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technical note

STUDY OF THE COMPATIBILITY OF FLOATING-TYPE INHIBITORS AND
CATHODIC PROTECTION

E. R. Streed

FC

U. S. Naval Civil Engineering Research and Evaluation Laboratory
Port Hueneme, California

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SUMMARY

A controlled study of two proprietary floating-type corrosion inhibitors and cathodic protection for use in floating drydock ballast tanks is described in this report.

Test coupon results after exposure for one year indicate that a floating-type inhibitor can effectively retard corrosion in the wet-and-dry and dry zones and will provide at least temporary protection in the wet zone. Cathodic protection, effective only on a submerged surface, is shown to achieve a 70-per cent reduction in corrosion under severe exposure conditions. Cathodic currents were reduced by a factor of five when used with a floating inhibitor. No serious interference was detected when the two methods were used together.

A comprehensive field-testing program is recommended to correlate laboratory studies and in-service results.

INTRODUCTION

The magnitude of corrosion and corrosion mitigation measures for fuel and ballast compartments of floating equipment has exacted considerable study by both government and private organizations.^{1,2} This problem has been encountered by the Bureau of Yards and Docks in the maintenance of the ballast compartments of floating drydocks. The drydocks usually operate in sea water and are located in many parts of the world.

The interior of the compartments can be classified into three zones as follows: (1) wet (permanently submerged), (2) wet-and-dry (wet or dry, dependent upon the water level during normal operation of the drydock), and (3) dry (above the normal high water level). Corrosion is extensive throughout the interior of the drydock compartments. Although no quantitative data are available on corrosion rates in the respective zones, visual inspection of interior stiffeners has indicated that the wet-and-dry and the dry zones may actually suffer the most corrosion. It has been reported that the upper portions of tanker compartments carrying fuel and sea water ballast are more susceptible than the permanently submerged areas.³ A serious result of this rusting is the weakening of structural members and the pitting of internal piping.

The complex structure of the compartments and the poor accessibility of certain areas make proper surface cleaning and recoating difficult, costly, and time-consuming. Therefore, to obviate the problems associated with manually-applied coatings, less costly and more permanent methods of inhibition are being investigated. Individual experimental applications of cathodic protection⁴ and floating-type inhibitors,^{5,6} in use for several years by the Bureau of Yards and Docks, have shown promising results. However, limitations inherent in each method do not always permit optimum protection of all areas of the compartments.

The purpose of this investigation was to determine the compatibility and comparative effectiveness of two proprietary, floating-type organic inhibitors, and cathodic protection techniques for sea water ballast compartments of floating drydocks. The study was conducted under Project NY 450 004, Corrosion Prevention and Special Coatings, Subtask 4, Cathodic Protection. The primary objective of this subtask is to develop satisfactory methods for employing cathodic protection in order to prevent or inhibit corrosion of submerged or buried, metal surfaces.

THEORETICAL CONSIDERATIONS

The electrochemical corrosion of steel structures in a sea water environment or atmosphere has been extensively described.^{7,8} Other contributing factors such as structural stresses, metal composition, temperature, humidity,

and frequency and rate of liquid level changes may accelerate the corrosion rate. The significance of stresses and metal composition is usually determined by design considerations and will not be considered here.

Although floating drydocks are operated in many different latitudes, temperature extremes encountered are typical of ambient conditions which might vary from a low of about 0 F to a high of 120 F. Thus, while higher temperatures usually encourage greater corrosion rates, temperatures are not high enough to interfere with the protective action of most good coatings or inhibitors.

Extreme humidity is typical of exposure in an enclosed vessel containing sufficient water to maintain saturated conditions at all times. The amount of condensation occurring is dependent upon the rate and amount of temperature changes. Vernon⁹ has shown that the rate of atmospheric corrosion is dependent upon both relative humidity, and contamination of the air with gases and suspended particles. His studies indicated that incipient corrosion effects began with a relative humidity of about 60 per cent, and that a profound increase occurred at a relative humidity of approximately 80 per cent, with the rate increasing until the dew point was reached.

Of the various available methods of corrosion protection (paint, metallic coatings, dehumidification, cathodic protection, oil-soluble inhibitors, water-soluble inhibitors, and chemical-floating inhibitors) paint coatings have been relied upon principally until recent years. However, as previously stated in this report, the difficulty in adequately cleaning and applying painted coatings is costly in material and time. In instances where compartments are used to carry fuel and are ballasted or cleaned with sea water, the danger of cargo contamination restricts the use of inhibitor additives. The development of a vinylidene chloride acrylonitrile copolymer (saran)² coating has been reported for fuel-resistant tank linings on Naval vessels.

Metallic coatings such as flame-sprayed zinc or aluminum are being used increasingly for protection in a sea water environment but have been reported to be more costly to apply than painted coatings.¹⁰

Dehumidification techniques are being extensively employed for reducing corrosion of storage and machinery compartments of both active and reserve vessels. However, the constant existence of residual water in the ballast tanks of floating drydocks makes it virtually impossible to maintain a humidity below the critical point.

Cathodic protection techniques can be used to mitigate corrosion on permanently submerged surfaces. The fact that surface preparation is not necessary prior to installation and the relatively maintenance-free operation of a properly designed system are major factors in offsetting the high initial cost of cathodic protection. The choice of anode material, galvanic or inert, is dependent upon

the accessibility of the area to be protected and the availability of external power. Experience has indicated that, in tanker compartments, the wet-and-dry zones receive protection approximately proportional to the amount of time submerged.⁹ Since no protection is afforded areas above the high water level and only partial protection is achieved in wet-and-dry areas, a cathodic protection system must be justified primarily on the basis of corrosion reduction within areas below the normal, low water level.

Comprehensive reviews of the action of inhibitors have been published.^{11,12} Although corrosion inhibition is attributed to both physical adsorption, and chemisorption, the exact mechanism for inhibition is still controversial. It is generally concluded that the inhibitor must function by increasing the electrolytic resistance, or polarizing either the anodic, the cathodic, or both areas of the corroding surface.

The intake and discharge of ballast water for each dry-docking would appear to make the use of a water-soluble inhibitor uneconomical if a fresh supply of inhibitor were required for each change of water. Thus, an inhibitor which is relatively insoluble in water and can be applied with a minimum of labor is desirable. Preliminary studies of chemical compounds used as floating corrosion inhibitors have shown promise in six-month laboratory tests.¹³ These coatings usually consist of a petroleum-vehicle with chemical additives. The chemical additives assist in displacing water from the metal surface and form a non-corrosive, protective film which adheres to the metal surface. The coating material is added to the ballast compartments in sufficient amounts to maintain a continuous floating film, and to recoat the metal surface as the ballast water level is changed. While the protective action of floating inhibitors is usually restricted to those areas which can be recoated through normal, water level changes, areas above and below can be coated initially by spraying or brushing. Periodic dewatering or filling to extreme levels will provide additional protection to areas not normally coated.

TEST FACILITIES AND METHODS

A standard test procedure has been established for the evaluation of floating inhibitors (MIL-C-17936, Ships). However, the addition of cathodic protection with its associated current distribution system made it desirable to conduct the combined test in tanks large enough to require a current magnitude which could be easily controlled and measured. It was also desirable to provide sufficient interior area for mounting duplicate sets of test coupons in each of three exposure zones. Standard T6B, 1000-gal pontoons were readily available and required only slight modification. The pontoons shown in Figure 1, were located on the shore, adjacent to a sea water harbor, and were equipped with a suitable piping and pumping system to simulate drydock ballast operations. Because the frequency and rate of water level changes vary considerably with the size and location of various drydocks, a cycling period of two weeks was arbitrarily chosen.

