

ENGINEERING RESEARCH INSTITUTE  
UNIVERSITY OF MICHIGAN  
ANN ARBOR

FINAL REPORT

GALVANIC CORROSION IN WATER METERS

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Project 2216

BUFFALO METER COMPANY  
BUFFALO, NEW YORK

June, 1954

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## GALVANIC CORROSION IN WATER METERS

INTRODUCTION

This report covers the results of a study of the possible effects of galvanic couples in the corrosion of water meters, as indicated by electro-potential data. Tests were made on various electrically connected parts of the meters in several different types of water, the water samples being collected from various parts of the United States. Special equipment was assembled by means of which the solution potential of each part against a standard reference cell could be determined, as well as the amount and direction of electrical current flow between the parts through the water. Such tests indicate which of two metals are anodic (corroded), or cathodic (protected), and give a general idea of the location and extent of corrosive action.

The general objectives of this investigation as originally set up were as follows:

1. Study of information on corrosion of water meters in the literature and other available sources.
2. Tests on American frost-bottom meters to ascertain galvanic action between the bronze measuring chamber and the frost bottoms, the latter having been coated by various means.
3. Study of galvanic reactions set up by the insertion of a brass liner inside the frost bottom.
4. Study of galvanic reactions existing in various combinations of metals making up pinion and pivot parts in the gear trains.

These objectives were later extended somewhat to cover some other combinations of alloys in various meter parts, as will be evident from the Summary and material in later sections of the report.

Some points regarding the use and limitations of electropotential data should be considered. In general, the extent of possible corrosion of

the anodic metal is a function of the current as measured in milliamperes, but more specifically of the current density. The total current is a function of the conductivity of the water and the potential difference existing between anode and cathode. If, however, the anode area is small compared to the cathode area, the corrosion of the anode metal will be much more extensive than if the reverse is true. Indeed, with a large anode area the corrosion may be negligible.

Another factor in galvanic corrosion is polarization, which may occur on either anodic or cathodic metals. Polarization may be defined as the change in the solution potential of a metal surface in an electrolyte as a result of the flow of current to or from it. If the anode becomes polarized the solution potential decreases, while cathode polarization causes an increase in the solution potential. Thus in galvanic couples, the effect of polarization is to bring the potentials of the coupled metals closer together, to the point that corrosion may cease altogether. Polarization is the result of chemical reactions taking place on anode or cathode areas as a result of the electrolytic action of the cell. In actual tests, the presence of polarization is indicated by a decrease in current flow. This may happen quickly or may require a considerable time interval before it becomes evident.

In view of what has been said, it is clear that great care must be exercised in the interpretation of the results of potential measurements in corrosion when time does not permit extended study of possible effects of polarization or supplementary weight loss tests.

This investigation was authorized by the Buffalo Meter Company in January, 1954, and all meters and meter parts were supplied by them. They also arranged for shipment of water samples from various parts of the country. All tests were made in the laboratories of the Department of Chemical and Metallurgical Engineering at the University of Michigan.

#### SUMMARY OF RESULTS

##### 1. General Comparison of Water Types as Related to Meter Parts.

The Phoenix water is the most corrosive, but promotes polarization on meter parts which tends to inhibit corrosion. Polarization tendencies were also noted in Buffalo and Dixon waters. Los Angeles and Ann Arbor waters did not exhibit polarizing tendencies. Tests were not of sufficient duration to be final in this regard. It appears that Ann Arbor and Los Angeles waters would stand next to Phoenix in corrosiveness.

##### 2. Inner Coatings on American Frost Bottoms.

Aluminum paint and polyvinyl plastic decrease galvanic conditions somewhat, but other effects

indicate use of the plastic to be very questionable. The Aluminum paint may be a factor in causing deposits of a zinc compound on the inside of galvanized and painted frost bottoms.

3. Brass Liners. Galvanic action was more marked between galvanized and painted American frost bottom and brass liner, than between competitor's enameled frost bottom and brass liner, but polarization effects are stronger in the former combination, and it does not appear that corrosion of the frost bottoms would be troublesome.

4. Diaphragms. Galvanic effects would be negligible with any combination of monel, bronze, or stainless-steel diaphragms in contact with bronze measuring chambers.

5. Nickel Bronze Measuring Chamber. The regular bronze casing is anodic to the nickel bronze which would indicate that the bronze would corrode rather than the nickel bronze. This might be serious in highly alkaline waters but not otherwise.

6. Pinions. Evidence indicates that corrosion of the pinions is due to an anodic condition caused by coupling of the pivot and the chrome-plated gear and pinion assembly, aggravated by residual stresses in the pinion and surface stresses produced by rubbing of the gear on the pinion. Suggestions for removing the condition are made.

7. White Deposit in Frost Bottom. It is postulated that the white deposit sometimes found inside frost bottoms is the result of a reaction, galvanic or chemical, between aluminum sulphate, the aluminum asphalt-base paint, and the galvanized coating on the frost bottom.

8. PTI-Treated Parts. The treated measuring chamber was cathodic to both frost bottom and regular bronze bottom. This treatment would not eliminate galvanic effects.

#### REVIEW OF INFORMATION FROM OTHER SOURCES

Before starting test procedures, a search of available literature regarding corrosion in water meters was made. This included references which had been supplied by Buffalo Meter Company. Practically no references gave results of galvanic corrosion specifically applying to water meters, but there are, of course, almost numberless references concerning galvanic corrosion and corrosion in general.

In 1923, a short investigation\* of corrosion conditions in water meters in the city of Kalamazoo, Michigan, was made by the writer. At that time the city water contained a high bicarbonate hardness and this condition caused severe corrosion of gear trains in all-bronze meters. Laboratory tests as well as service tests in meter installations proved the value of anodic protection of the gear trains by using meters with cast-iron bodies. Under similar conditions of high alkalinity, the same principle holds true today, as it is a well known general means of corrosion control. Conditions in Kalamazoo, however, changed with the installation of a water-treating plant, and the condition causing the corrosion of gear trains was removed. It might be observed that in many cases, water treatment has only changed the complexion and location of corrosion troubles.

