pb	Volts at Elapsed Time of:					
		1 Min.	30 Mins.	50 Mins.	60 Mins. ^{***}	75 Mins.	90 Mins.
(3 Per Cent Sodium Chloride Solution)							
3180-29-A-1	2.08	0.808	0.812	0.813	0.812	—	0.811
—29-B-1	6.22	0.800	0.812	0.811	0.810	—	0.806
—29-C-1	13.1	0.774	0.809	0.808	0.808	—	—
(Distilled Water)							
3180-29-A-1	2.08				0.364	0.395	0.408
—29-B-1	6.22				0.386	0.421	0.436
—29-C-1	13.1				0.400	0.500	0.498
(Distilled Water Saturated With Carbon Dioxide)							
3180-29-A-1	2.08	0.717	0.741	0.741	0.742	—	—
—29-B-1	6.22	0.714	0.743	0.742	0.743	—	—
—29-C-1	13.1	0.715	0.746	0.745	0.746	—	—

* All values are negative.

** 60-minute values plotted in Figure 29.

TABLE 37. POTENTIAL-TIME DATA FOR CAST ZINC-CHROMIUM ALLOYS, MEASURED AT 90°F, IN 3 PERCENT SODIUM CHLORIDE SOLUTION, DISTILLED WATER, AND DISTILLED WATER SATURATED WITH CARBON DIOXIDE, SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	Zn Cr	Volts at Elapsed Time of:					
		1 Min.	30 Mins.	50 Mins.	60** Mins.	75 Mins.	90 Mins.
(3 Per Cent Sodium Chloride Solution)							
3180-63-A-1	0.43	1.015	1.033	1.034	1.035	-	1.036
-63-B-1	2.04	1.018	1.035	1.035	1.036	-	1.036
-63-C-1	5.36	1.020	1.035	1.035	1.035	-	1.036
(Distilled Water)							
3180-63-A-1	0.43				0.792	0.820	0.832
-63-B-1	2.04				0.733	0.785	0.789
-63-C-1	5.36				0.725	0.772	0.804
(Distilled Water Saturated With Carbon Dioxide)							
3180-63-A-1	0.43	1.055	1.052	1.055	1.056	-	-
-63-B-1	2.04	1.043	1.055	1.059	1.061	-	-
-63-C-1	5.36	1.047	1.053	1.057	1.058	-	-

* All values are negative.

** 60-minute values plotted in Figure 30.

TABLE 38. POTENTIAL-TIME DATA FOR CAST ZINC-MANGANESE ALLOYS,
MEASURED AT 90°F., IN 3 PER CENT SODIUM CHLORIDE
SOLUTION, DISTILLED WATER, AND DISTILLED WATER
SATURATED WITH CARBON DIOXIDE. SATURATED CALOMEL
SCALE, VALUES IN VOLTS*

Specimen No.	% Mn	Volts at Elapsed Time of:					
		1 Min.	30 Mins.	50 Mins.	60 Mins.**	75 Mins.	90 Mins.
(3 Per Cent Sodium Chloride Solution)							
3180-60-A-1	1.65	1.036	1.056	1.058	1.059	---	---
---60-B-1	3.04	1.037	1.055	1.057	1.057	---	---
---60-C-1	5.18	1.036	1.056	1.057	1.058	---	---
---60-D-1	9.60	1.040	1.059	1.060	1.061	---	---
(Distilled Water)							
3180-60-A-1	1.65	---	---	---	0.869	0.885	0.912
---60-B-1	3.04	---	---	---	0.844	0.858	0.868
---60-C-1	5.18	---	---	---	0.826	0.852	0.852
---60-D-1	9.60	---	---	---	0.845	0.855	0.869
(Distilled Water Saturated With Carbon Dioxide)							
3180-60-A-1	1.65	1.076	1.063	1.069	1.071	---	---
---60-B-1	3.04	1.065	1.062	1.065	1.066	---	---
---60-C-1	5.18	1.062	1.060	1.063	1.064	---	---
---60-D-1	9.60	1.066	1.056	1.059	1.060	---	---

* All values are negative.