The pontoons were simultaneously filled with fresh sea water to the upper limit, 12 in. below the top of the pontoon, and allowed to remain full for one week. The water level was then drained simultaneously to the lower limit, 16 in. above the bottom of the pontoon, where it remained for an additional week. Filling and draining rates of approximately 1-1/4 in.-per-minute were used.

Commercially available floating inhibitors can generally be classified into two groups. The material, termed Type I in this report, is normally nongelling and is obtainable ready-mixed. The Type II material is a two-component product composed of an inhibitor and a diluent. The inhibitor gradually gels into a semisolid coating which tends to build up on the metal surface. The diluent is added as required to maintain the viscosity of the residual floating material at a point low enough to permit the recoating of vertical surfaces.

Since it was desirable to determine both the efficiency and the compatibility of the two types of materials with cathodic protection, a test facility comprised of six pontoons was employed. Pontoon No. 1 contained Type I inhibitor only. Pontoon No. 2 contained an impressed current cathodic protection system only. Pontoons Nos. 3 and 4 contained impressed current cathodic protection systems combined with Type I and Type II inhibitors, respectively. Pontoon No. 5 contained a galvanic anode cathodic protection system with a Type I inhibitor. Pontoon No. 6 contained Type II inhibitor only.

The two different anode types (impressed current and galvanic) were incorporated in the cathodic protection installations to determine their individual reactions when coated with the inhibitor. The anodes were mounted horizontally on 1/2-in. studs, welded to the bottom stiffeners of the pontoon. The graphite anodes, employed in Pontoons Nos. 3 and 4, were appropriately drilled in two places to accommodate phenolic resin-laminated sleeves, which insulated them from the mounting studs. The Duriron anode, used in Pontoon No. 2, was bolted with polyvinyl-plastic screws between two pieces of phenolic resin-laminated sheeting. The magnesium anodes, mounted in Pontoon No. 5, were rectangular in shape with a pipe core extending through the center, and were mounted in the same manner as the graphite anodes. An external lead was soldered to a washer that was bolted to the pipe core, and the whole connection-area was filled with an oil-insoluble potting compound. Five magnesium anodes were originally mounted on the bottom to insure adequate current distribution. It was found that one centrally located anode sufficed. The top of the anodes were approximately fifteen in. from the bottom of the pontoon and were in the permanently wet zone.

A selenium rectifier supplied the power for the impressed current anodes and suitable rheostats were incorporated in all anode leads for current control. By mounting them on wooden dunnage and using plastic pipe nipples in the external piping, the pontoons were electrically-insulated from each other.

Because of the shielded areas under the stiffeners and in the pontoon corners a potential of 1.0 volt negative, with respect to a copper sulfate reference cell at the high water level, was considered optimum. All potential readings were

measured on a weekly schedule, with a potentiometer-voltmeter, before the water level was changed. Since contamination of the porous plug of the half cell by the floating inhibitor would influence potential readings, a balsa wood float with a plastic pipe 4 in. long and 2 in. in diameter extending through the center was constructed. The assembly was floated on the surface of the inhibitor, with one end of the pipe protruding into the sea water. All inhibitor was removed from the interior of the pipe, and the half cell was lowered into the sea water through the pipe.

The effectiveness of the two methods of corrosion mitigation was determined by the use of preweighed, 1/4-in. thick, mild steel test coupons. The coupons were sandblasted and mounted as shown in Figure 2, in each of the three exposure zones. Sandblasted coupons were used because of their ease in handling, and because of the accuracy that they afforded in corrosion-loss determination. Two coupons, one of which was electrically insulated, were bolted to the interior surfaces of the pontoons that contained cathodic protection. Insulated test coupons located in Pontoon No. 2 were used as controls for determining the corrosion rate of unprotected coupons.

The interiors of the pontoons were initially covered with a thin coating of rust, which covered over about 25 per cent of the surface area. The remaining 75 per cent of the area was covered with mill scale. The bottoms of the pontoons were spotted with powdered rust and were dampened; but there were no water puddles.

After installing the test coupons, approximately 2-1/2 gallons of the proper floating inhibitor were applied with standard paint-spray equipment. The underside of the pontoon tops, and the bottom and side surfaces one foot above the bottom, were coated in this manner. Sea water was slowly admitted to the pontoons until the level had reached one foot. Additional inhibitor, in the amount prescribed by the inhibitor manufacturer for this size tank, was added to the pontoon. The water level was then raised until the entire interior of the pontoon was filled. This level was maintained for ten minutes. Then, the water was lowered to the 16-in. depth level. The water remained at the lower level for twenty-four hours and then the tanks were completely filled. Upon dewatering to the lower level, the cathodic protection systems were energized and the regular two-week cycling schedule was maintained for one year.

An additional amount of diluent was added to the Type II inhibitor on two occasions as the material gelled beyond the prescribed viscosity. A small amount of Type II inhibitor was also added during the test to maintain a uniform layer on the water surface.

All test coupons remained in position for one year. At the completion of the study, the coupons were removed, steam-cleaned, washed with solvent, and electrolytically descaled in a five per cent sulphuric acid sea water bath, containing a rust inhibitor. The coupons were wire-brushed and weighed immediately

after drying. Calculations of weight loss and corrosion rates were made, as shown in the Appendix.

TEST COUPON DATA RESULTS

Table I lists the individual coupons according to location, size, and weight loss. In general, the losses were characteristic of corrosion phenomena in that considerable variation was experienced. However, in two cases, excessive weight losses were found which were apparently not representative. One coupon, No. 2, located in the wet zone of Pontoon No. 1, was visually detected as not being adequately coated on one side. Coupon No. 66, located in the wet-and-dry zone of Pontoon No. 2 had become insulated from the pontoon and received very little protection. The data from these two coupons was not included in the results reported in Table II, the list of corrosion rates of test coupons in various exposure zones.

As anticipated, the corrosion rate for sea water only, in the wet zone was less than that experienced in the wet-and-dry and dry zones. Although the degree of protection afforded by cathodic protection appears low in the wet zone, it should be noted that the coupons were mounted parallel to the interior surface and stood out approximately three-quarters of an inch from the surface. It was believed that this mounting position would better duplicate areas shielded from the anodes, such as the underside of stiffeners and the pontoon corners. Thus, the measured corrosion rates of these coupons is indicative of one of the more severe exposure conditions encountered in ballast tanks subjected to cathodic protection. The favorable protection afforded the coupons which had received only the initial application of floating inhibitor and no cathodic protection was surprising. Upon removal, after one year of exposure, the coupons in the wet zone had lost their shiny, oily appearance, and isolated areas were beginning to show some rusting, indicating that the coating was on the verge of failure. No interaction affecting the individual protective abilities of the two techniques was observed or detected by coupon losses which are shown in Table II.

A breakdown of coupons in the wet zone into those vertically and horizontally mounted is shown in Table III. Corrosion losses for cathodically protected coupons in the wet zone were virtually independent of coupon orientation. The greater losses exhibited by vertically mounted, inhibitor-protected coupons is attributed to the tendency of the inhibitor to drain off of the metal surface. Those coupons protected by both techniques exhibited negligible corrosion losses, (See Figure 3).

As illustrated in Table II, the performance of the floating inhibitors in the wet-and-dry zone was definitely superior to cathodic protection. If it is assumed that the surface of a cathodically protected coupon, facing the anode, receives 100-per cent protection while submerged, it is doubtful if this same surface would receive over 50-per cent protection under the wet-and-dry exposure

conditions employed. No additional protection was discernible in this zone for these coupons receiving cathodic currents in conjunction with the inhibitor. Figure 4 shows coupons that were exposed in the wet-and-dry zone.

