An investigation of the corrosion of domestic hot water tanks

Sereda, P. J.; Thomas, W. R.; Cohen, M.

National Research Council Canada   Conseil national de recherches Canada

Canada

18498

NATIONAL RESEARCH COUNCIL

CANADA

ANALYZED

AN INVESTIGATION OF THE
CORROSION OF DOMESTIC HOT WATER TANKS

BY

P. J. SEREDA
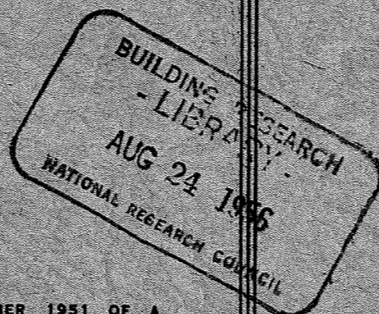DIVISION OF BUILDING RESEARCH

W. THOMAS AND M. COHEN
DIVISION OF CHEMISTRY

RESEARCH PAPER NO. 2

OF THE

DIVISION OF BUILDING RESEARCH

OTTAWA

NRC NO. 2512
DBR NO. 31

PRICE 15 CENTS

This publication is one of a series being produced by the Division of Building Research of the National Research Council as a contribution towards better building in Canada. It may therefore be reproduced, without amendment provided only that the Division is advised in advance and that full and due acknowledgment of this original publication is always made. No abridgment of this report may be published without the written authority of the Division. Extracts may be published for purposes of review only.

Publications of the Division of Building Research may be obtained by mailing the appropriate remittance,(a Bank,Express, or Post Office Money Order or a cheque made payable at par in Ottawa,to the Receiver General of Canada, credit National Research Council) to the Publications Section, Division of Building Research, National Research Council, Ottawa. Stamps are not acceptable.

A coupon system has been introduced to make payments for publications relatively simple. Coupons are available in denominations of 5, 25, and 50 cents and may be obtained by making a remittance as indicated above. These coupons may be used for the purchase of all National Research Council publications,including specifications of the Canadian Government Specifications Board.

AN INVESTIGATION OF THE CORROSION OF DOMESTIC HOT WATER TANKS[1]

By P. J. Sereda,[2] W. R. Thomas,[3] and M. Cohen[4]

Abstract

A method for the examination of corrosion in domestic hot water tanks is described.   Results based on physical and metallographic examination of tanks taken from 15 localities in Ontario are given.   Evidence is presented to show that the polarity of the zinc–iron couple reverses under certain service conditions. Discussion of the causes of failure and possible methods of prevention are included.

Introduction

The records of Central Mortgage and Housing Corporation over the past few years indicate that a considerable number of domestic hot water tanks have failed by corrosion after a short service life in certain localities.   This represents an economic loss because of replacement costs.   An investigation of this problem was undertaken by the National Research Council at the request of Central Mortgage and Housing Corporation.   Although the problem exists in varying degrees throughout Canada, the initial study of this problem was confined to Ontario.

A summary of records of tank performance compiled for a period of six months appears in Table I.

The general problem of the corrosion of galvanized hot water tanks has been studied extensively by Hoover (6) and Bialosky (1).   Similarly, the corrosion of zinc and zinc coatings on steel in aqueous media has been studied by several investigators (3, 4, 5, 10).   A number of papers (2, 7, 8, 13) have been published reporting on the mechanism of corrosion of zinc coatings in hot water under laboratory conditions.   Evidence has been presented in these reports to indicate that a reversal of polarity of the zinc versus steel couple sometimes occurs in service.

This paper reports on tanks which failed in service and includes:

      1. Percentage failures;

      2. Physical examination;

      3. Metallographic examination.

In the investigation described here photomicrographs were made of the zinc coatings on steel.   These were taken from tanks which had failed in service under various conditions in order to observe the mechanism of failure and to

---

3356231

detect, if possible, evidence of the reversal of polarity. The methods used by Rowland and Romig (12) for metallographic examination of zinc coatings were adapted for this investigation.

TABLE I

RECORDS OF TANK SERVICE FOR PERIOD NOVEMBER, 1949 TO APRIL, 1950

Locality	Type of tank	Age of project, yr.	Total no. of houses	Total no. of tank failures*	Av. service life of failed tanks, yr.	Tanks examined
Brantford	Standard	$3\frac{1}{2}$	647	30	3	1
	Wartime	6	50	5	6	
Hamilton	Standard	6	1531	7	3	6
	Wartime	6	731	20	6	7
Collingwood	Standard	6	136	2		
	Wartime	6 to 7	120	9	5 to 6	
North Bay	Standard	3	106	14	3	1
Kingston	Standard	1 to 2	108	3		1
	Wartime	7 to 8	300	10	7 to 8	
Renfrew	Standard	$1\frac{1}{3}$	219	4	$1\frac{1}{6}$	1
	Wartime	$6\frac{1}{2}$	22	1	$2\frac{1}{2}$	
Lindsay	Standard	3	127	23	2	17
	Wartime	4	50	38	3 to 4	
Malton	Wartime	6	131	18	6 to 7	3
Long Branch	Standard	3	93	0		
	Wartime	6	107	17	6	2
St. Catharines	Standard	9	225	16	8	1
	Wartime	6 to 7	150	18	7	
Port Hope	Standard	5	72	8		8
	Wartime		70			
Belleville	Standard	2	103	44	$\frac{1}{2}$ to $\frac{3}{4}$	3
Campbellford	Standard	3	25	8	$\frac{3}{4}$	2
Smiths Falls	Standard	$3\frac{1}{2}$	100	1	$2\frac{1}{2}$	1
Ottawa	Standard	2				1

Experimental

The laboratory investigation consisted of physical and metallographic examination. A routine procedure was developed for cutting open the tanks to obtain suitable samples. The method of cutting is illustrated in Fig. 1 and the areas from which the samples were taken are illustrated in Fig. 2. The samples for the metallographic examination were taken from the areas which were examined physically in order to provide a basis for correlation.