** Sixty-minute values are plotted in Figure 31.

TABLE 39. POTENTIAL-TIME DATA FOR ELECTRODEPOSITED ZINC-TIN, CADMIUM-SILVER, AND ZINC-LEAD ALLOYS, MEASURED AT 90°F, IN 3 PERCENT SODIUM CHLORIDE SOLUTION, SATURATED CALOMEL SCALE, VALUES IN VOLTS*

Specimen No.	% Sn	Volts at Elapsed Time of:			
		1 Min.	30 Mins.	50 Mins.	60 mins.**
(Zinc-Tin)					
3942-23-A	15	1.043	1.067	1.070	1.070
—22-A	41	1.032	1.053	1.058	1.059
—16-A	63	1.006	1.013	1.022	1.023
—14-A	80	1.010	0.982	0.974	0.980
—15-A	85	0.953	0.802	0.795	0.779
(Cadmium-Silver)					
	% Ag				
3942-20-H	2.95	0.814	0.822	0.824	0.825
—21-E	5.75	0.822	0.826	0.826	0.826
(Zinc-Lead)					
	% Pb				
3363-20-C	17.7	1.033	1.050	1.051	1.052
—21-B	13.3	1.030	1.060	1.062	1.062

* All values are negative.

** 60-minute values for Zinc-Tin alloys are plotted in Figure 32.

TABLE 40. POTENTIAL-TIME DATA FOR ELECTRODEPOSITED
POROUS ZINC AND MANGANESE, MEASURED AT
90°F., IN 3 PER CENT SODIUM CHLORIDE
SOLUTION. SATURATED CALOMEL SCALE.
VALUES IN VOLTS*

Specimen No.	Treatment	Volts at Elapsed Time of:			
		1 Min.	30 Mins.	50 Mins.	60 Mins.
(Porous Zinc)					
3942—10-A	None	1.049	1.063	1.070	1.073
—10-H	Oiled	1.021	1.030	1.029	1.031
—10-D	Cronak	1.035	1.041	1.039	1.037
—10-J	Iridite	1.035	1.047	1.048	1.048
(Manganese)					
3180—48-A	**	1.317	1.292	1.282	1.279
—48B	None	1.389	1.312	1.297	1.292

* All values are negative.

** Thirty-second dip in 5 per cent $\text{Na}_2\text{Cr}_2\text{O}_7$ solution at room temperature

TABLE 41. INITIAL AND 24-HOUR DYNAMIC POTENTIAL AND CORROSION CURRENT DATA FOR CAST ZINC-NICKEL, CADMIUM-NICKEL, AND ZINC-CHROMIUM ALLOYS COUPLED WITH STEEL. COUPLES IMMERSSED IN 3 PERCENT SODIUM CHLORIDE SOLUTION AT 90°F, FOR THE 24-HOUR PERIOD. SATURATED CALOMEL SCALE

Specimen No.	%Ni	Initial Measurements		24-Hour Measurements	
		Coupled Alloy (Volts)	Corrosion	Coupled Alloy (Volts)	Corrosion
			Current Density (Ma./In. ²)		Current Density (Ma./In. ²)
(Zinc-Nickel Alloys)					
2875--83-A-1	0.03	1.050	0.75	1.057	0.55
--83-B-1	2.58	1.043	0.71	1.056	0.47
--83-D-1	11.44	1.043	0.65	0.961	0.38
--83-E-1	11.9	1.040	0.54	0.913	0.29
--83-G-1	47.2	*	*	*	*
(Cadmium-Nickel Alloys)					
3180--14-A-1	0.84	0.793	0.23	0.735	0.22
--14-B-1	2.75	0.795	0.17	0.718	0.25
(Zinc-Chromium Alloys)					
	<u>%Cr</u>				
3180--63-A-1	0.48	1.022	0.67	1.044	0.57
--63-B-1	2.04	1.029	0.64	1.044	0.55
--63-C-1	5.36	1.022	0.64	1.045	0.43

*Alloy was more noble than steel. No dynamic measurements were made.