Corrosion losses were also negligible for coupons located in the dry zone, and initially covered with inhibitor, as shown in Table II. The coupon surfaces, illustrated in Figure 5, retained their oily appearance except in the upper portion of vertically mounted coupons, where rusting had commenced particularly on those coated with Type I inhibitor. The Type II inhibitor retained its tackiness and adhered very well to the coupon surface. The coupons that were in the pontoon without inhibitor were completely covered by rust, with rust nodules prevalent in about 25 per cent of the surface area. Although pitting was more evident in the dry zone than in the other areas, no pits deeper than one-sixteenth of an inch were found. In general, the coupons closely resembled the pontoon interior surfaces.

During the test period, the differences in corrosion rates within the dry zone, between the pontoons with and without floating inhibitor became visibly apparent. In addition to rust, the presence of condensed moisture was found on the underside of the horizontal surfaces in the pontoon without inhibitor.

No special precautions had been taken to control the temperature or humidity inside the pontoons because of their symmetry, and because of the location of the test facility. The 15 in. by 23 in. manhole was covered with a bolted-down 1/4-in. plate but it was not airtight. A 2-in. vent pipe was uncapped when filling or draining the tanks. Simultaneous measurements of the temperature and relative humidity of the interior of pontoons, with and without floating inhibitor, and of exterior ambient conditions were made for one week with individually recording hygro-thermographs. The differences between the two pontoons, as shown in Figure 6, are not striking but they are believed significant since the humidity in the pontoon with floating inhibitor rarely reaches the dew point (100 per cent). By contrast, the relative humidity in the pontoon without floating inhibitor is continually maintained at, or near, the dew point.

The records of cathodic protection current and potential values illustrate the difficulty in maintaining static conditions. Potentiometer readings were taken according to a weekly schedule.

As previously stated, it was hoped that a current level could be established which would maintain a potential of 1.0 volt negative, with respect to a copper sulfate half cell. However, with the weekly changes in water level, the use of one rectifier, and the low driving voltage required for the three impressed current systems, it was impossible to reach equilibrium conditions. Between the ninth and eleventh weeks of operation, faulty rectifier contacts and modification of the current control systems caused an inadequate supply of current and a resultant low potential. Fluctuations were particularly troublesome in the system

using cathodic protection only, as indicated in the upper portion of Figure 7, because of the greater difference in current requirements between the high and low water levels. Initially, an average impressed current of 1.3 amp was supplied to the pontoon with cathodic protection. As some calcareous deposits accumulated on the metal surface, the current requirements gradually decreased to a value of about 1.1 amp at the end of the test.

There was very little difference in impressed current requirements between the two pontoons containing inhibitor only as shown in Figure 8. An average initial current of 0.15 amp was impressed into the pontoon with Type I inhibitor, and approximately 0.10 amp was impressed into the pontoon with Type II inhibitor. The average final currents were increased to about 0.25 amp for both of these pontoons.

The current and potential for the pontoon equipped with the galvanic anode was more stable. An average current of approximately 0.10 amp was able to maintain the desired potential. The lower current requirement for this pontoon was attributed to either slight differences in the condition of the interior surface, or to the increasing concentration of magnesium ions in the electrolyte, as the anode was consumed. The pH measurements of the residual water at the end of the study indicated a slightly higher condition (more alkaline) than in the other pontoons. However, the difference in pH was not great enough to explain the differences in current amounts that were required.

The lower current requirements for the surfaces coated with the floating inhibitor are significant and emphasize the value of using a coating with cathodic protection. This reduction in current may not decrease the number of anodes because of the current distribution problem but it should materially reduce the size of anodes and the current capacity of associated components. The current control problem is also minimized because of the reduced current fluctuations caused by water level changes.

Potential measurements also were taken in the pontoons containing floating inhibitor only, and are plotted in Figure 9. Unfortunately, no measurements were recorded between the first and twelfth weeks. The differences between the two inhibitors' potential readings were attributed to special chemical additives contained in the basic material. Type II material is known to contain lanolin and small amounts of cresylic acid which could account for the more negative potentials. It is understood the Type I material contains a wetting agent additive, but no specific corrosion inhibitor was added. The initially more negative potential of the surfaces coated with Type I material was apparently caused by the inherent polarizing action of the material itself. The potentials gradually decreased as the polarizing constituents were dissipated.

On two separate occasions, the water level was lowered to recoat the graphite anodes with the floating inhibitor in order to determine if the coating would

have any effect on the current-discharge efficiency of the anode. The water level was immediately raised and current measurements, before and after recoating, coincided within a period of minutes. Figure 10 illustrates the condition of the graphite anodes, in use with the floating inhibitor, at the completion of the test. The graphite anode, on the right, was wiped relatively clean to clearly exhibit areas where the greater portion of the current had been discharged. These areas were pitted to a depth of about 1/8-in. and it is not known if pitting would have become more severe, or if a greater surface area of the anode would be utilized, if higher current densities were used. Admittedly, the anodes were much larger than necessary because the current requirements could not be accurately predicted before the study began. The magnesium anode appeared to deteriorate in a normal manner and is shown in Figure 11. After the study had progressed for six months, this anode was the sole source of current for Pontoon No. 5. Evolution of a gas that was assumed to be hydrogen was evident by the accumulation of bubbles on the surface of the floating material directly above the anode. Because of the relatively small amount of current discharged, this phenomenon was not serious.

After six month's exposure to Type II inhibitor, swelling of the neoprene-jacketed electric cable was observed. The swelling increased the diameter of the cable by one-fourth, and softened it. This could ultimately reduce the cable's abrasion resistance. Neoprene is susceptible to swelling in certain aromatic solvents, chlorinated hydrocarbons, and creosote. ¹⁴

The phenolic resin-laminated insulating material used for mounting the anodes showed a slight tendency to warp and to split after one year of exposure.

CONCLUSIONS

Under the conditions specified for simulating the operation of ballast tanks for a floating drydock, several conclusions, based upon the corrosion losses of preweighed, sandblasted, mild steel coupons that were exposed for one year, can be made.

1. The combined use of cathodic protection and one application of a floating-type inhibitor reduced corrosion in the permanently wet zone to negligible amounts. In individual test installations of the two methods, the corrosion rate was reduced by at least 70 per cent and was somewhat dependent upon the location of the metal surface. No serious interference between the two methods was detected.

2. The corrosion rate of surfaces in the wet-and-dry zone was effectively retarded by the use of floating-type inhibitors. Cathodic protection in this area is effective only when the surface is submerged.

3. An initial application of floating inhibitor to metal surfaces in the dry zone reduced the corrosion rate by approximately 99 per cent.

4. The addition of special chemical additives to a floating-type inhibitor did not significantly increase the protection in the wet-and-dry or dry zones, when compared with a floating-type product purported to contain a wetting-agent only. Protection in these areas may be abetted by maintaining the relative humidity below the dew point figure.

5. After a one-year exposure period, the cathodic protection current required in conjunction with a floating inhibitor was one-fifth the magnitude of current required without a floating inhibitor.

RECOMMENDATIONS

Although the present study has shown that the combined use of floating-type inhibitors and cathodic protection is effective in controlling the corrosion of interior compartments, the ultimate value of the two methods can best be determined by actual service. It is therefore recommended that these or other promising floating-type inhibitors be evaluated, with and without cathodic protection, in operating drydocks. Preferably the in-service test should be conducted in the same drydock to insure duplication of exposure conditions. The efficiency of the two methods should be determined individually, and together, by exposing a sufficient number of test coupons, both clean and rusted, in the various zones of the ballast compartments. Removal and weighing of typical coupons should be scheduled for six-month or yearly intervals in order to maintain progressive data on the corrosion rate.