Classified statistical information from studies of meters which have been in service for several years would be the best source of information regarding behavior of metal couples under various corrosive conditions. The only information of this type was received in a personal communication\*\* listing five varieties of available measuring chambers with tentative recommendations for conditions under which they might be used. Basis for recommendations were not included. The conclusions mentioned are:

- "1. Meters with standard bronze chambers and stainless steel trim (division plates, driving dogs, etc.). These are suitable in cases where corrosion is noted only on these parts.
2. Meters with yellow brass chambers. These are suitable for sulphide waters and some hard waters high in bicarbonates.
3. Nickalloy chambers (65 copper - 20 nickel - 5 tin - 5 lead - 5 zinc) for waters high in chlorides.
4. Standard meter with a zinc liner where electrolytic action results in slight pitting of the chamber.
5. Meters with electro-tinned chambers - good in many well waters and waters high in carbon dioxide."

The value of such general statements would depend upon the number of units observed and a most complete knowledge of the conditions of operation of each unit. If based on rather casual observations, their value would be questionable.

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\*Report No. 77, Dept. Eng. Research, University of Michigan

\*\*Letter from Mr. H. F. Barrett dated April 13, 1954.

Visits were made to the water-treatment plant and meter-maintenance division of the Ann Arbor water department. Trident meters are used exclusively in this water system, and an opportunity was given to inspect some meters which had recently been pulled off the line. No corrosion of gears and pinions was observed, and the maintenance crew stated that deterioration of pinions, when observed seemed to be due more to wearing away of the metal than to corrosion. Corrosion was probably a factor, but was not recognized as such. The meters all have brass liners inside the frost bottoms, and upon inquiry the crew stated that the brass liners greatly facilitate cleaning out the frost-bottom chamber. Without the liner the corrosion product in the frost bottom is hard and adherent, requiring vigorous scraping to remove it, whereas with the liner the product is soft and easily removed.

Some corrosion of the pit type was noted on the brass liners; in some cases there were small holes completely through the liners. The pits were surrounded by greenish-colored corrosion product. In general, it appeared that this corrosion started on the inside of the liner and was local in nature - not a result of any galvanic action. It was stated that some plastic-type liners had been used but were not satisfactory, particularly where warm water was being metered.

#### WATERS INVESTIGATED

Since the use of water meters is universal throughout the country, it was deemed advisable to secure as wide a variety of waters as possible with which to carry out tests. Waters were secured from:

Ann Arbor, Michigan,  
Buffalo, New York,  
Dixon, Illinois,  
East Aurora, New York  
Los Angeles, California,  
Phoenix, Arizona.

Table I presents a comparative tabulation of the analysis of these waters. The complete analyses as submitted will be found in the Appendix. Table I includes only those factors which would have a bearing on corrosion.

The Ann Arbor water probably represents about the average condition of a softened municipal supply. It is made up of 30 to 40 percent deep-well water which is quite hard (400-450 ppm total hardness) and 60 to 70 percent water from the Huron River which flows through the city, and is quite soft. The high pH value is maintained to offset the high dissolved oxygen, which would otherwise make the water more corrosive. Concurrently, the alkalinity

TABLE I

WATER ANALYSES  
 Values Shown Are in Parts Per Million

Chemical Constituents in Water	Ann Arbor, Mich.	Buffalo, N. Y.	Dixon, Ill.	East Aurora, N. Y.	Los Angeles, Cal.	Phoenix, Ariz.
Total hardness as CaCO <sub>3</sub>	83.2	136	307	62	210	288
Total dissolved solids	190	165	308	--	340	1,011.5
Alkalinity as CaCO <sub>3</sub>	35	90	300	Bicarbonates reported as 337	169	229 (Bicarbonate)
Calcium	18.8	--	66.9	16	57	68
Magnesium	8.8	--	34	6	17	28.7
Sodium	28.8	--	4.1	--	37	241.2
Chlorides	22	20	2	38	46	424
Nitrates	--	0.08	Tr	--	--	--
Sulphates	77.4	32	13.2	120	55	20
Oxygen dissolved saturated	saturated	saturated	--	--	--	--
Hydrogen-ion concentration as pH	10-10.5	7.8	7.0-7.2	7.5	--	--

is maintained at such a point that there is a slight scale-forming tendency, it being reported from the control laboratory that a thin scale is frequently found in meters which have been pulled off the line for overhauling and inspection.

No alum is used as coagulant in the Ann Arbor treating plant, since magnesium hydroxide, formed as a result of the softening process, acts as a satisfactory coagulant.

The Buffalo water is taken from Lake Erie and is typical of Great Lakes water used in many cities such as Cleveland, Detroit, and Chicago. It is relatively soft, does not receive extensive softening treatment and is high



in dissolved oxygen. The pH represents about neutral conditions, and no attempt is made to offset the high oxygen content by increasing the pH.

The Dixon, Illinois, water is a typical, hard, well water with high carbonate hardness. The pH is reported as 7.0-7.2, and this seems strange in view of the very high alkalinity. It would seem that this water would cause corrosion in all-bronze meters.

The East Aurora, New York, water has high sulphate and bicarbonate hardness, but the analysis must be incomplete, since the magnesium and calcium present could not be coupled with all the sulphate bicarbonate and chloride present. In any event, it appears to be a well water which has not received any treatment. If the bicarbonate figure is correct, it seems strange that the pH is not higher. In this respect it is similar to the Dixon water.

The Los Angeles and Phoenix waters differ from the others in chloride content, the chlorides existing largely as sodium and magnesium chlorides. This condition is quite typical of many waters from the southwestern part of the United States. The presence of the chlorides increases the conductivity of the water and thus accelerates galvanic corrosion. The greater corrosiveness of these waters is indicated by the results of the presently reported study.

#### EQUIPMENT AND LABORATORY PROCEDURE

The equipment assembled for the laboratory tests was modeled after that described by LaQue and Cox,\* and is illustrated in Figs. 1 and 2. Figure 1 is a detail drawing of one test unit and Fig. 2 is a photograph of the entire assembly. The panel board (10 in Fig. 1) was equipped with binding-past terminals for the simultaneous operation of six test cells as will be noted in Fig. 2. Only one test cell is shown in Fig. 1 as the others were identical in every detail. The identity of each part of the test cells is indicated on Fig. 1.

In starting a test on two metal parts, one end of a 2-foot length of heavily insulated No. 14 copper wire was soldered to a convenient point on each test piece. The soldered joint was then completely covered with a specially prepared, waterproof, insulating lacquer. This lacquer was available through the courtesy of Dr. L. L. Carrick of the Department of Chemical and Metallurgical Engineering at the University. The lacquer was allowed to harden for twenty-four hours.