TABLE 42. INITIAL AND 24-HOUR DYNAMIC POTENTIAL AND CORROSION CURRENT DATA FOR CAST ZINC-LEAD, CADMIUM-LEAD, AND ZINC-MANGANESE ALLOYS COUPLED WITH STEEL. COUPLES IMMERSSED IN 3 PERCENT SODIUM CHLORIDE SOLUTION AT 90°F, FOR THE 24-HOUR PERIOD. SATURATED CALOMEL SCALE

SCALE

Specimen No.	%Pb	Initial Measurements		24-Hour Measurements	
		Coupled Alloy (Volts)	Corrosion Current Density (mA./In. ²)	Coupled Alloy (Volts)	Corrosion Current Density (mA./In. ²)
(Zinc-Lead Alloys)					
3180--29-D-1	0.52	1.052	0.81	1.053	0.55
2875--86-A-1	1.04	1.037	0.58	1.050	0.52
--86-I-1	99.05	0.687	0.00	*	*
(Cadmium-Lead Alloys)					
3180--29-A-1	2.08	0.788	0.32	0.728	0.23
--29-B-1	6.22	0.789	0.31	0.727	0.25
--29-C-1	13.1	0.787	0.29	0.733	0.22
(Zinc-Manganese Alloys)					
	<u>%Mn</u>				
3180--60-A-1	1.65	1.040	0.79	1.031	0.68
--60-B-1	3.04	1.038	0.82	1.039	0.59
--60-C-1	5.18	1.039	0.74	1.025	0.53
--60-D-1	9.60	1.040	0.74	1.041	0.62

No dynamic measurements were made.

*Alloy was more noble than steel. No dynamic measurements were made.

APPENDIX IV

This Appendix contains the Bibliography resulting from the literature survey.

BIBLIOGRAPHY

In the following list of references, those which have been examined in abstract form have the abstract reference as well as the original reference. The symbol CA stands for Chemical Abstracts.

1. "Über die Chemischen und Electrochemischen Eigenschaften von Kupfer - Zink Legierungen, die in Schmelzprozess und auf Electrolytischen Wege Erhalten Werden", F. Sauerwald, Z. Anorg. Chem., 111, 243 (1920)
2. "A Textbook of Metallurgy", G. Tamman, pp. 329-345, Chemical Catalog Co., N. Y. (1925)
3. "Structure of Alloys Deposited by Electrolysis - II Copper-Zinc Alloys", E. Raub and D. Krause. Z. Electrochem., 50, 91 (1944)
Met. Abst., 13, 217 (1946)
4. "The Structure of the Galvanic - Precipitation Alloys - I Silver-Lead Alloys", E. Raub and A. Engel, Z. Electrochem., 49, 89, (1943), C.A., 37, 5005 (1943)
5. "Constitution of Lead-Silver Alloys", A. J. Dornblatt, ASM Metals Handbook, 1939 edition, pp. 1523-1524.
6. "The Principles of Applied Electrochemistry", A. J. Allmand and H. J. T. Ellingham, Longmans Green and Co. (1924)