An accurate record of costs associated with each method would be valuable in justifying their adoption for general use.

The use of laminated-plastic materials for anode support, and neoprene-jacketed electrical cable, is not recommended, particularly if used with compounds similar to the Type II material. Unplasticized polyvinyl is suggested for use as a mounting component and polyvinyl or polyethylene are recommended for electrical cable insulation.

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APPENDIX

CALCULATION OF WEIGHT LOSS AND PER CENT CORROSION RATE OF TEST COUPONS

A. Area of 4-1/4" x 4-1/4" x 1/4" coupons:

$$\text{sides } (4.25)^2 = 18.06 \text{ sq in.}$$

$$\text{edges } (4.25)(.25) = 1.06$$

∴ the total area

$$= (4)(1.06) + (2)(18.06) = 40.38 \text{ sq in.}$$

B. Area of 4-1/4" x 8-1/2" x 1/4" coupons:

$$\text{sides } (4.25)(8.5) = 38.125 \text{ sq in.}$$

$$\text{edges } (8.5)(.25) + (4.25)(.25) = 3.1825$$

∴ the total area

$$= (2)(38.125) + (2)(3.1825) = 82.625 \text{ sq in.}$$

C. To calculate the inches of penetration per year:

$$\frac{\text{grams lost}}{(\text{density grams/cu in.})(\text{area of coupon in sq in.})} = \text{inches}$$

$$\frac{\text{grams lost}}{(7.83)(16.387 \text{ (area of coupon sq in.)})} = \text{inches of penetration}$$

1. For the small coupons (4-1/4" x 4-1/4" x 1/4")

$$\text{ipy (inches per year)} = \frac{\text{grams lost}}{(128.31)(40.375)} = \frac{\text{grams lost}}{5.18 \times 10^3}$$

2. For the large coupons (4-1/4" x 8-1/2" x 1/4")

$$\text{ipy} = \frac{\text{grams lost}}{(128.31)(82.625)} = \frac{\text{grams lost}}{1.060 \times 10^4}$$

$$\text{mpy (mils per year)} = \frac{\text{ipy}}{10^3}$$

D. Corrosion rates based on the weight loss of control coupons.

$$\text{Corrosion rate (\%)} = \frac{(\text{wt loss of control}) - (\text{wt loss of test coupon}) \times 100}{\text{wt loss of control}}$$

TABLE I. Coupon location and weight

Exposure Zones	Pontoon No. 1 Type I inhibitor		Pontoon No. 2 Seawater with impressed current cathodic protect. ion.		Pontoon Type I with impr current c protect
	Coupon No.	Wt Loss (gms)	Coupon No.	Wt Loss (gms)	Coupon No.
Bottom Corners (4-1/4" x 4-1/4")			41*	5.6	14*
Vertical Coupons	2	13.6	42	16.9	15
W			45*	4.7	16*
E	4	6.0	38	21.8	17
T			61*	4.1	59*
Bottom	15	0.6	67	27.7	60
(4-1/4" x 8-1/2")			5*	10.4	57*
Horizontal Coupons	14	0.6	4	19.9	58
W			33*	28.2	12*
E	1	1.3	40	42.7	13
T			43*	27.4	18*
&	3	0.9	44	38.5	19
D			3*	55.9	53*
R	15	2.3	2	86.8	54
Y			6	92.0	56*
Vertical Coupons	16	1.9	66*	85.1	55
D					
R	19	1.0	20	72.9	22
Y					
Horizontal Coupons (4-1/4" x 8-1/2")	18	1.7	21	75.8	23

* Coupons Cathodically protected.

** No coupons used because of duplicate exposure conditions.

(1)

nd weight loss of individual coupons.

Pontoon No. 3 Type I inhibitor with impressed current cathodic protection		Pontoon No. 4 Type II inhibitor with impressed current cathodic protection		Pontoon No. 5 Type I inhibitor with galvanic-type cathodic protection		Pontoon No. 6 Type II Inhibitor	
Coupon No.	Wt Loss (gms)	Coupon No.	Wt Loss (gms)	Coupon No.	Wt Loss (gms)	Coupon No.	Wt Loss (gms)
14*	0.4	47*	0.5	24*	0.4		
15	4.3	46	0.1	23	1.8	6	0.8
16*	1.0	51*	1.1	26*	0.7		
17	5.3	50	3.0	25	1.9	5	8.2
59*	0.3	78*	0.5	69*	1.4		
60	2.6	77	0.8	70	0.6	7	1.0
57*	0.6	79*	0.1	75*	0.1		
58	1.8	80	0.9	74	1.1	8	0.3
12*	0.5	49*	1.3				
13	1.3	48	1.1	**	**	7	0.5
18*	0.4	52*	1.3				
19	0.9	53	0.6	**	**	8	0.5
53*	1.2	64*	0.7	68*	2.0		
54	1.2	65	1.2	76	1.6	9	1.0
56*	1.5	62*	0.2	72*	0.9		
55	0.7	63	0.8	71	1.0	17	0.6
22	0.1	**	**	**	**	28	0.4
23	1.8	**	**	**	**	29	0.2



TABLE II. Corrosion rates of test coupons in various exposure zones

Exposure	Wet Zone		Wet-and-Dry Zone		Dry Zone	
	Average Loss (mpy)*	Reduction in Corrosion Rate (%)	Average Loss (mpy)	Reduction in Corrosion Rate (%)	Average Loss (mpy)	Reduction in Corrosion Rate (%)
Sea Water (control)	3.0	0	8.14	0	7.02	0
Cathodic Protection	0.839	72.2	5.33	34.5	7.02	0.0
Type I Inhibitor	0.411	86.3	0.151	97.2	0.108	98.5
Type I Inhibitor with Cathodic Protection	0.088	97.1	0.122	98.4	**	**
Type II Inhibitor	0.325	89.1	0.108	98.7	0.028	99.7
Type II Inhibitor with Cathodic Protection	0.093	97.0	0.147	97.3	**	**

* mils per year penetration (inches per year multiplied by 10^{-3})

** no data obtained

TABLE III. Corrosion rates of test coupons located in the wet zone

Exposure	Vertical		Horizontal	
	Average Loss (mpy)*	Reduction in Corrosion Rate (%)	Average Loss (mpy)	Reduction in Corrosion Rate (%)
Sea Water	3.37	0	2.27	0
Cathodic Protection	0.994	73.3	0.685	69.8
Type I Inhibitor	0.83	77.7	0.115	94.4
Type I Inhibitor with Cathodic Protection	0.121	96.7	0.056	97.6
Type II Inhibitor	0.586	84.4	0.071	96.4
Type II Inhibitor with Cathodic Protection	0.159	95.7	0.028	98.7

* mils per year penetration (inches per year multiplied by 10^{-3})