A. Physical Examination

The inside surfaces of the tanks were photographed to provide a record of their appearance. Representative samples of these are illustrated in Figs. 5, 6, 7, 8, and 9. General observations were also recorded.

Physical measurements were made on the areas designated in Fig. 2 and consisted of the following:

    1. Wall thickness;

    2. Total pits counted and recorded as pits per 10 sq. in.;

    3. Depth of all pits (recorded as average depth).

* *These tank failures are for the designated six month period. The rate of failure before this time is not known and for this reason the apparent service life of the wartime tanks is probably not representative.*

The zinc thickness was measured on the outside of the tank. Five measurements were made, located in the plane of the vertical axis spaced about one foot apart. The measurements were made with a General Electric Thickness Gauge, Type B.
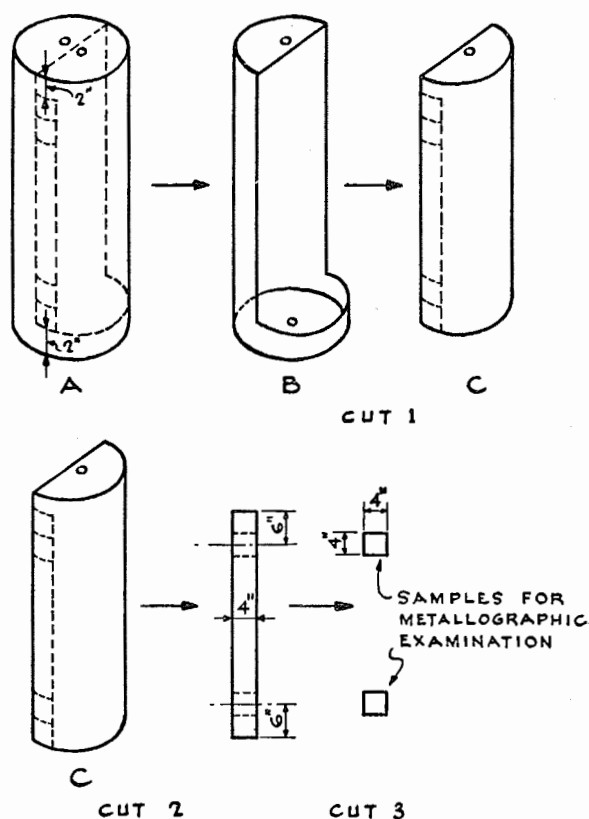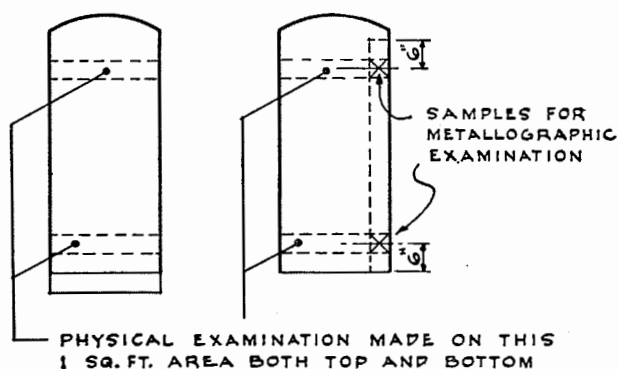

FIG. 1. *Method of cutting a tank for examination.*

FIG. 2. *Areas marked for examination.*

B. Metallographic Examination
Procedure

Specimens were cut from the samples indicated above, dipped in bakelite lacquer, drained, baked dry at 275° F., and mounted in bakelite. The lacquer coat improved the edge preservation. The mounted specimens were then ground down to 4/0 emery paper in the normal fashion. Preliminary wet polishing was done on silk cloth using a special levigated alumina buffered to a pH of 7. The final polish was done on Kittens Ear broadcloth with the same abrasive. At no time were the specimens washed with water because this tended to stain and etch the zinc. Specimens were always carefully wiped off with cleansing tissue. The following etches were found satisfactory for all the specimens:

> 1. 0.15 gm. picric acid
>   50 ml. water
>   10 ml. ethanol
> 2. 0.075 gm. picric acid
>   50 ml. water
>   10 ml. ethanol.

The first was used for the corroded edge, and the second for the outside edge. The complete edge of each specimen was examined and photomicrographs were made of portions that were fairly representative. The photographs were made on metallographic plates using a Leitz Panphot microscope. All are at a magnification $\times$ 250.

Results

A. Analysis of Water

Analysis of the tap water from the five localities included in this investigation are compiled in Table II.

B. Physical Examination
Wall Thickness

Two general types of tanks were examined. These were classed as the "wartime" and the "standard". The wall thickness of the wartime tanks varied between 0.070 and 0.077 in. with an average of 0.075 in. The standard tanks had a wall thickness in the range of 0.080 to 0.092 in. with an average of 0.085 in.

Zinc Coatings

It was assumed that the zinc coating on the outside of the tanks was representative of the zinc coating on the inside. Visual observation suggested that this assumption was perhaps erroneous, and it appeared that the coating on the inside was not as good as that on the outside. It was noted that more dross inclusions were found in the inside coating.