7. "Metallography", C. Desch, p. 277, Longmans Green and Co. (1922)
8. "Industrial Electrochemistry", C. L. Mantell, p. 145, McGraw-Hill (1931)
9. "Electrode Potentials of Iron - Manganese Alloys", C. Wells and J. C. Warner, Trans. Electrochem. Soc., 62, 145 (1932)
10. "Constitution of Iron - Manganese Alloys", V. N. Krivobok and C. Wells, ASM Metals Handbook, 1939 edition, p. 380.
11. "The Measurement of Irreversible Potentials as a Metallurgical Research Tool", R. H. Brown, W. L. Fink, and M. S. Hunter. Trans. AIME, 143, 115 (1941)
12. "Brass Plating", H. P. Coats, Trans. Electrochem. Soc., 80, 445 (1941)
13. "Relations Between Crystal Structure and Corrosion", G. Derge, Trans. Electrochem. Soc., 75, 449 (1939)
14. "The Corrosion of Alloys and its Connection With the Constitutional Diagram", E. I. Gurovich, Trudy Vtoroi Konferentsii Korozii Metallov, 1, 95 (1940), CA, 37, 5937 (1943)

15. "Theoretical and Applied Electrochemistry", M. de K Thompson, Macmillan (1939)
16. "Metallic Corrosion Passivity and Protection", U. R. Evans, Longmans Green and Co. (1946)
17. "The Structure of Metals and Alloys", W. Hume - Rothery, Institute of Metals (Lond.) Monograph No. 1 (1945)
18. "The Electrochemistry of Corrosion", R. H. Brown and R. B. Mears, Trans. Electrochem. Soc., 74, 495 (1938)
19. "A Theory of Cathodic Protection", R. B. Mears and R. H. Brown, Trans. Electrochem. Soc., 74, 519 (1938)
20. "Causes of Corrosion Currents", R. B. Mears and R. H. Brown, Ind. Eng. Chem., 33, 1001 (1941)
21. "Cathodic Protection", R. H. Brown and R. B. Mears, Trans. Electrochem. Soc., 81, 455 (1942)
22. "Relation Between the Resistance of Metals to Corrosion and the Potential Assumed by Them in Solution", F. Arbitrio, Chimica e Industria, 20, 791 (1938), QA 33, 3317 (1939)
23. "Basic Principles of Corrosion", C. W. Borgmann, "Corrosion of Metals", ASM (1946)

24. "Corrosion of Light Metals", E. H. Dix, "Corrosion of Metals", ASM (1946)
25. "The Electrode Potential Behavior of Corroding Metals in Aqueous Solutions", O. Gatty and E. C. R. Spooner, Clarendon Press (1938)
26. "The Corrosion of Metals ", R. M. Burns, Bell System Tech. Jnl., 15, 20 (1936)
27. "Mechanism of Corrosion Processes", R. M. Burns, ASTM Bull. No. 126, p. 17, Jan. (1944)
28. "The Electrochemistry of Protective Metallic Coatings", T. P. Hoar, Jnl. Electrodep. Tech. Soc., 14, 33 (1938)
29. "Overvoltage and its Significance in Corrosion", S. Glasstone, Corrosion and Material Protection, 3, 15 (1946)
30. "Corrosion Resistant Alloys", H. W. Gillett, ASTM Symposium on Protecting Metals Against Corrosion, Detroit (1938)
31. "Galvanic Corrosion", R. H. Brown, ASTM Bull. No. 126, p. 21, Jan. (1944)
32. "Fundamental Factors in Corrosion Control", H. H. Uhlig, Chem. and Eng. News, 24, 3155 (1946)

33. "The Velocity of Corrosion from the Electrochemical Standpoint - Pt. II", U. R. Evans and T. P. Hoar, Proc. Royal Soc. (A), 137, 343 (1932)
34. "The Effect of Cathodic Reactions on the Corrosion of Metals from the Viewpoint of the Local Cell Theory", W. J. Moller, Trans. Electrochem. Soc., 76, 167 (1939)
35. "Corrosiveness of Water to Metals, I", T. R. Camp, Jnl. New Eng. Water Works Assn., 60, 188 (1946), CA 40, 6397 (1946)
36. "The Passivity of Metals - Pt. V. The Potential-Time Curves of Some Iron Alloys", L. C. Bannister and U. R. Evans, Jnl. Chem. Soc., 113, 1361 (1930)
37. (a) "Handbook of Chemistry and Physics", C. D. Hodgman, Chemical Rubber Publishing Co., 24th ed., p. 1398
- (b) "Handbook of Chemistry", N. A. Lange, Handbook Publishers, Inc. (1944), p. 1094.
- (c) cf. Ref. 15.
38. "The Deterioration of Material in the Tropics", W. G. Hutchinson, Scientif. Monthly, 63, 165, Sept. (1946)
39. "Corrosion in the Tropics", G. W. Grupp, Metal Finishing, 43, 326 (1945)