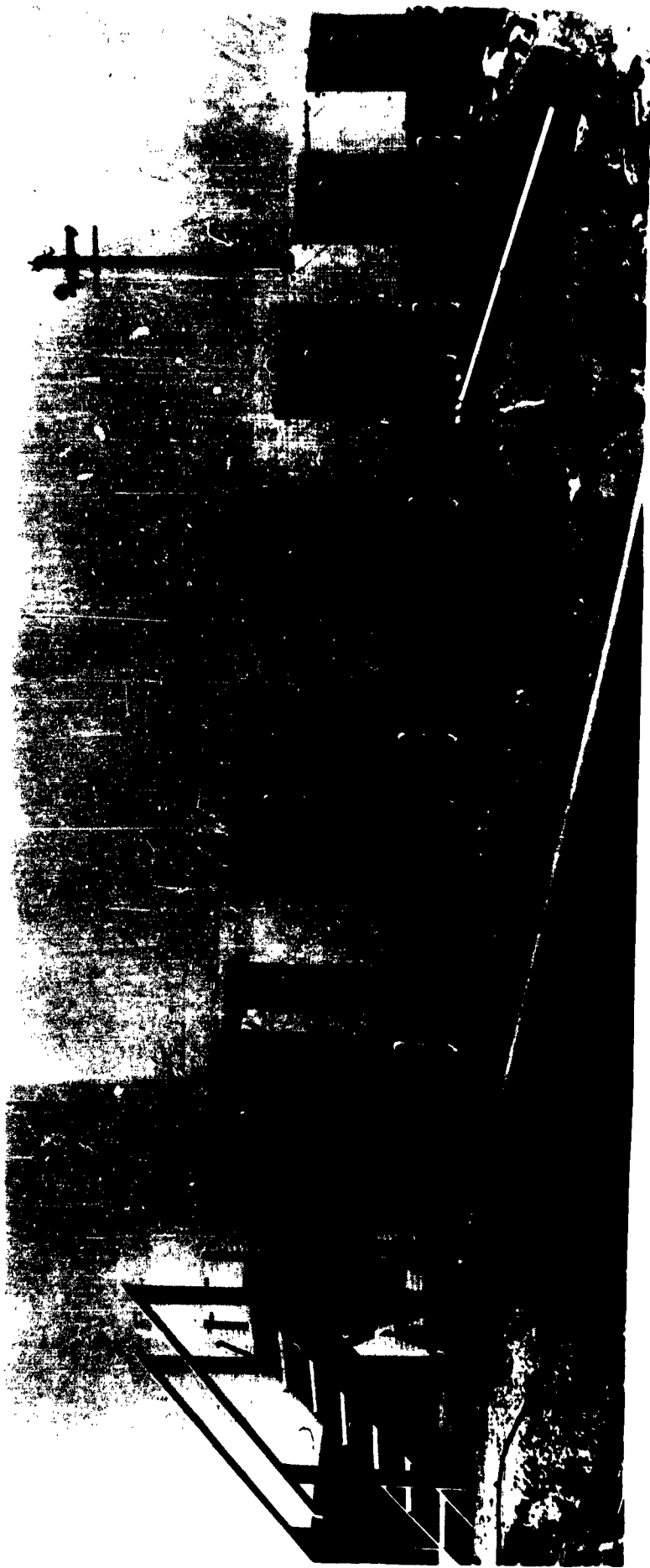


Figure 1. Test Facility. (The 2-1/2 in. line in the lower foreground leads to a 40,000 gph capacity pump, used for filling the pontoons. The individual filling lines, shown near the top center of each pontoon, extend through the side and come down to within 6 in. of the bottom of the pontoon.)

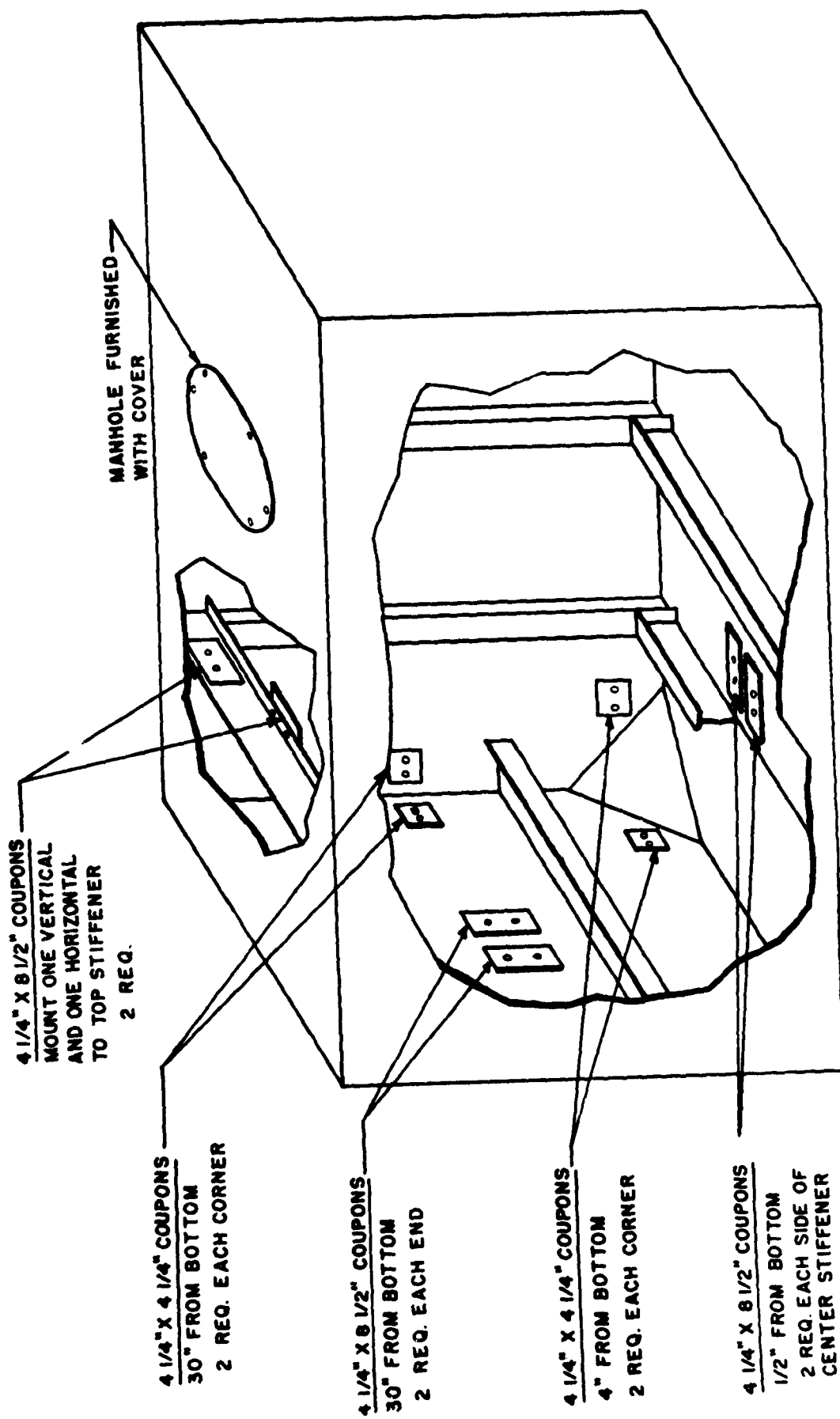


FIG. 2 CUT-A-WAY OF T6B PONTON SHOWING LOCATION OF TEST COUPONS

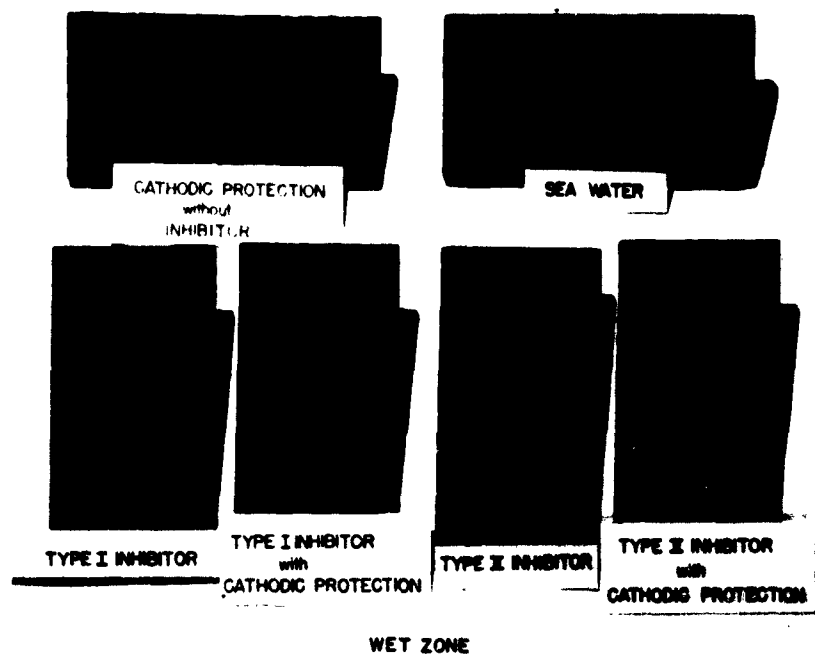


Figure 3. Typical coupons exposed for one year in the wet zone.