\*Proc. Am. Soc. Test. Mat. Vol. 40, p. 670 (1940).

Legend

1. 2 Gallon pyrex jar
2. Sample under test
3. Sample under test
4. Wood slat support for samples
5. 100 cc beaker
6. Glass tubing
7. Flat 2 hole rubber stopper
8. Stop cocks
9. Saturated calomel reference cell
10. Masonite panel board
11. Binding post for reference cell
12. Low resistance switch
13. Calibrated resistance
14. Binding post for test sample
15. Leads to potentiometer
16. K<sub>2</sub> precision potentiometer

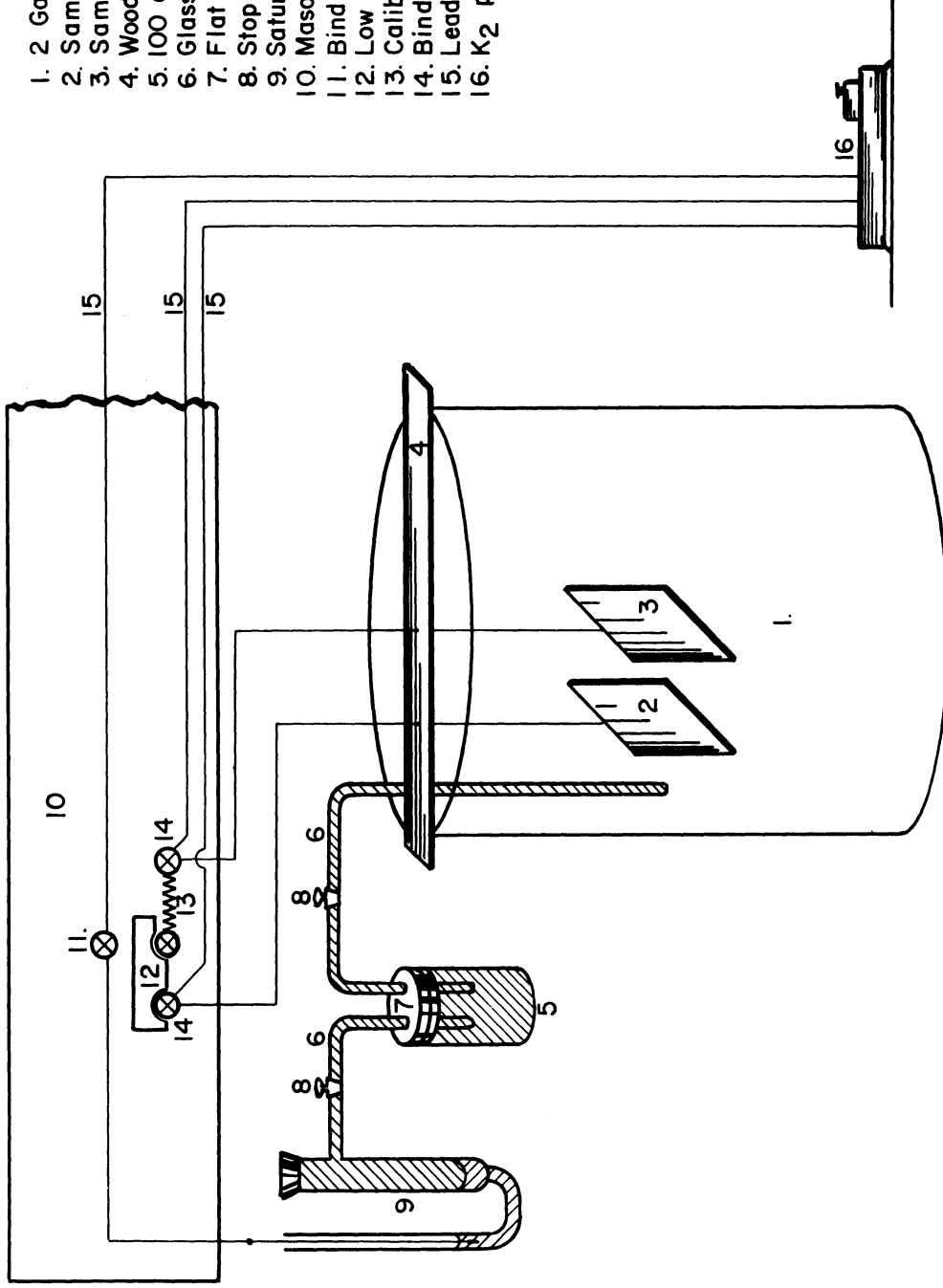


Fig. 1. Equipment for electrochemical measurements in corrosion tests

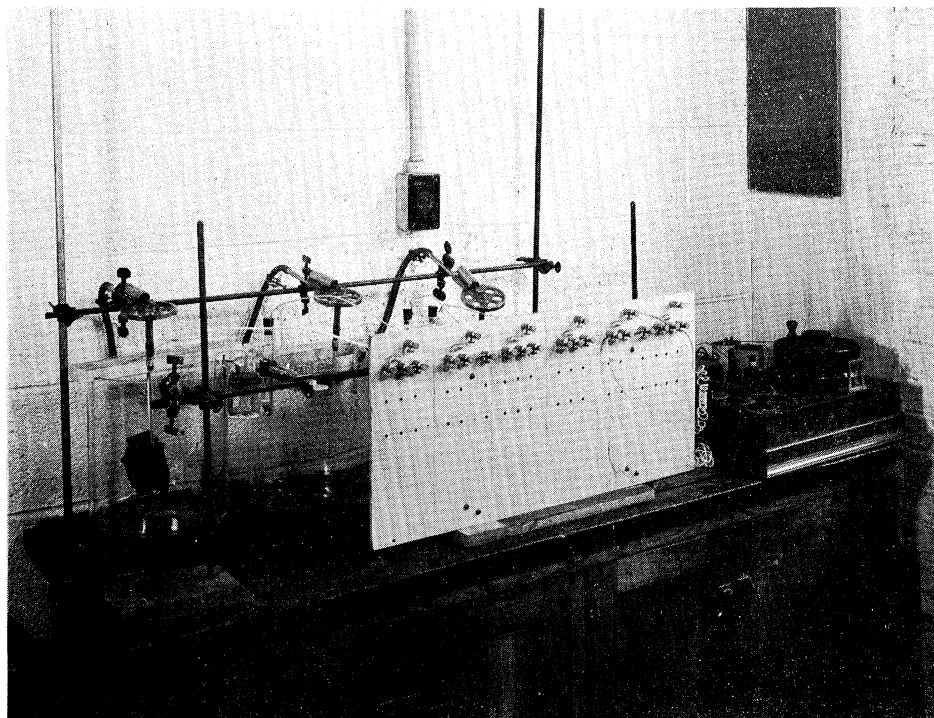


Fig. 2

The pyrex jar (1) (numbers in parentheses refer to Fig. 1) having been filled with the water to be used in the test, the two metal parts (2 and 3) were suspended in the water, supported by a wooden slat (4) resting on top of the jar. The No. 14 copper wire provided both a means of suspension and a low-resistance electrical connection to the samples. A stirring device driven by compressed air (shown in Fig. 2) provided mild agitation of the water. The free ends of the copper wire were next connected to the binding posts (14) on the panel board, connection of the saturated calomel half-cell having previously been made to the binding post (11). The stirring device was then started, and about an hour later the first readings were made.

In making solution-potential readings, the leads from the precision potentiometer (16) were connected to the binding post (11) and one of the terminals (14) from the samples, switch (12) being open. The emf between the sample and the standard half-cell was then read. The standard voltage of the saturated calomel half-cell is  $-0.2458$  volt, so that readings on the potentiometer represent the positive difference between this standard reference voltage and that of the sample. It is customary to report the voltage of the complete cell each time rather than making the required algebraic computation, since it is only the difference in the voltage which is significant, and this is the same in either case.

To make a current reading the switch (12) is first closed. This completes the circuit to the test samples through the resistance (13), which has a value of about 1 ohm. The leads from the potentiometer are next connected to the binding posts (14) and the emf over the resistance (13) determined. The calculation of the current is then simple, since emf and resistance are both known. Current values are reported in milliamperes.

Similar readings were made at various intervals over the period of the run. On completion of the test, the water from the jars was siphoned into the original containers.

While no weight-loss tests were made, the samples after test were compared visually with parts of meters which had corroded in service, as far as it was possible.

## RESULTS AND DISCUSSION

### Frost Bottoms vs Measuring Chambers

In this test, galvanic conditions between American measuring chambers and frost bottoms with various coatings were observed. All six types of waters were used. Results are tabulated in Table II. While at first glance the table may seem to consist of a mass of confusing and scattered figures, close study reveals consistency in most respects, some definite trends, and the suggestion of some questions. Conclusions should be reached from comparison of group data and not individual items. Since the relative areas of the parts here involved are not widely different, the so-called "area effect" is not important, and observed variations can largely be attributed to polarization effects, the fundamental factors of which, it must be confessed, are not clearly understood. Corrosion authorities are agreed on this.

The first clearly indicated condition is that in every case, no matter what the conditions, the frost bottoms are anodic (have higher solution potentials) and current flow as from the frost bottoms through the water to the measuring chambers. This means that corrosion will take place on the frost bottoms, and the measuring chambers will be protected. The relative rates of corrosion are indicated by the current values and these are quite consistent throughout. For example, one would predict most trouble from the Phoenix water, and this is a known fact.