The thickness of the zinc coatings as measured on the outside surfaces of the tanks varied over the range 2 to 6 mils. Data presented in Fig. 3 show the

TABLE II
ANALYSES OF CIVIC WATER SUPPLIES

	Sample point				
	Plant tap			Lab. tap	Town tap
	Locality and source of water				
	Belleville, Ont. Bay of Quinte	Hamilton, Ont. Lake Ontario	Lindsay, Ont. Scugog River	Ottawa, Ont. Ottawa River	Port Hope, Ont. Lake Ontario
pH	7.5	8.3	7.8	8.4**	8.3
Color	10	0	15	4**	0
Turbidity	4.6	1.1	algae	6.0	0.4
Spec. conductance*	217.1	302.8	225.2	61.16	298.6
Residue on evap.					
Dried at 105° C.		175.8	160.8	64.0	173.6
Ignited at 530° C.		150.6	109.6	36.6	155.2
Alk. as $CaCO_3$					
(phenolphthalein)	0	2.0	0	0	5.6
Alk. as $CaCO_3$ (MeO)	83.4	100.0	104.0	31.2	98.0
Calcium (Ca)	39.3	39.8	39.8	6.7	40.3
Magnesium (Mg)	3.8	10.4	7.9	2.7	8.6
Sodium (Na)	2.0	8.6	3.0	4.2	8.7
Potassium (K)	1.2	1.6	1.0		1.1
Sulphate (SO_4)	41.4	24.5	22.8	11.7	27.7
Chloride (Cl)	1.0	18.6	5.9	2.3	18.5
Nitrite (NO_2)				0	
Nitrate (NO_3)		1.8	2.2	.8	1.3
Bicarbonate (HCO_3)	101.8	117.1	126.9	27.4**	105.9
Carbonate (CO_3)		2.4	0	2.1**	6.7
Silica (SiO_2) grav.		2.6	1.4	8.0	3.2
col.	4.8	2.1	2.0	5.6	1.9
Hardness as ($CaCO_3$)					
Noncarbonate	30.9	42.1	27.8	0	37.9
Total	114.3	142.1	131.8	27.9	135.9

Micromhos at 25° C.
**Average of daily results for 1948 from filtration plant.*
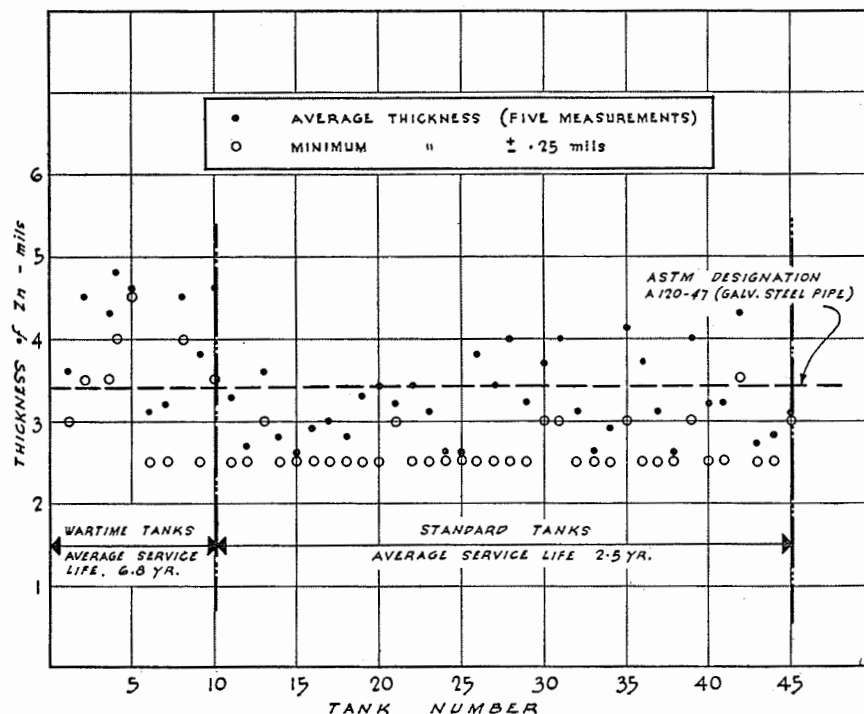

FIG. 3. *Thickness of zinc coatings on individual sample tanks.*

average and the minimum thickness of zinc coatings on the tanks examined. Deviation of the minimum thickness from the average on any one tank was found to be 0.5 to 1.5 mils. Similar variation in the thickness of the zinc coating could be found on an area of 1 sq. in. of some of the tanks.

Pits

The size and number of pits per unit area were characteristic of the locality where the tanks were in service. Figs. 7 and 8 illustrate this point. Considering the area of 1 sq. ft. at the top of the tanks, the average number of pits per 10 sq. in. varied from 0.3 to 30. These data could not be correlated with service life. Similarly the average pit depth for the area in question varied from 0.025 to 0.060 in. at the time when several pits had produced holes in the wall of the tank. Pits on tanks from localities such as Hamilton, Lindsay, Port Hope, and Ottawa were covered with caplike nodules of corrosion products as shown in Figs. 5, 7, 8, and 9. In the case of the tanks from Belleville the pits exposed shiny metal (Fig. 6).

C. Metallographic Examination

In all, 185 photomicrographs were made from samples of 46 tanks taken from 15 different localities. The majority of those examined were from Hamilton, Lindsay, Port Hope, and Belleville. Photomicrographs of tanks from these localities and one tank from Ottawa have been included. The nomenclature used in describing the layers of the coating is the same as that used by Daesen (4) and Rowland (11). These designations are indicated in Fig. 10.

The photomicrographs are arranged in groups of three, showing cross sections of (A) the outside zinc coating, (B) the inside corroded zinc coating at the top of the tank, and (C) the inside corroded zinc coating at the bottom of the tank.

Discussion

The corrosion of domestic hot water tanks involves the destruction by electrochemical action of galvanized steel in the presence of water and is affected by the following variables:

1. Water composition;
2. Temperature;
3. Rate of flow of water or total volume of water;
4. Variation in the thickness of the zinc coating;
5. Porosity of zinc.

Assuming a perfect tank the initial corroding system consists of water in contact with the outer layer of pure zinc which is pore-free and continuous.