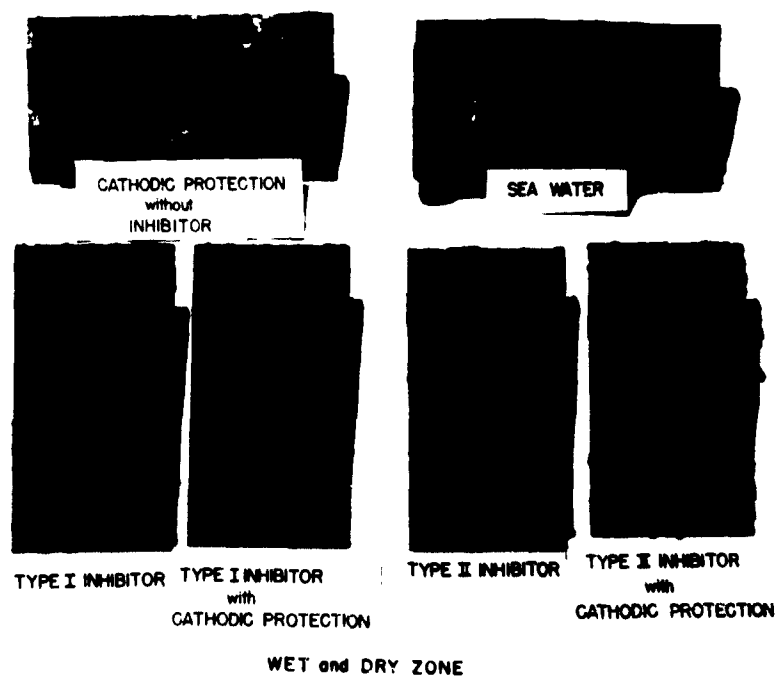


Figure 4. Typical coupons exposed for one year in the wet-and-dry zone.

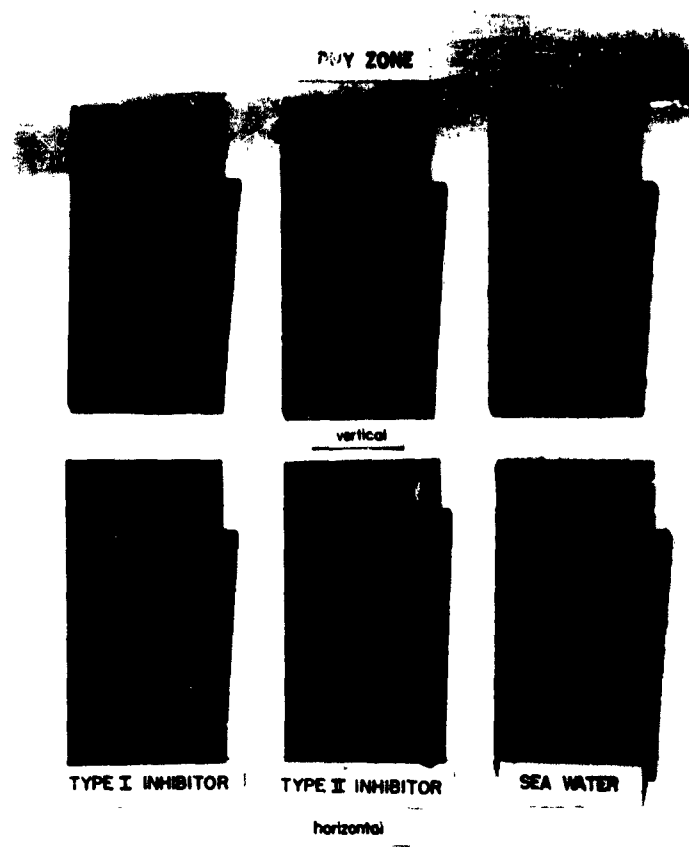


Figure 5. Typical coupons exposed for one year in the dry zone

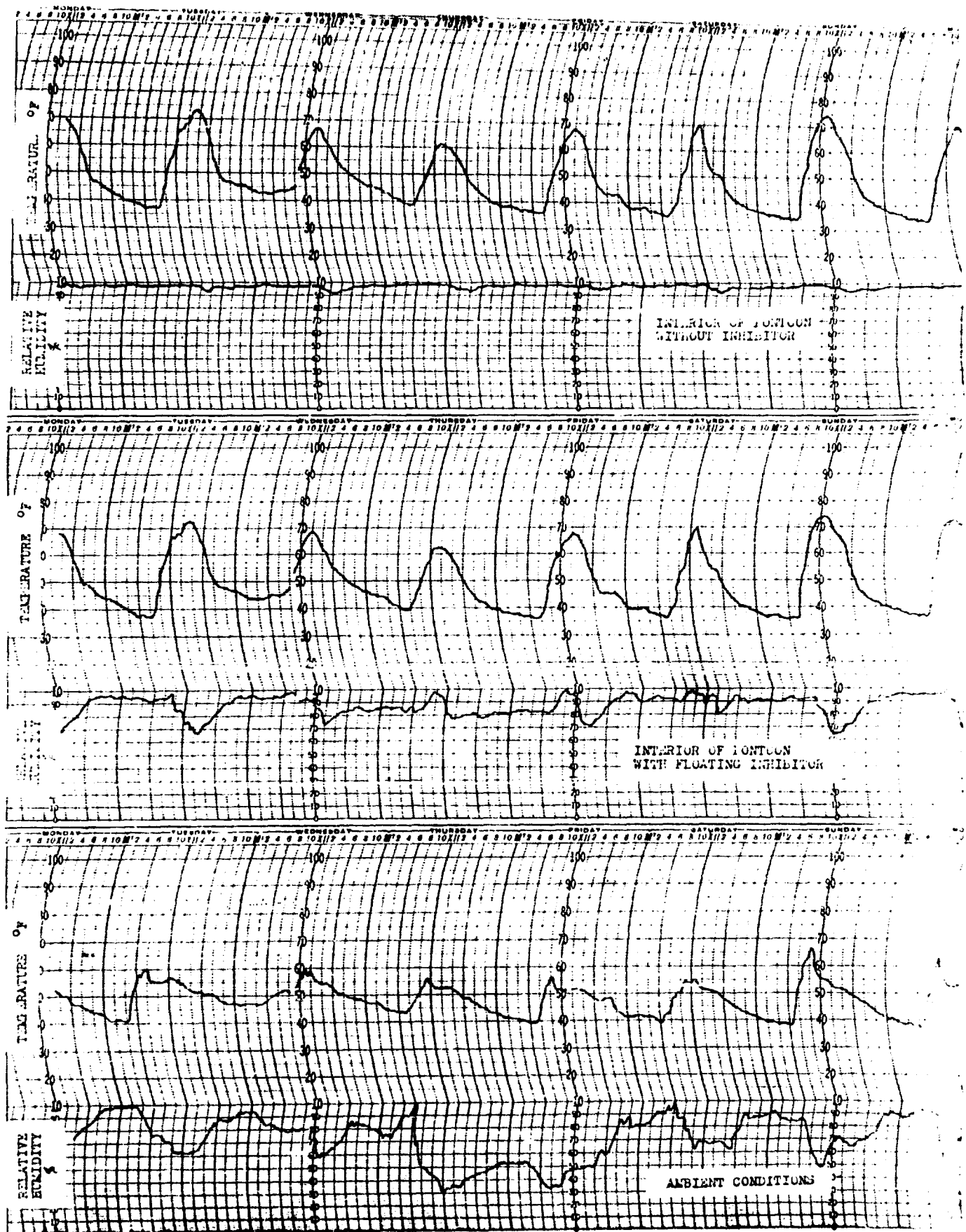


Figure 6. An illustration of the difference in the interior relative humidity of the test pontoons with and without floating inhibitor.