Regarding the effects of the three inner coatings on the frost bottoms, some trends are indicated. If one averages the average current values in the six types of water for the three types of frost bottoms (an entirely



arbitrary procedure) it will be found that the averages for the painted and plastic-coated frost bottoms are not widely different, but both are less than the average for the frost bottom galvanized only. This would indicate at least a little decrease in galvanic action by coating the inner surface of galvanized frost bottoms. When the painted and plastic-coated frost bottoms are compared on the basis of average current there is little difference, but this gives an entirely erroneous picture, for when the variation in current is studied it is seen that in the case of the plastic-coated frost bottoms the current increased during the test with one exception (the Phoenix water). The painted frost bottoms with one exception (the Dixon water) showed a decrease in current flow during the test. This indicates the presence of some type of depolarizing action as a result of the presence of the plastic, and its use would be questionable.

Regarding the Phoenix and Dixon waters it should be stated that considerable difficulty was encountered in obtaining constant readings at a given time. The Phoenix water conditions seemed to change quickly when disturbed, and the Dixon water appeared to have a strong polarizing tendency, as evidenced by an increase in solution potential of the measuring Chambers and low current values. This was noted in other waters too, but similar measurement difficulties were not encountered. For this reason, the fact that the Phoenix and Dixon waters were the exceptions mentioned in the previous paragraph may be due to the unsteady conditions at the times that potential readings were being made. The increase in current in the case of the Dixon water is not great.

In the majority of the runs reported, the outside of the frost bottoms were not lacquered. In three of the runs the outside was lacquered. This decreased the total current but did not change the trends observed, and as time was a factor, runs were not all repeated with this outer coating.

An anomalous situation seems to exist with regard to the Ann Arbor, Buffalo, and Dixon waters and shows that mineral content alone is not a complete guide to the corrosiveness of the water. The Ann Arbor water is the softest one used, the Dixon water is quite hard and the Buffalo water is intermediate in hardness. To explain the low current values in Buffalo and Dixon waters one must turn to polarization effects. It will be noted that except when the plastic-coated frost bottom was in the current, the solution potentials of the measuring chambers were much higher than in the Ann Arbor and Los Angeles water. One of the evidences of polarization is an increase in cathode potential. By the same token Ann Arbor and Los Angeles waters do not appear to have definite polarizing tendencies. In this connection it may be recalled that the Ann Arbor softening plant is very meticulous in maintaining a pH of 10.0-10.5 for corrosion control. This pH is considerably higher than usual. Some serious cases of corrosion in hot water service in the Ann Arbor area have come to the writer's attention.

The solution potentials of the plastic-coated frost bottoms are all lower than in the other tests, which would indicate a polarizing effect. Solution potentials of the coupled measuring chambers, on the other hand, are also lower, which indicates depolarization, and this latter effect appears to control, since the current flow increased. Changes in solution potential, however, are no guide to interpreting current flow; their only value is to indicate direction of current flow.