40. "Tropical Deterioration of Air Force Materiel and Equipment",
Report of Army Air Forces Tropical Science Mission, WF-0-29 Nov. (1946)

41. "Tropicalization News", Issues 1, 2, and 3. Trop. Deterioration
Center, Geo. Washington Univ., Wash., D. C.

42. "Official Summary Technical Report", Over-all Activities of the
Tropical Deterioration Administrative Committee. Office of Publications
Board, U. S. Dept. Commerce, Wash. 25, D. C.

43. "Atmospheric Corrosion of Metals", W. H. J. Vernon, Soc. Chem.
Ind., Chem. Eng. Group, Proc., 19, 14 (1937), CA 34, 4717 (1940)

44. "Corrosion Stability of Electrolytic Zinc Coatings", M. Schlötter,
Stahl und Eisen, 60, 724 (1940), CA 36, 3139 (1942)

45. "Corrosion of Zinc in Distilled Water Alone or in Presence of a
Gaseous Atmosphere", I. Taboury and E. Gray, Compt. Rend. 205, 985 (1937),
CA 32, 898 (1938)

46. "The Behavior of Zinc in Sodium Chloride Solutions and in Sea
Water at Atmospheric Conditions", G. Schikorr, Z. Metallkunde, 32, 314
(1940), CA 36, 2831 (1942)

47. "The Influence of the Deliquescence of the Corrosion Product in
Determining Corrosion in a Stevenson Screen", J. C. Hudson, Trans. Far.
Soc., 25, 204 (1929)

48. "Corrosion of Zinc from the Viewpoint of the Battery Chemist",
C. Drottschmann, Korrosion und Metallschutz, 19, 188 (1943), CA 40, 6347
(1943)

49. "The Behavior of Zinc Subjected to Atmospheric Conditions",
E. Deiss, Wiss. Abhandl. Deut. Materialprüfungs - Anstalt, 2, 31 (1941),
CA 37, 4676 (1943)

50. "The Use of Zinc and Zinc Alloys with Special Reference to
Corrosion", K. Bayer, Chem. Fabrik (1940) p. 384, CA 35, 1014 (1941)

51. "Electroplated Zinc Coatings from Acid and Alkaline, Dull, and
Bright Baths. Effect of the Structure of Zinc Coatings Upon Their
Behavior Against Corroding Influences", M. Schlötter and H. Schmellenmaier,
Korrosion und Metallschutz, 17, 117 (1941), CA 35, 7838 (1941)

52. "Corrosion of Zinc and Chromium Plated Iron", E. Raub, Z.
Metallkunde, 32, 105 (1940), CA 35, 2102 (1941)

53. "Anomalies in the Rate of Corrosion of Zinc", J. E. Maconachie.
Trans. Electrochem. Soc., 66, 217 (1934)

54. "Corrosion of Galvanized Coatings and Zinc by Waters Containing
Free Carbon Dioxide", L. Kenworthy and M. D. Smith, Int. Inst. Metals,
70, 464 (1944)

55. "Effect of Temperature on the Corrosion of Zinc", G. L. Cox,
Ind. Eng. Chem., 23, 902 (1931)

56. "Fifth Corrosion Report of the Corrosion Committee of the Iron and Steel Institute", (Lond.) 1938.