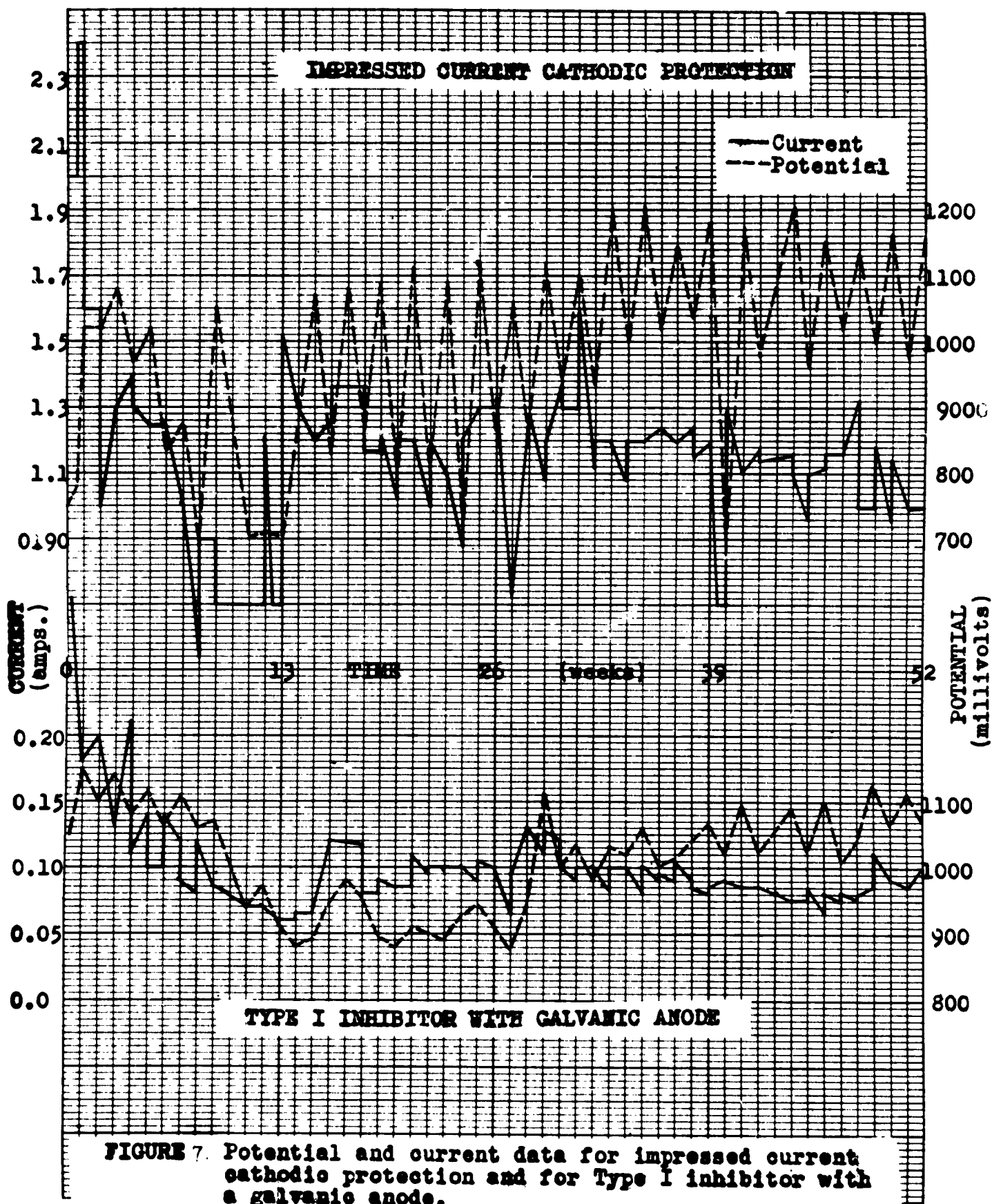


FIGURE 7. Potential and current data for impressed current cathodic protection and for Type I inhibitor with a galvanic anode.