A visual examination of the three types of frost bottoms after being immersed in all the different types of waters for various periods of time shows the plastic-lined ones to have the worst appearance. Brownish-red films of ferric oxide were observed inside and outside; a condition not seen on either of the other types. The galvanized frost bottoms presented the best appearance, since the ones painted on the inside have a white powdery deposit which rubs off on the fingers, while the galvanized bottoms showed no such deposit. This latter condition suggests a line of speculation related to information on page 2 of a letter from Mr. Barrett dated January 5, 1954, although it is not known whether the meters involved had frost bottoms painted inside with aluminum asphalt paint.

In the letter mentioned above it was stated that a white deposit was noted on the frost bottoms of some meters installed in Buffalo and Philadelphia, and it was thought that some relation existed between the residual aluminum sulphate in the water and the formation of the white deposit. Analyses supplied with the letter showed the presence of large amounts of zinc in the deposit. From an entirely hypothetical viewpoint, provided the aluminum paint was present, it might be possible that some reaction, chemical or galvanic, would take place between the aluminum sulphate, the aluminum paint, and the galvanized surface, by means of which relatively large amounts of zinc compound might be found. The sulphide, sulphate, and oxide of zinc all are white, so that actual identification by analysis would be necessary. This is a shot in the dark, but under the circumstances, it was considered to be worth mentioning.

Based on the results of this test it may be stated that the aluminum paint and the plastic coating decrease galvanic effects somewhat, compared to the frost bottom galvanized only, but the effect of the plastic coating on the galvanic conditions, coupled with observed corrosion products, render its use very questionable. Granting ignorance on several paints, the following question is in the writer's mind: Why is any supplementary coating necessary if a brass liner is to be used?

#### Frost Bottoms vs Brass Liners

In this test, galvanic conditions between cast-iron frost bottoms and brass liners were studied. For one cell, the couple consisted of an

enameled Rockwell frost bottom with brass liner, and in the other cell was an American frost bottom, galvanized and painted inside with aluminum paint, with brass liner. Ann Arbor and Phoenix waters were used in the test. Results are presented in Table III.

A comparison of current averages indicates that there is less galvanic action between the enameled frost bottom and the brass liner than between the American frost bottom and the liner. However, it is interesting to note that in the Phoenix water, which is definitely more polarizing than the Ann Arbor water, the current in the American frost bottom-brass liner couple has dropped to about half the value of the other couple. The polarizing effect of the Phoenix water is shown not only by the drop in current in both cases but also by the rise in cathode potential (liner) in both cases. The conclusion then is that the American frost bottom-brass liner combination will work as well and probably better than the other in water that is strongly polarizing in effect, such as the Buffalo and Dixon waters.

#### Measuring Chambers vs Diaphragms

The results of these runs are shown in Table IV.

Here galvanic effects were so nearly absent that comparisons are not feasible. Solution-potential readings were in some cases fairly constant, but current readings were practically negligible. About the only conclusion to be drawn is that any combination of these metals as measuring chambers and diaphragms will be satisfactory.

#### Bronze Casing vs Nickel-Bronze Measuring Chamber

In this case a bronze casing and bottom were run against a nickel-bronze measuring chamber. Results are shown in Table V.

The bronze casing and bottom are here definitely anodic to the nickel-bronze measuring chamber, indicating protective action of the nickel bronze by the regular bronze. Current flow increases in both cases, the test in the Buffalo water being run for 72 hours to see whether polarizing conditions would be seen. Copper and nickel are not as much subject to polarizing conditions as other metals, but it would be expected that if the tests could have been continued for a longer period, current flow would begin to decrease. One would not expect that any serious corrosion of the bronze would result when coupled with the nickel bronze unless highly alkaline waters were being metered.



TABLE III

GALVANIC CONDITIONS BETWEEN FROST BOTTOMS AND BRASS LINERS

Couple	Water Used	Duration of Test, hours	Solution Potentials vs Calomel Half-Cell, volts						Current From Frost Bottom to Liners, milliamperes		
			At Start			At Finish			At Start	At Finish	Average
			Frost Bottom	Liner	Difference	Frost Bottom	Liner	Difference			
Rockwell enameled frost bottom vs brass liner	Ann Arbor Phoenix	48 48	0.645 0.611	0.098 0.125	0.547 0.486	0.646 0.656	0.085 0.140	0.561 0.516	0.80 1.50	1.08 1.18	0.94 1.34
American galvanized and painted frost bottom vs brass liner	Ann Arbor Phoenix	48 48	1.015 0.979	0.127 0.200	0.868 0.779	1.025 0.955	0.183 0.307	0.842 0.648	4.66 2.42	3.27 0.57	3.95 1.49

TABLE IV

## GALVANIC CONDITIONS BETWEEN MEASURING CHAMBERS AND DIAPHRAGMS

Couple	Water Used	Duration of Test, hours	Solution Potentials vs Calomel Half-Cell, volts						Current Flow as Indicated, milliamperes		
			At Start			At Finish			At Start	At Finish	
			Diaphragm	Meas. Chamber	Difference	Diaphragm	Meas. Chamber	Difference			
American bronze meas. chamber vs bronze diaphragm	Ann Arbor	40	0.543	0.133	0.410	0.092	0.083	0.009	0.015	0.00	--
	Phoenix	24	not constant	not constant	--	not constant	not constant	--	0.027	0.00	--
American bronze meas. chamber vs monel diaphragm	Ann Arbor	40	0.292	0.182	0.110	0.303	0.144	0.159	0.007	0.00	--
	Phoenix	24	not constant	not constant	--	not constant	not constant	--	0.02	0.005	--
Neptune brass chamber vs stainless-steel diaphragm	Ann Arbor	72	0.219	0.200	0.019	0.102	0.033	0.069	0.05	0.005	--
	Buffalo	72	0.176	0.065	0.111	0.00	0.00	--	0.02	0.00	--

TABLE V  
GALVANIC CONDITIONS BETWEEN BRONZE CASING AND NICKEL-BRONZE MEASURING CHAMBER

Couple	Water Used	Duration of Test, hours	Solution Potentials vs Calomel Half-Cell, volts				Current Flow From Bronze to Nickel Bronze, milliamperes				
			At Start		At Finish		At Start	At Finish	At Start	At Finish	
			Bronze	Nickel Bronze	Difference	Bronze					Nickel Bronze
Bronze vs Nickel Bronze	Ann Arbor Phoenix	24 72	0.400 0.454	0.171 0.115	0.229 0.339	0.500 0.422	0.127 0.039	0.373 0.383	0.64 0.748	0.71 1.20	0.68 0.974

Galvanic Conditions Between Gears, Pinions, and Pivots

These tests were carried out in order to determine whether or not galvanic conditions could account for unpredictable corrosion of pinions (parts 67 and 68) in American meters. Prior to August, 1944, these pinions had been made from sand-cast bronze rod of the 85 copper - 5 tin - 5 zinc - 5 lead type, but since that date these parts have been made from drawn bronze pinion rod of the 88-4-4-4 type. The gear and pinion assemblies are chrome plated before installation in meters. When the trouble develops it consists of disintegration of the pinion teeth where they are in contact with the gear teeth.