If the zinc corrodes evenly and without forming a protective layer, the life of the tank will be determined by the rate of the corrosion of the zinc, the rate of penetration of the steel by corrosion and/or pitting, and by the thickness of the zinc and the steel. Examples of this are the tanks from Lindsay, Ont., where the zinc corrodes evenly with time (Fig. 12). When the zinc no longer

covers the steel, owing either to the removal of zinc by corrosion or discontinuous initial application, the life of the tank becomes dependent upon the pitting rate of the steel in the water. Corrosion by pitting is an erratic and unpredictable process. The useful service life of a tank must be considered as that period before pitting begins.

Continuous zinc coating is the initial barrier against pitting. The final barrier which leads to long tank life is a scale deposited from the heated water on the tank surface. The scale may or may not contain corrosion products. If the deposited scale is not protective (or if no scale is deposited) the zinc will protect the iron if it is anodic to the iron, for a period depending upon the rate of corrosion of zinc in the hot water and the thickness of the zinc layer. The rate of corrosion of zinc in hot water is generally high.

Theoretically zinc, being the more electronegative metal, protects steel in aqueous environment by acting as a sacrificial anode. Therefore, small areas of exposed steel should be protected as long as they are surrounded by a layer of zinc. However, the results of the metallographic examination of corroded edges showed that this was not always the case (Figs. 10, 11, 13, and 14). Pitting of steel has been observed adjacent to areas where most of the zinc coating was still present, as shown in Fig. 11. Separation of the eta layer from the remaining zinc coating and the corrosion of the zeta layer in the presence of the eta layer was observed and is shown in Figs. 10, 13, and 14. This observation confirms the reversal of polarity between eta and zeta layers as well as between steel and the zinc coating. Results of laboratory investigations by a number of workers (7, 8), and (13) indicate that under certain conditions of temperature and composition of water, the polarity of the zinc–iron couple reverses. The above is evidence of this happening under service conditions.

The measured thickness of zinc on the tanks examined is shown in Fig. 3. It indicates the fact that most of the tanks which had a service life of less than three years had areas of zinc coating less than 3.4 mils which is the minimum thickness of zinc specified by A.S.T.M., Designation A 120-47, for zinc coatings on steel pipe. It may be noted that the groups of tanks which had a service life of over six years in most cases had a minimum thickness of zinc exceeding 3.4 mils.

The present method of tank manufacture does not allow application of a uniform coating of zinc to the inside surfaces. Streaky accumulations of zinc as well as large areas of dross were observed on the surfaces. This is the result of application of the zinc coating after the tank has been made. The flux and spelter must be introduced through small openings in the tank and because of this, complete fluxing of surfaces and uniform drainage of the spelter is not achieved.

Generally, with an evenly corroding system, the rate of attack will be increased by increasing the temperature. This was observed in tanks where temperature gradients existed owing to the method of heating. Fig. 4 illus-

trates the temperature distribution found in a tank full of hot water when
three different types of heaters were used. In the tanks examined the distri-
bution and depth of pits along the height of the tank were related to the
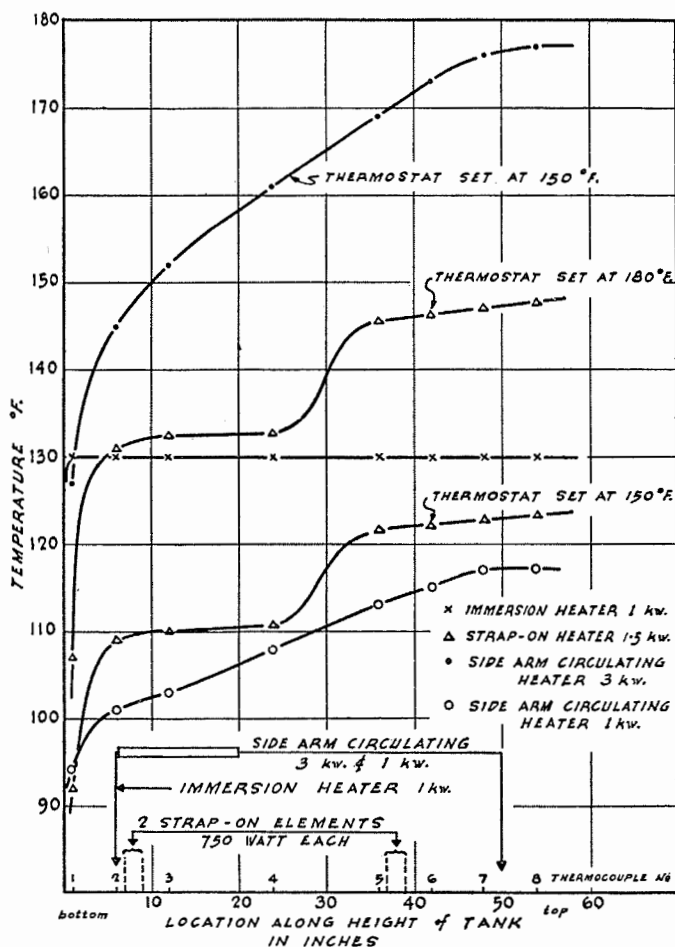temperature variation. When no temperature gradient existed as in the case

FIG. 4. *Variation of the temperature of the water along the height of the tank heated by
means of three types of electric heaters.*

when an immersion heater was used, the number and depth of pits were nearly
constant. Sample tank, Fig. 7, is an example of this case. When a side arm
circulating heater was used the depth and number of pits increased with height
of tank from the bottom. The depth of the pits at the top was twice the depth
of the pits at the bottom in tanks heated in this manner, (Fig. 6). Several
tanks were examined which were heated by means of a strap-on heater element

placed around the tank at a location about two ft. from the bottom. In these cases there was no evidence of pitting in the tank below the heater location whereas serious pitting of the tank occurred above the heater location, resulting in failure. From Fig. 4 it is evident that water would be heated only above the location of the strap-on element and there would be no tendency for the water below the heater to circulate and mix with the hot water.