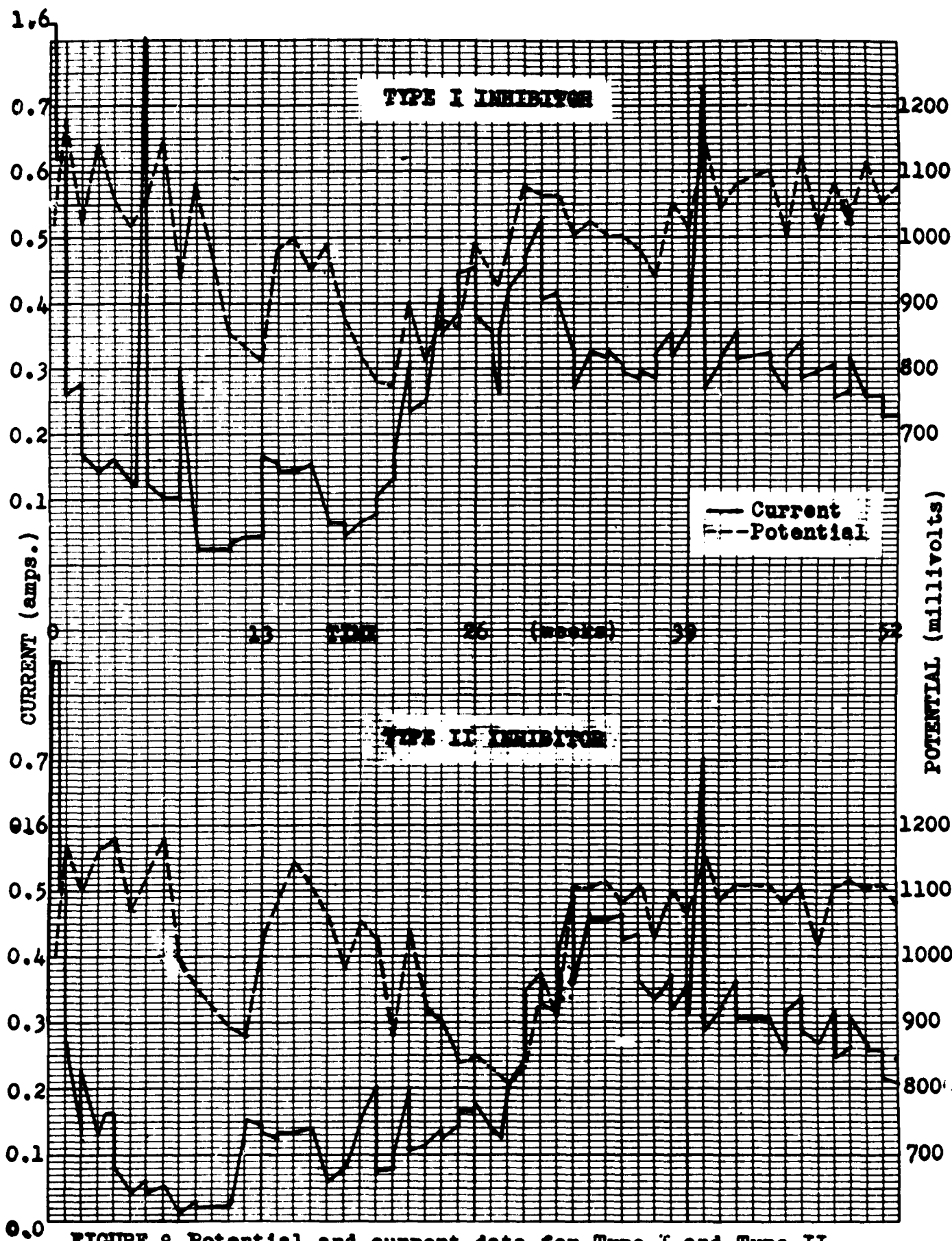


FIGURE 8. Potential and current data for Type I and Type II inhibitors with impressed cathodic protection current.

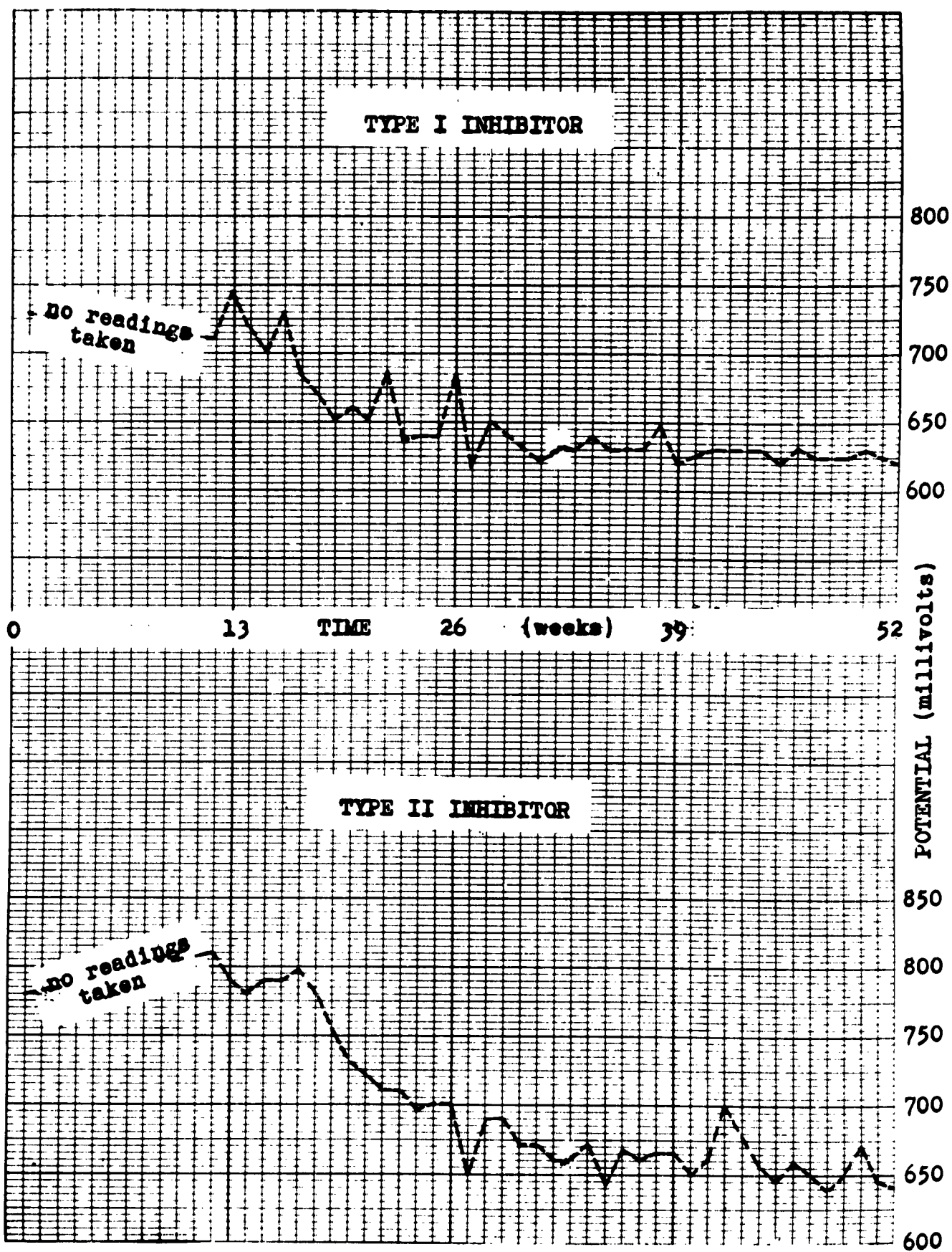


FIGURE 9. Potential data for Type I and Type II inhibitors without cathodic protection.

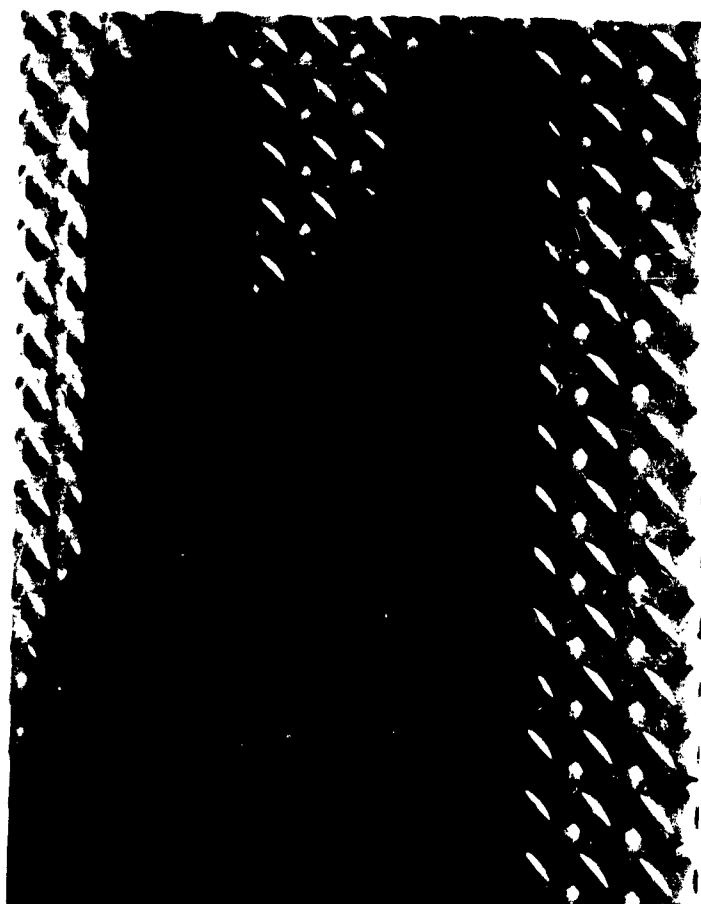


Figure 10.

Graphite anodes used in conjunction with the floating inhibitors. The anode on the left is shown upon removal from the pontoon. The anode on the right was wiped clean to show deterioration.



Figure 11. Magnesium anode used in conjunction with floating inhibitor.