Three groups of tests were run in this connection; the couples used, as well as results, are presented in Tables VI, VII, and VIII. Several pinions which had suffered this type of deterioration were also available and provided a valuable picture of the results of the corrosive action.

As will be noted from Tables VI, VII, and VIII, no current flow could be detected in the majority of the tests, and where any could be detected it was very small. It is necessary therefore to tabulate the anodic and cathodic areas as indicated by solution-potential readings and decide whether or not any trends are indicated. Such a tabulation has been prepared in Table IX. This can be done without reference to the type of waters, since the couples behaved similarly in each of the two waters used.

No definite trend as to possible relative susceptibility to corrosion of the cast pinion as compared to the drawn pinion is evident from Table IX. In the case of the cast gear and drawn pinion there was a reversal of polarity with the pinion becoming anodic during the course of the test. If the pinion rod is cold-drawn, one would expect it to be on the anodic side since strain-hardened metal is more subject to corrosion than fully annealed metal of the same composition.

There appears to be a definite trend when chrome-plated parts are involved in tests with the bronze and monel pivots. In all cases the chrome-plated gear and pinion assemblies are anodic to the pivots and in three out of four cases it was possible to obtain slight current-flow values with these couples. It is thought that these results might lead to a hypothesis regarding the corrosion of the pinions since they are in metal-to-metal contact with the cathodic pinions.

Before further discussion, a consideration of the gear and pinion assembly shown in Fig. 3 is in order. These two parts were removed from American meter No. 1,475,548, through which had passed 17,657 gallons of liquid, supposedly water. In any event, the liquid was quite corrosive judging from the overall appearance of the meter. The teeth of the pinions have obviously been eaten away where they were in contact with the teeth of the other intermediate gear. On either side, however, there is very little disintegration of

TABLE VI

GALVANIC CONDITIONS BETWEEN GEARS AND PINIONS

Couple	Water Used	Duration of Test, hours	Solution Potentials vs Calomel Half-Cell, volts						Current Flow, milliamperes		
			At Start			At Finish			At Start	At Finish	Average
			Gear	Pinion	Difference	Gear	Pinion	Difference			
Cast gear vs cast pinion	Ann Arbor	40	0.087	0.271	0.184	0.039	0.239	0.200	0.03	0.02	0.025
	Phoenix	40	0.122	0.301	0.179	0.102	0.380	0.278	0.02	0.02	0.02
Cast gear vs drawn pinion	Ann Arbor	40	0.128	0.117	0.011	0.046	0.125	0.079	0.00	0.00	0.00
	Phoenix	40	0.159	0.148	0.011	0.145	0.200	0.0555	0.00	0.00	0.00
Cast gear vs drawn pinion, both chrome-plated	Ann Arbor	40	0.300	0.082	0.218	0.207	0.095	0.112	0.00	0.00	0.00
	Phoenix	40	0.264	0.102	0.162	0.260	0.112	0.148	0.00	0.00	0.00

TABLE VII

## GALVANIC CONDITIONS BETWEEN BRONZE PIVOTS AND GEAR ASSEMBLIES

Couple	Water Used	Duration of Test, hours	Solution Potentials vs Calomel Half-Cells, volts						Current flow, milliamperes		
			At Start			At Finish			At Start	At Finish	Average
			Gear and Pinion	Pivot	Difference	Gear and Pinion	Pivot	Difference			
Bronze pivot vs cast gear and cast pinion	Ann Arbor	24	0.220	Unsteady	0.220	Unsteady	0.200	0.200	0.01	0.02	0.015
	Buffalo	24	0.241	0.220	0.020	0.279	0.057	0.222	0.015	0.01	--
Bronze pivot vs cast gear and drawn pinion	Ann Arbor	24	0.149	0.332	0.183	0.137	0.140	0.003	0.01	0.02	0.015
	Buffalo	56	0.189	0.300	0.111	0.132	0.150	0.018	0.00	0.00	0.00
Bronze pivot vs chrome-plated cast gear and drawn pinion	Ann Arbor	24	0.291	0.133	0.158	0.183	0.034	0.149	0.015	0.005	--
	Buffalo	24	0.193	0.035	0.158	0.247	0.022	0.225	0.01	0.008	--

TABLE VIII

GALVANIC CONDITIONS BETWEEN MONEL PIVOTS AND GEAR ASSEMBLIES

Couple	Water Used	Duration of Test, hours	Solution Potentials vs Calomel Half-Cell, volts						Current Flow, milliamperes		
			At Start			At Finish			At Start	At Finish	Average
			Gear and Pinion	Pivot	Difference	Gear and Pinion	Pivot	Difference			
Monel pivot vs cast gear and pinions	Ann Arbor	25	0.104	0.193	0.089	0.200	0.270	0.070	0.00	0.00	0.00
	Buffalo	25	0.200	0.270	0.070	0.228	0.222	0.006	0.00	0.00	0.00
Monel pivot vs cast gear and drawn pinions	Ann Arbor	24	0.149	0.332	0.183	0.137	0.140	0.003	0.00	0.00	0.00
	Buffalo	24	0.189	0.300	0.111	0.132	0.150	0.018	0.00	0.00	0.00
Monel pivot vs chrome-plated cast gear and drawn pinions	Ann Arbor	72	0.262	0.110	0.152	0.155	0.056	0.099	0.01	0.003	--
	Buffalo	24	0.137	Unsteady	--	0.226	Unsteady	--	0.00	0.00	--