57. "The Corrosion of Zinc in Chloride Solutions", C. W. Borgman and U. R. Evans, Trans. Electrochem. Soc., 65, 249 (1934)

58. "Corrosion Resistance of Zinc Alloys", Louis Light, Metal-lurgia, 22, 136 (1940), CA 35, 7922 (1941)

59. "The Effect of Copper on Hot Dip Zinc Coatings", W. Imhoff, Wire and Wire Products, 17, 391 (1942), CA 36, 6488 (1942)

60. "Galvanizing", W. Eckardt, Korrosion und Metallschutz, 17, 401 (1941), CA 36, 5124 (1942)

61. "Effect of Foreign Constituents on the Corrosion of Zinc", A. I. Samokhotskii and A. P. Byudov, Vestnik Metalloprom., 15, No. 12, 122 (1935), CA 31, 2155 (1937)

62. "Solubility of Zinc in Sulfuric Acid", F. W. Harris, Trans. Electrochem. Soc., 57, 313 (1930)

63. "Testing Electrolytic Coatings on Iron Under Natural Atmospheric Conditions", Y. L. Vertsman, Vestnik Metalloprom., 18, No. 7, 107 (1938), CA 33, 2465 (1939)

64. "Corrosion Resistance of Cadmium and Zinc Electrodeposits Under Marine Conditions", A. Mankowich, Monthly Review, Am. Electroplaters' Soc., 27, 833 (1940)
65. "Salt-spray Corrosion Tests on Electrically Deposited Zinc-Cadmium Alloys", L. E. Stout and C. L. Faust, Metl. Ind. (N. Y.) 28, 381 (1930)
66. "Corrosion Resistance of Zinc-Cadmium Alloys", N. S. Gorbunov, Compt. Rend. Acad. Sci. U.R.S.S., 27, 228 (1940), CA 34, 7270 (1940)
67. "The Stability Toward Sea and River Water of Metallic Coatings Applied to Steel by Atomizing", I. Y. Klinov, J. App. Chem. (U.S.S.R.) 10, 1366 (1937), CA 32, 1636 (1938)
68. "Outdoor Atmospheric Corrosion of Zinc and Cadmium Electrodeposited Coatings on Iron and Steel", C. L. Hippensteel and C. W. Borgmann, Trans. Electrochem. Soc., 58, 23 (1930)
69. "Study of the Deposition Potentials and Microstructures of the Electrodeposited Nickel-Zinc Alloys", B. Lustman, Trans. Electrochem. Soc., 84, 363 (1943)
70. "Indium", W. S. Murray, Proc. Am. Electroplaters' Soc. (1942) p. 99.
71. "Intercrystalline Corrosion of Zinc III", K. Lohberg, Z. Metallkunde, 34, 73 (1942), CA 37, 6237 (1943)

72. "Intercrystalline Corrosion of Zinc Alloys", G. Petrich and W. Wolf, Z. Metallkunde, 32, 412 (1940), CA 36, 2831 (1942)
73. "Corrosion Resistance of Steel Electroplated with Zinc and Zinc-Mercury Alloys", C. J. Wernlund, Trans. Electrochem. Soc., 45, 273 (1924)
74. "Diffused Nickel-Zinc Coatings", Geo. Black, Metal Finishing, 44, 207 (1946)
75. "Diffusion Coatings on Metals", F. N. Rhines, ASM Preprint No. 46, Oct. (1940)
76. "The Corrosion Resistance of Experimental Zinc-Base Die Cast Alloys", L. Koch, Metallwirtschaft, 20, 841 (1941), CA 36, 4464 (1942)
77. "Bright Alloy Plating", Anon., Steel, 118, 105, Feb. 25 (1946)
78. "Developments in Tin and Tin Alloy Coatings", E. S. Hedges, Chem. and Ind., p. 370 (1945), CA 40, 2075 (1946)
79. "Corrosion Resisting Properties of Electrodeposited Tin-Zinc Alloys", R. M. Anglee and R. Kerr, Tin Research Inst. Engineering, 161, 289 (1946), Abstract - Corrosion 2, 37, Sept. (1946)
80. "The Corrosion of Cadmium - Antimony Alloys", M. G. Yartsev, Sbornik Nauch. - Issledovatel. Rabot Kuibyshev. Ind. Inst., p. 97 (1940), CA 37, 5688 (1943)