It is interesting to note that there is a poor relationship between the temperature setting of the commercial thermostat and the temperature of the water.

A large number of recent installations of hot water systems consist of a galvanized tank connected with copper tubing. This is not good practice because dissimilar metals constitute an electrochemical cell and may accelerate the corrosion of one metal. In addition, it has been reported by Kenworthy (9) that traces of copper which may be dissolved in such a system would deposit on the zinc coating of the galvanized tank, resulting in local failure. The effect of the above factors is, however, difficult to evaluate in an investigation such as this. At least half of the tanks examined had been connected with copper tubing, the remainder with galvanized iron pipe. From the data available no conclusions can be drawn.

A survey of the performance of a large number of tanks in one locality revealed that tanks equipped with 3-kw. heaters (manually controlled) gave longer service than tanks equipped with 500-w. heaters (automatically controlled). Study of the method of operation of the two groups of units revealed one significant difference. The heaters of the first group were operated intermittently resulting in the storage of hot water for a relatively short period each day, the capacity of the heater being large enough to meet the demand after being on for two to three hours. The heaters of the second group being of low capacity were left on continuously resulting in the storage of hot water in the tanks for the greater part of each day. Thus it would appear that tanks using large heaters operated intermittently constitute the better system. The thermostat should be used only as a safety device.

Four tanks from Lindsay had magnesium anodes for cathodic protection. The average service life of these tanks was one year and seven months. Fig. 9 illustrates the condition of a typical anode after use and the appearance of the tank in which it was installed. The appearance of the inside of this tank was similar to that of the standard tank not equipped with a magnesium anode (Fig. 8). The deterioration of the anode appears to be due· to local action between the magnesium and the steel core upon which it was cast. It is evident that this type of magnesium anode does not protect the tank and hence does not improve the service life of a galvanized tank in service at Lindsay.

An improved design of magnesium anode might be more effective than those used in Lindsay, especially if it was used in areas where the water has a high conductivity and the ability to deposit a protective scale.

Corrosion Prevention

The methods of preventing or decreasing the corrosion of hot water storage tanks can be listed generally as follows:

1. Improved design of tanks and better manufacturing control, using existing materials;
2. Treatment of water;
3. Cathodic protection;
4. Use of other materials for tanks.

As was discussed above, a thick uniform coating of zinc is desirable even under the best conditions and therefore all possible effort should be made to achieve this. If necessary, the design of the tank should be changed to allow for close inspection during manufacture and this should result in a better quality product.

The characteristics of the water are basic when considering corrosion prevention. A great deal has been written regarding the various methods of treating water to make it less corrosive. These methods usually involve considerable cost when the entire supply of water is to be treated. Less than 25% of domestic water supply is heated and passes through the hot water system where, because of the higher temperatures involved, corrosion is the greatest problem. It is suggested therefore, that the use of corrosion inhibitors such as polyphosphates or silicates be considered to protect individual household hot water systems. This would involve the treatment with inhibitor of a relatively small quantity of water. A program to test the usefulness of these inhibitors in hot water tank systems is now being initiated.

Acknowledgments

References

1. BIALOSKY, J. M. Corrosion, 3: 192-197. 1947.
2. BONILLA, C. P. Trans. Electrochem. Soc. 87: 237-254. 1945.
3. BURNS, R. M. and SCHUH, A. E. Protective coatings for metals. Reinhold Publishing Corporation, New York. 1939.
4. DAESEN, J. R. Galvanizing handbook. Reinhold Publishing Corporation, New York. 1946.
5. GILBERT, P. T. Pittsburgh International Conference on Surface Reactions. Corrosion Publishing Co., Pittsburgh. 1948.

6. HOOVER, C. P. Corrosion, 3: 185-191. 1947.
7. HOXENG, R. B. Corrosion, 6: 308-312. 1950.
8. HOXENG, R. B. and PRUTTON, C. F. Corrosion, 5: 330-338. 1949.
9. KENWORTHY, L. Metallurgia, 27: 203-204. March, 1943.
10. KENWORTHY, L. and SMITH, M. D. J. Inst. Metals, 70: 463-489. 1944.
11. ROWLAND, D. H. Trans. Am. Soc. Metals, 40: 983-1011. 1948.
12. ROWLAND, D. H. and ROMIG, D. E. Trans. Am. Soc. Metals, 31: 980-997. 1943.
13. SCHIKORR, G. Trans. Electrochem. Soc. 76: 247-258. 1939.
14. STOCKWELL, H. P. Eng. and Contract Record, 54: 10-18. October, 1941.

EXPLANATION OF PLATES

PLATE I

FIG. 5. *Sample of standard tank in service at Port Hope, Ont., for two years.* *Failed by pitting.*
FIG. 6. *Sample of standard tank in service at Belleville, Ont., for two years.* *Failed by pitting.*
(*Note dross inclusions and lack of corrosion products over pits.*)
FIG. 7. *Sample of standard tank in service at Hamilton, Ont., for three and one-half years.* *Failed by pitting.*
FIG. 8. *Sample of standard tank in service at Lindsay, Ont., for two and three-quarter years.* *Failed by pitting.*
FIG. 9. *Sample of a tank and the magnesium anode (used to provide cathodic protection) in service at Lindsay, Ont., for two years.* *Failed by pitting.*

PLATE II

FIG. 10. *Samples from Hamilton.* (A_1 and A_2). *Outside zinc coating—showing the zinc alloy layers and the steel base; 1, eta; 2, zeta; 3, delta$_1$; 4, gamma; 5, steel.* (B_1 and B_2). *Inside top—showing the steel, the slightly attacked delta$_1$ layer, the blistered zeta layer, the complete replacement of the eta phase by corrosion products (c), and the scale (b) deposited by the water.* (C_1 and C_2). *Inside bottom—similar to (B_1), except that the eta layer has been partially replaced by corrosion products and there is a thicker scale deposited from the water. The bakelite lacquer and the bakelite mount marked (a) are visible above the scale in C_1.*

NOTE:

1. The indication of polarity reversal between the zeta layer and the delta$_1$ layer, as evidenced by the failure of the zeta layer to completely protect the delta$_1$ layer.
2. That there is a heavy scale formed from the hard water which is not too protective.