TABLE IX

ANODIC AND CATHODIC PARTS AS INDICATED  
BY RESULTS IN TABLES VI, VII, AND VIII

Table	Couple	Anode (Corroded)	Cathode (Protected)
VI	Cast-bronze gear and pinion	Pinion	Gear
VI	Cast-bronze gear - drawn-bronze pinion	Gear at start, pinion at finish	Pinion at start, gear at finish
VI	Cast-bronze gear - drawn-bronze pinion, both chrome plated	Gear	Pinion
VII	Bronze pivot and cast-bronze gear and pinion assembly	Gear and pinion assembly	Pivot
VII	Bronze pivot and cast gear-drawn pinion assembly	Pivot	Gear and pinion assembly
VII	Bronze pivot and chrome-plated cast gear - drawn pinion assembly	Gear and pinion assembly	Pivot
VIII	Monel pivot and cast-bronze gear and pinion assembly	Pivot	Gear and pinion assembly
VIII	Monel pivot and cast-bronze gear - drawn-bronze pinion assembly	Pivot	Gear and pinion assembly
VIII	Monel pivot and chrome-plated cast-bronze gear - drawn-bronze pinion assembly	Gear and pinion assembly	Pivot

the teeth. The same condition was observed in four other gear and pinion assemblies which were at hand.

That corrosion has been active on the pinion is also evident by the accumulation of corrosion product on and around the pinion. This is the characteristic basic copper carbonate which is associated with the corrosion of



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See ERI File Copy

are two other considerations that would enter the picture. The pinion is made of drawn 88-4-4-4 bronze and, whether it is cold-drawn or extruded, the metal would contain residual stresses which would give it a higher solution potential. Another factor is the constant rubbing of the pinion against the gear. Contacts are much more frequent on the pinion than on the gear. This will tend to cold work the bronze surface more, and since the whole system is immersed in water the wearing away of the teeth could be a sort of corrosion fatigue process. In other words, resistance to wear and abrasion is lowered when corrosion is present and vice versa.

A metallographic examination of a longitudinal section of an unused pinion was made in order to determine whether or not the crystal structure showed evidence of strain. Typical strain lines were found throughout, as well as some distortion of the crystals, thus giving evidence of the cold worked condition of the bronze. When such a structure exists, the metal is more susceptible to corrosion.

It is also felt that the type of water would have a quite definite effect on the course of this pinion corrosion. A water of high alkalinity or bicarbonate hardness would tend to accelerate the effect.

The fact that the attack is so rigidly confined to the actual contact points of the pinion and interlocking gear gives weight to the conclusion that the anodic condition on the pinion is increased locally by the cold working of the pinion surface. If, as stated, this trouble has developed since the drawn-bronze pinion rod was used, that would be further evidence, since the cast rod would not have as much residual strain as the drawn rod.

Three possible remedies for the condition come to mind. The first would be to remove the residual stresses in the pinion rod by annealing at around 1300°F. This would recrystallize the metal and leave it in a stress-free condition, with lower solution potential. The benefit of this treatment could be checked by comparing solution potentials of the annealed and cold-drawn rods. Annealing would, of course, reduce the hardness and strength of the pinion, but these properties would be at least as good as those of the cast pinion rod used formerly. Machinability of the annealed rod might not be as good, but the presence of the lead would help in this operation.

Another change might be the substitution of stainless-steel pinions for the bronze pinions, but here too the metal should be in a stress-free condition. Two factors are behind this thought. Stainless steel, at least in sea water, polarizes more readily than copper-base alloys and this would be a favorable condition. Then too, stainless steel contains chromium which might set up a more favorable reaction with the chrome-plated gear.

The third suggestion is to use a pinion made of some plastic material, as it is known that gears for some applications have been made of these

materials. The plastic would furnish insulation of the gear from the pivot. It is felt however, that the choice of a plastic gear should be contingent upon service tests under highly corrosive conditions.

Tests Involving PTI-Treated Part

In these tests, galvanic conditions between a PTI-treated measuring chamber and bronze and cast-iron bottoms were made. The PTI treatment involves essentially, coating a part with molybdenum sulphide. The results of these tests are presented in Table X.

As would be expected, the frost bottom was anodic to the PTI-treated measuring chamber. The current flow is somewhat less than if an untreated chamber had been used, but the difference is not great. The untreated bronze bottom is also anodic to the PTI-treated chamber and, at the start, the current flow from the bottom to the chamber was higher than expected. In three days, however, it had decreased considerably and would be expected to fall off more as time went on.

Under the test conditions, the untreated bronze part was protecting the PTI-treated chamber. The solution potential of the treated chamber was somewhat lower than that of untreated bronze, suggesting that if the treatment were used it would be well to treat the whole meter rather than specified parts.

TABLE X

GALVANIC CONDITIONS BETWEEN PTI-TREATED MEASURING CHAMBER AND BRONZE AND CAST-IRON BOTTOMS

Couple	Water Used	Duration of Test, hours	Solution Potentials vs Calomel Half-Cell				Current Flow From Bottoms to Chambers, milliamperes				
			Bottom	PTI Chamber	Difference	At Finish	At Start	At Finish Average			
PTI-treated chamber vs plastic-coated frost bottom	Ann Arbor	24	0.516	0.118	0.398	0.674	0.155	0.519	0.85	1.65	1.25
PTI-treated chamber vs ordinary bronze bottom	Los Angeles	72	0.182	0.059	0.123	0.106	0.041	0.065	0.913	0.154	0.533