81. "The Magnitude of the Protection from Corrosion Afforded Zinc by Amalgamation", C. Drotschmann, Batterien, 9, 36 (1940), CA 37, 5359 (1943)
82. "Nickel-Zinc Corronizing", L. G. Conradi, Corrosion and Material Protection, 3, No. 7, p. 12 (1946), CA 40, 7133 (1946)
83. "Corrosion of Binary Alloys", R. Landau and C. S. Oldach, Trans. Electrochem. Soc., 81, 521 (1942)
84. "The Corrosion of Tin. I - Potential Measurements of High Purity Tin in Carbonate Solutions", G. Derge, AIME, Inst. Metals Div., Tech. Publ. No. 913 (1938)
85. "The Protective Value of Lead and Lead - Tin Deposits on Steel", A. H. DuRose, Trans. Electrochem. Soc., Preprint 89-7 (1946)
86. "Corrosion of Lead - Indium Diffusion Alloys", J. M. Freund, et al., Trans. Electrochem. Soc. 84, 65 (1943)
87. "The Binary Alloys of Indium and Tin", C. G. Fink, et al., Trans. Electrochem. Soc., 75, 463 (1939)
88. "Properties of Some New Manganese Alloys of Probable Commercial Significance", C. T. Anderson, Conf. Met. Research, Met. Div., Bur. Mines (Salt Lake City), CA 34, 5034 (1940)

89. "Metal Finishing for Military Aircraft", F. R. Irwin and J. Teres, Proc. Am. Electroplaters' Soc. (1942), p. 134.

90. "Dissimilar Metal Couples - Corrosion Resistance from Current and Potential Measurements", M. R. Whitmore and J. Teres, Ind. Eng. Chem., 31, 608 (1939)

91. "Tidewater and Weather Exposure Tests on Metals Used in Aircraft, II", W. Mutchler and W. G. Galvin, NACA Tech. Note No. 842, CA 40, 7113 (1946)

92. "Corrosion of Metals Used in Aircraft", W. Mutchler, Jnl. Research, Natl. Bur. Stds., 25, 75 (1940)

93. "Report of Subcommittee VIII (B3) on Galvanic and Electrolytic Corrosion", L. J. Gorman, et al., Proc. ASTM, 39, 247 (1939)

94. "Properties of Plated Lead Coatings on Steel", G. Soderberg, Proc. ASTM, Preprint No. 30 (1943)

95. "The Atmospheric Corrosion Resistance and Protective Value of Metallic Coatings", S. G. Clarke, Jnl. Electrodep. Tech. Soc., 15, 141 (1939)

96. "Treating Zinc and its Alloys", L. Netter, German Pat. 711,947, CA 37, 4357 (1943)

97. "Anodic Oxidation of Zinc and its Alloys - Details of an Improved Anodic Process", H. Fischer and N. Budiloff, Metal Ind., (Lond.) 57, 222 (1940), CA 35, 984 (1941)
98. "Electrolytic Treatment of Zinc", J. Schulein Trans. Electrochem. Soc., 66, 223 (1934)
99. "Cadmium Plate and Passivated Cadmium Plate Coatings", E. E. Halls, Metallurgia 34, No. 204, p. 295, Oct. (1946)
100. "The Iridite Process", A. G. Taylor, Proc. Am. Electroplaters' Soc., June (1944), p. 6.
101. "Chromate Passivation of Zinc and Cadmium Surfaces", Frank Taylor, Metallurgia 30, 275 (1944)
102. "Tests on Iridite Finish for Cadmium and Zinc Plated Steel", K. F. Dorcas and N. H. Simpson, Iron Age, 156, No. 4, 61, 143 (1945), CA 39, 4576 (1945)
103. "Zinc Yellow in the Inhibition of Corrosion Fatigue of Steel in Sodium Chloride Solution", C. G. Fink, et al, Trans. Electrochem. Soc., 83, 377 (1943)
104. "Treatment of Electrodeposited Zinc Coatings", Brit. Pat. 514,814, R. O. Hull to E. I. du Pont de Nemours Co., CA 35, P2848 (1941)