PLATE III

FIG. 11. *Samples from Ottawa.* (A). *Outside zinc coating—showing the steel, the gamma, the delta$_1$, the zeta, and the eta layers.* (B). *Inside top—showing the steel, the delta$_1$ layer, the pitted zeta layer, the complete replacement of eta by corrosion products, some scale, the lacquer, and the bakelite.* (C). *Inside bottom (unetched)—showing the pitted steel and the remainder of the zinc.*

NOTE:

1. The indication of polarity reversal between the zinc and the steel as evidenced by the failure of the zinc to protect the steel.
2. That the scale was nonprotective.

FIG. 12. *Samples from Lindsay.* (A_1 and A_2). *Outside zinc coating—showing the steel, and the alloy layers (Fig. 10).* (B_1 and B_2). *Inside top—showing the steel, some gamma, the delta$_1$, the slightly blistered zeta layer, the complete replacement of the eta layer by corrosion products, the bakelite lacquer and the bakelite mount. Note that there is some evidence of a scale deposited from the water on B_2.* (C_1 and C_2). *Inside bottom—similar to (B_1) except that the zeta layer shows no blistering and some of the eta layer remains. There is some evidence of scale deposited from the water on C_2.*

NOTE:

1. That no reversal of polarity is indicated between the phases of the zinc coating.
2. That in spite of Lindsay's comparatively hard water there is no evidence of heavy scaling. The scale that does form is nonprotective.
3. That there would be a linear relationship between tank life and the thickness of the zinc coating (secondarily the thickness of the steel).

PLATE IV

FIG. 13. *Samples from Port Hope.* (A_1 and A_2). *Outside zinc coating—showing the steel, the gamma, delta$_1$, zeta, and eta layers.* (B_1 and B_2). *Inside top—showing the steel, some gamma, the attacked delta$_1$ layer, the blistered zeta layer, the complete replacement of the eta layer by corrosion*

products, and some evidence of scale deposited from the water. (C_1 and C_2). Inside bottom— showing the steel, the gamma, delta$_1$, and zeta layers fairly intact, the partial replacement of the eta layer by corrosion products, and some evidence of a scale deposited from the water.

NOTE:

1. That there is an indication of a reversal of polarity between the zeta and delta$_1$ layers of the zinc coating.

2. That the scale deposited from the water is only slightly protective.

FIG. 14.   *Samples from Belleville.   (A_1 and A_2).   Outside zinc coating—showing the steel, the gamma, delta$_1$, zeta, and eta layers.   (B_1 and B_2).   Inside top—showing the steel, some gamma, the attacked delta$_1$ layer, the blistered zeta layer, the complete replacement of the eta layer by corrosion products, and some evidence of scale deposited from the water.   (C_1 and C_2).   Inside bottom—showing the steel, the gamma, delta$_1$, and zeta layers fairly intact, the partial replacement of the eta layer by corrosion products and some evidence of a scale deposited from the water.*

NOTE:

1. That there is an indication of a reversal of polarity between the zeta and delta$_1$ layers of the zinc coating.

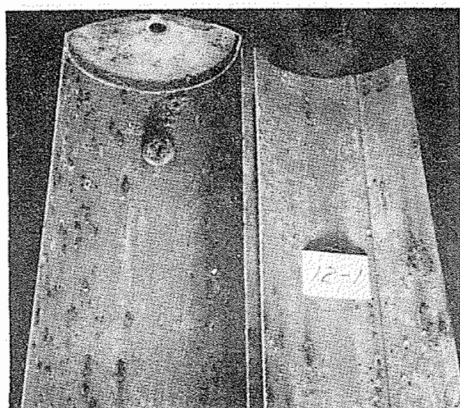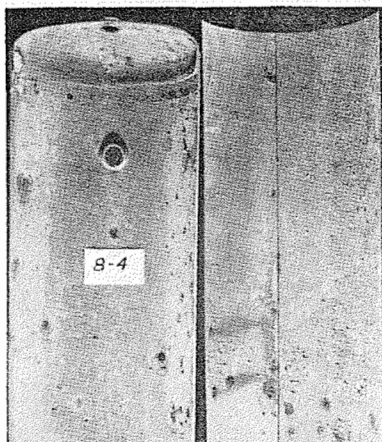*2. That the scale deposited from the water is only slightly protective.*
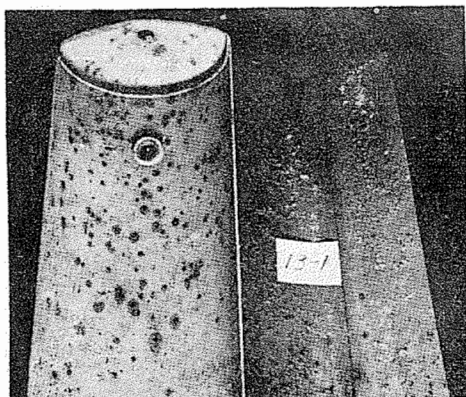
PLATE I
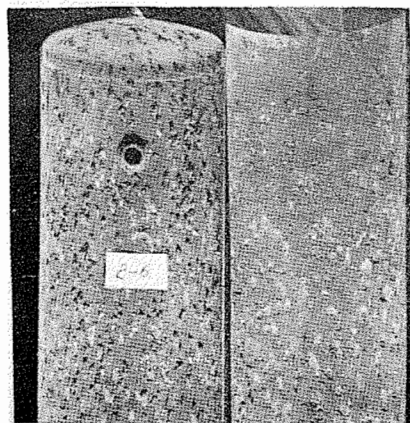