## APPENDIX

WATER DEPARTMENT -- ANN ARBOR, MICHIGAN  
REPORT OF CHEMICAL EXAMINATION OF WATER

Source Average Analysis - Finished Water

	ppm	me.	
Dissolved Metallic Ions			Hydrogen Ion Concentration expressed as pH 10.0-10.5
Aluminum Al <sup>+++</sup>			Specific Conductance at 25° C-MHOS cm
Calcium Ca <sup>++</sup>	18.8	0.938	Carbonate Alkalinity as CaCO <sub>3</sub> ppm
Iron, Ferrous Fe <sup>++</sup>	Nil		Bicarbonate Alkalinity as CaCO <sub>3</sub> 31.0
Iron, Ferric Fe <sup>+++</sup>	Nil		Hydroxide Alkalinity as CaCO <sub>3</sub> 3.0
Hydrogen H <sup>+</sup>			Total Alkalinity as CaCO <sub>3</sub> Nil
Magnesium Mg <sup>++</sup>	8.8	0.725	Hydrogen (H) Acidity as CaCO <sub>3</sub> 35.0
Sodium by difference Na <sup>+</sup>	28.8	1.257	Calcium Hardness as CaCO <sub>3</sub> Nil
Total Dissolved Metallic Ions	56.4	2.920	Magnesium Hardness as CaCO <sub>3</sub> 46.9
			Carbonate Hardness as CaCO <sub>3</sub> 36.3
Dissolved Nonmetallic Ions			Noncarbonate Hardness as CaCO <sub>3</sub> 35.0
Bicarbonate HCO <sup>-</sup>	4.0	0.066	Total Hardness as CaCO <sub>3</sub> 48.2
Carbonate CO <sub>3</sub> <sup>--</sup>	18.7	0.623	Fluoride 83.2
Chloride Cl <sup>-</sup>	22.0	0.620	Turbidity 1.0
Hydroxide OH <sup>-</sup>			Color Nil
Phosphate PO <sub>4</sub> <sup>----</sup>			Odor Nil
Nitrate NO <sub>3</sub> <sup>-</sup>			Taste
Sulphate SO <sub>4</sub> <sup>--</sup>	77.4	1.611	Sodium Sulphate-Sodium Carbonate Ratio
Total Dissolved			
Nonmetallic Ions	122.1	2.920	
Acid Insoluble			
Dissolved Mineral Solids	10.0		
Dissolved Organic Matter			
Suspended Mineral Matter			
Suspended Organic Matter			
"Total Solids"			
Total Solids by Evaporation	190.0		
Dissolved Oxygen			
Free Carbon Dioxide CO <sub>2</sub>			
Total Iron			

Remarks: Being an average this analysis will not balance. We attempt to turn out a water which is safe, palatable, reasonable soft, neither excessively corrosive or scale forming. Naturally we will vary from these standards at times, but in the main and on the average we meet the standards.

Analyzed by \_\_\_\_\_  
Date Completed \_\_\_\_\_

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DEPARTMENT OF PUBLIC WORKS  
CITY OF BUFFALO  
NEW YORK

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November 10, 1953

ANALYSIS OF BUFFALO CITY WATER

	<u>Parts per million</u>
Turbidity	0.00
Color	None
Odor	None to slightly marshy
Taste	Palatable
Total Hardness as CaCO <sub>3</sub>	136.00
* Carbonate Hardness	90.00
Sulphate Hardness	32.00
Total Solids	165.00
Volatile Solids	70.00
Nitrogen:-	
Free Ammonia	0.02
Nitrites	None
Combined Ammonia	0.10
Nitrates	0.08
Oxygen consumed	0.40
Chlorine as Chlorides	20.00
Iron	Trace
pH	7.8
Dissolved Oxygen	98 to 105 percent saturation
Temperature	33' F. to 76' F.

\* Bicarbonate Alkalinity

Signed,

Henry F. Wagner  
Chief Chemist

HFW/M.

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Y

THE DIXON WATER COMPANY  
Glen F. Coe, Secretary  
121 East First Street  
Phone 3-9751

C  
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Y

Dixon, Illinois  
November, 1953

Chemical Analysis Well No. 3

		<u>ppm</u>	<u>epm</u>
Iron (total)	Fe	0.6	
Manganese	Mn	Tr	
Calcium	Ca	66.9	3.35
Magnesium	Mg	34.0	2.79
Ammonium	NH <sub>4</sub>	0.1	0.01
Sodium	Na	4.1	0.18
Silica	SiO <sub>2</sub>	14.4	
Fluoride	F	0.3	
Chloride	Cl	2.0	0.06
Nitrate	NO <sub>3</sub>	Tr	Tr
Sulfate	SO <sub>4</sub>	13.2	0.27
Alkalinity (as CaCO <sub>3</sub> )		300.0	6.00
Hardness (as CaCO <sub>3</sub> )		307.0	6.14
Residue		308.0	
Turbidity	Tr		
Color	0		
Odor	0		
Temperature	57.4° F.		

ppm - parts per million

epm - equivalent per million

ppm x .0583 - grains per gallon

residual chlorine 3/10 of one part per million

pH - 7.0 to 7.2



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J. FORREST CAIN, Mayor  
VILLAGE OF EAST AURORA  
Erie County, New York

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June 18, 1954

Mr. Herbert Barrett  
Buffalo Meter Company  
2917 Main Street  
Buffalo, New York

Dear Sir:

The following is an analysis of the water supplied the Village. This analysis was reported February 15, 1954 by Calgon Inc.

Hydroxide	0	ppm
Carbonate	0	
Bicarbonate	337	
Sulfate	120	
Chloride	38	
Manganese	less than 0.1	
Iron (Fe)	0.1	
Calcium	16	
Magnesium	6	
Hardness (as CaCO <sub>3</sub> )	62	
pH value as received	7.5	
Sample appearance	Clear	

Yours very truly

Edward J Maurer  
Village Engineer

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TYPICAL WATER ANALYSIS CALIFORNIA WATER  
SERVICE, LOS ANGELES COUNTY, CALIFORNIA

Parts per Million

Chloride	46
Sulphate	55
Bicarbonate	206
Calcium	57
Magnesium	17
Sodium	37
Silicate	28
Iron	.04
Alkalinity	169
Total dissolved	
solid	340
Hardness	210

SOUTHWESTERN LABORATORIES  
PHOENIX, ARIZONA

REPORT OF WATER ANALYSIS

Submitted by Suburban Pump and Water Company

Address 20 East Jefferson Phoenix, Arizona

Date Submitted 7-24-53 Date Reported 7-27-53

Analyses Requested Domestic Breakdown

Designation: ALTADENA PLANT - East Well - Corona and South Central

Laboratory No.	Constituent	Parts per Million
19c	Total Soluble Salts	1,011.5
	Total Hardness as Calcium	
	Carbonate (Gr./U.S. Gal. 16.8)	288.0
	Calcium	68.0
	Magnesium	28.7
	Sodium	241.2
	Potassium	
	Carbonates	0.0
	Bicarbonates	229.3
	Chlorides	424.0
	Sulphates	20.0
	Fluorine	0.3

\_\_\_\_\_  
Chief Chemist