105. "Laws Governing the Growth of Films on Metals", U. R. Evans, Trans. Electrochem. Soc., 83, 335 (1943)
106. "Study of Atmospheric Oxidation of Metals and Alloys at Different Temperatures by Electron Diffraction", M. Bound and D. A. Richards, Proc. Phys. Soc., (Lond.) 51, 256 (1939), CA 33, 4567 (1939)
107. "The Structure of Magnesium, Zinc, and Aluminum Films", G. I. Finch and A. G. Quarrell, Proc. Roy. Soc. (A) 141, 398 (1933)
108. "Crystal Structure and Orientation in Zinc Oxide Films", G. I. Finch and A. G. Quarrell, Proc. Phys. Soc., 46, 148 (1934)
109. "Electron Diffraction Examination of Metals", M. L. Fuller, Met. and Alloys, 10, 85, 122 (1939)
110. "Corrosion of Zinc", M. L. Fuller and E. A. Anderson, Met. and Alloys, 10, 282 (1939)
111. "An Electron Diffraction Study of Oxide Films Formed on Alloys", J. W. Hickman and E. A. Gulbranson, Metals Tech., Tech. Paper 2069, Oct. (1946)
112. "Corrosion Products of Tin and Lead-Tin Alloys", J. A. Smythe, Jnl. Inst. Metals, 66, Pt. 10, 355 (1940)
113. "X-Ray Analysis of Corrosion Products from Galvanized Sheets", F. R. Morral, Trans. Electrochem. Soc., 77, 279 (1940)

114. "The Vapor Pressure of Glycerin Solutions at 20°C.", Jnl. Soc. Chem. Ind., Trans., 52, Pt. 3, 175 (1940)
115. "Measuring Stray Currents in Underground Pipes", C. Hering, Trans. Am. Inst. Elec. Eng., 31 (Pt. II), 1449 (1912)
116. "Electrochemical Measurements for Corrosion Studies", P. T. Gilbert, Jnl. Sci. Instruments, 22, 235 (1945)
117. "The Mechanism of Electrode Potentials", H. L. S. Britton, Jnl. Sci. Instruments, 23, 89 (1946)
118. "Bibliography of Corrosion Testing Methods, 1935 - 1945", L. Voigt, Corrosion, 2, No. 5, p. 16 of news section (1946)
119. "The Nature of Passivity in Stainless Steels and Other Alloys - III Time-Potential Data for Cr - Ni, and Cr - Ni - Mo Steels", H. H. Uhlig, Trans. AIME, 140, 387 (1940)
120. "Das Potential und die Chemische Konstitution der Metall Legierungen", N. Puschin, Z. Anorg. Chem., 56, 1 (1907-08)
121. "The Constitution of Copper - Zinc and Copper - Tin Alloys", A. P. Lourie, Jnl. Chem. Soc., 53, 104 (1888)
122. "The Alloys of Lead, Tin, Zinc, and Cadmium", A. P. Laurie, Jnl. Chem. Soc., 55, 677 (1889)

123. "The Electromotive Force of Alloys in a Voltaic Cell", A. P. Laurie, Jnl. Chem. Soc., 65, 1031 (1894)

124. "Elevated Temperature Tension Tests on Galvanized Steels", J. H. Craig, ASTM - AIME Symposium on Stress Corrosion (1944)

125. "Alloy Plating", C. L. Faust, Modern Electroplating, Electrochem. Soc. (1942)

CLF:LB