FIGURE 5

FIGURE 8

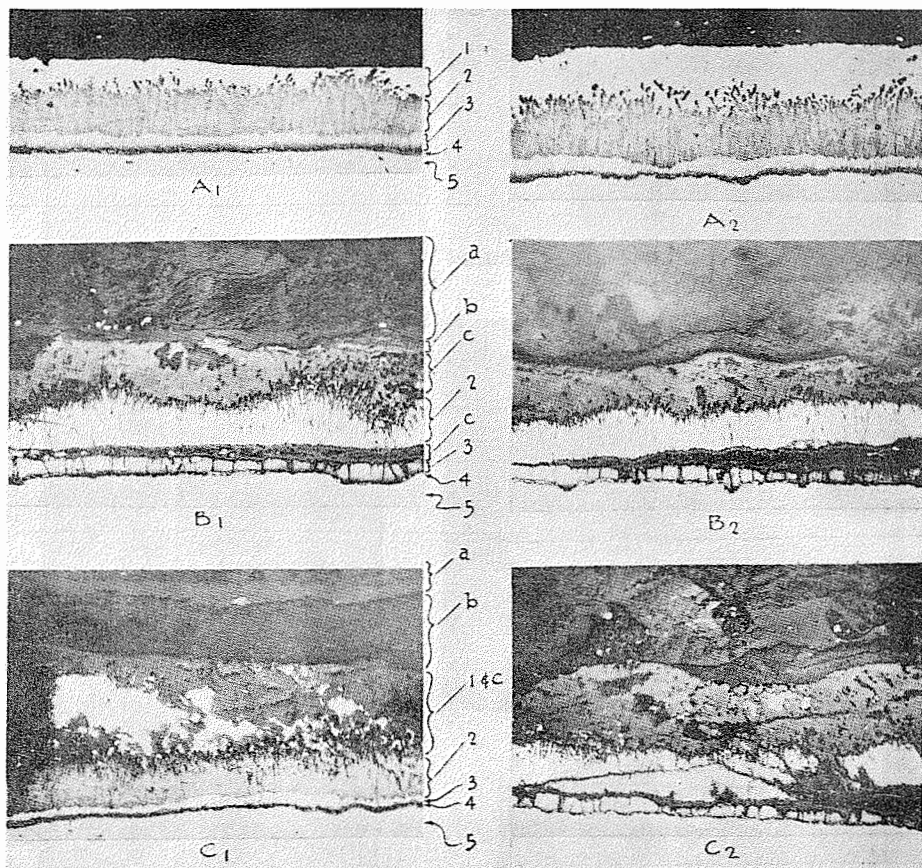FIGURE 6

FIGURE 9

FIGURE 7

PLATE II

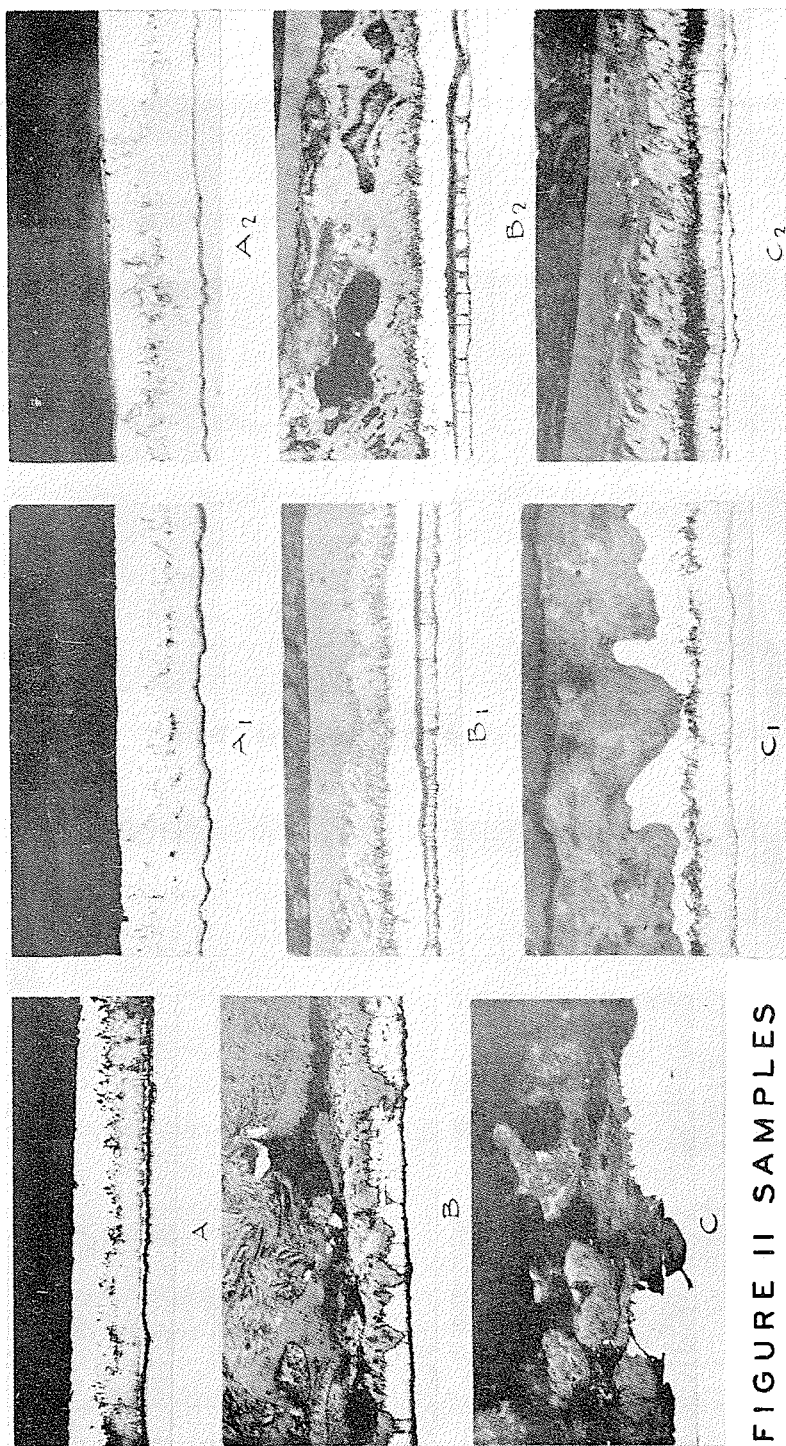FIGURE 10   SAMPLES FROM HAMILTON

PLATE III

FIGURE II SAMPLES FROM OTTAWA

FIGURE 12 SAMPLES FROM LINDSAY

PLATE IV
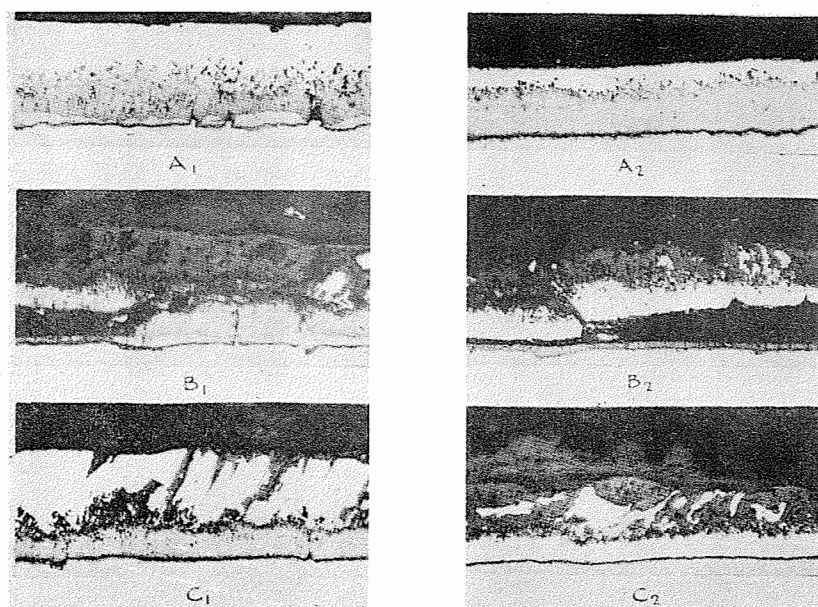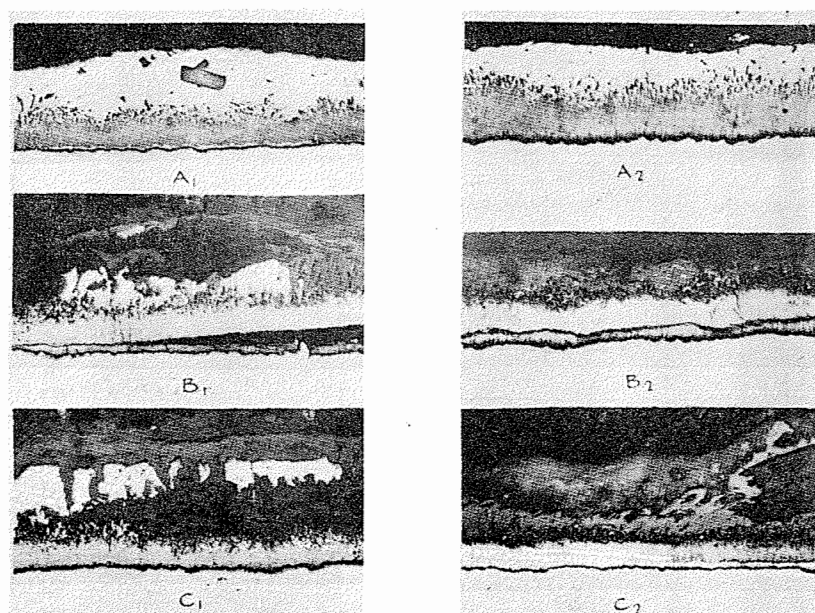

FIGURE 13   SAMPLES FROM PORT HOPE

FIGURE 14   SAM   FROM BELLEVILLE

RESEARCH PAPERS

of the

DIVISION OF BUILDING RESEARCH

Order No.		Price
DBR 21	Soil temperature studies - a progress report by R.F.Legget and F.L.Peckover. Reprint Proceedings Highway Research Board. Dec. 1949.	10 cents
DBR 27	A study of vibrations produced in structures by heavy vehicles by H.B.Sutherland. Reprint Proceedings Highway Research Board. Dec. 1950.	10 cents
DBR 29	Stress distribution below pavements under trolley bus loadings by R.M.Hardy and P.J.Rivard. Reprint Proceedings Highway Research Board. Dec. 1950.	10 cents
NRC 2512	An investigation of the corrosion of domestic hot water tanks by P.J.Sereda, W.R.Thomas and M.Cohen. Reprint Canadian Journal of Technology. Oct.1951.	10 cents

A list of all publications of the Division of Building Research may be obtained from the Publications Section, Division of Building Research, National Research Council, Ottawa.