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RUST INHIBITION OF CHLORIDE SALTS USED IN ICE CONTROL OR DUST PALLIATION

By

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In recent years the increased use of sodium chloride (rock salt) and calcium chloride on highways for ice control and dust palliation has drawn considerable comment from motorists, a great majority of whom seem to be of the opinion that these chloride salts are the chief cause of the corrosion of automobile fenders and bodies. The Research Laboratory gave the problem of corrosion control some attention as early as the summer of 1945 in connection with a study of concrete scaling due to the use of chlorides, and again in 1947 during an investigation of brines employed for dust palliation. In March, 1948 the present study was undertaken with the definite objects of determining the extent to which these salts affect corrosion and investigating the feasibility of decreasing corrosion by adding certain inhibiting chemicals to the salts. The study has been confined to the corrosion of bare mild steel of the type used for automobile bodies, and the results do not necessarily apply to plated or coated surfaces.

This report is intended to acquaint those concerned with the nature and scope of the investigation and to disclose the more important and significant results so far obtained in the following phases of the work:

(1) Laboratory study of the relative corrosive effects of chloride solutions and distilled water, at various concentrations, temperatures, and amounts of aeration;

(2) Laboratory study of inhibitors, consisting of a preliminary study of some seventeen chemical compounds from which many were eliminated, and a detailed study of several of the most promising ones;

(3) Field tests, to compare corrosion under fenders of cars in

cities using inhibitors in ice-control salt with that in cities using untreated salt;

(4) The toxicity of the chemicals under consideration; and

(5) Approximation of the cost of using inhibitors.

Phases (1), (4), and (5) have been completed. In phase (2) the search for a suitable inhibitor has narrowed down to an investigation of two types of compound: chromates and glassy phosphates. The present testing program includes the phosphate-type commercial compounds Banox and Nalco 818C, and a pretreated rock salt to which potassium dichromate has been added by the Hardy Salt Company. These tests are designed to determine both the minimum concentration of inhibitor in the solution to give good protection from corrosion, and the quantity of such a solution required to establish a protective inhibitor coating on a given area of steel surface.

In the third phase, two sets of field tests were performed during the past winter and spring. The field tests consisted essentially of determining the rate and extent of corrosion of steel test panels fastened under the fenders of cars in two cities, one of which used inhibitor-treated salt for winter maintenance while the other used untreated salt. Additional field tests of a similar nature are planned for the forthcoming winter.

The work completed to date indicates that dilute chloride solutions are slightly more corrosive to body steel than pure distilled water at the same temperature, but that distilled water at summer temperatures causes more rapid corrosion than the chloride solutions at winter temperatures. The chromate and phosphate inhibitors have shown beneficial effects in laboratory tests and additional tests are being carried out, but the sum total of information gained so far does not conclusively justify the use of inhibitors in salts used for highway maintenance.

The Mechanism of Corrosion

The mechanism by which common corrosion takes place is electrolytic in nature and is very similar to the reaction in a galvanic cell. A piece of metal may have many positive and negative areas, due to internal stresses, heterogeneity, ruptures in a protective coating, concentration gradients in an adjacent solution, and perhaps other factors. When corrosion takes place, metal dissolves at the positive area (anode) and corrosion products are deposited on the negative area (cathode). Some metals, such as aluminum, chromium, and stainless steel, form a dense, impenetrable, adherent film of corrosion products with the first corrosion, and this film thereafter stops or retards further corrosion. The corrosion products of iron and steel do not have such protective characteristics. However, it is possible to retard the corrosion of iron and steel by the use of certain chemicals that form a protective film over either the anodic or cathodic areas--or both--thereby inhibiting corrosion.[1, 2]

Laboratory Test Procedures

Laboratory studies have consisted of exposing cleaned, weighed plates of automobile body steel (19 gauge, SAE 1008), measuring 2-by 2 inches, to the particular corrosive conditions being investigated. Corrosion was evaluated at weekly intervals by scrubbing all corrosion products from the plates, drying them, and weighing them to determine the loss in weight. Tests were carried out in triplicate and the arithmetic mean of the results

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[1] F. N. Speller, Corrosion Causes and Prevention, New York, McGraw-hill Book Co., (1935).

[2] H. H. Uhlig, Corrosion Handbook, New York, John Wiley & Sons, Inc. (1948).

reported. Results are expressed throughout in units of milligrams per square decimeter for amount of corrosion, and milligrams per square decimeter per day for rate of corrosion.

Most of the tests were carried out as illustrated in Figure I, with the bare steel plate suspended by a glass hook in 300 milliliters of a solution that was continuously aerated and agitated by a stream of washed compressed air. This procedure was deviated from in two cases: a series of stagnant bath tests, wherein the solutions were boiled to remove dissolved gases and placed in sealed jars to limit the oxygen supply; and a series of alternate immersion tests wherein the plates were subjected to a daily cycle of 16 hours of immersion (without air bubbling), 2 hours of air exposure, 4 hours of immersion, and 2 hours of air exposure. The alternate immersion method was used to check the work of a prominent manufacturer of inhibitors (Calgon, Inc., of Pittsburgh, Pa.).

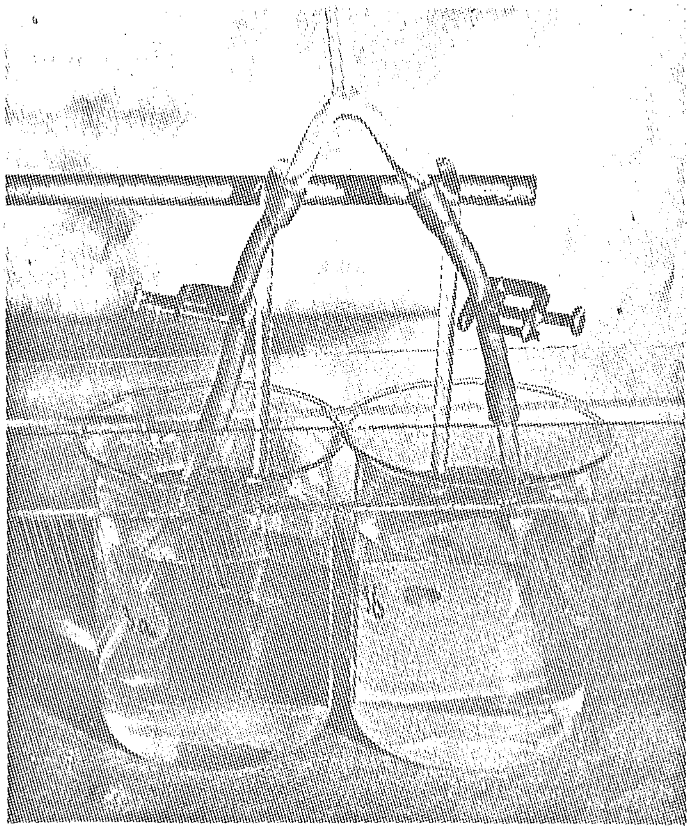


Figure I. Apparatus for Aerated Corrosion Tests.

Relative Corrosive Effects of Chloride Solutions and Distilled Water

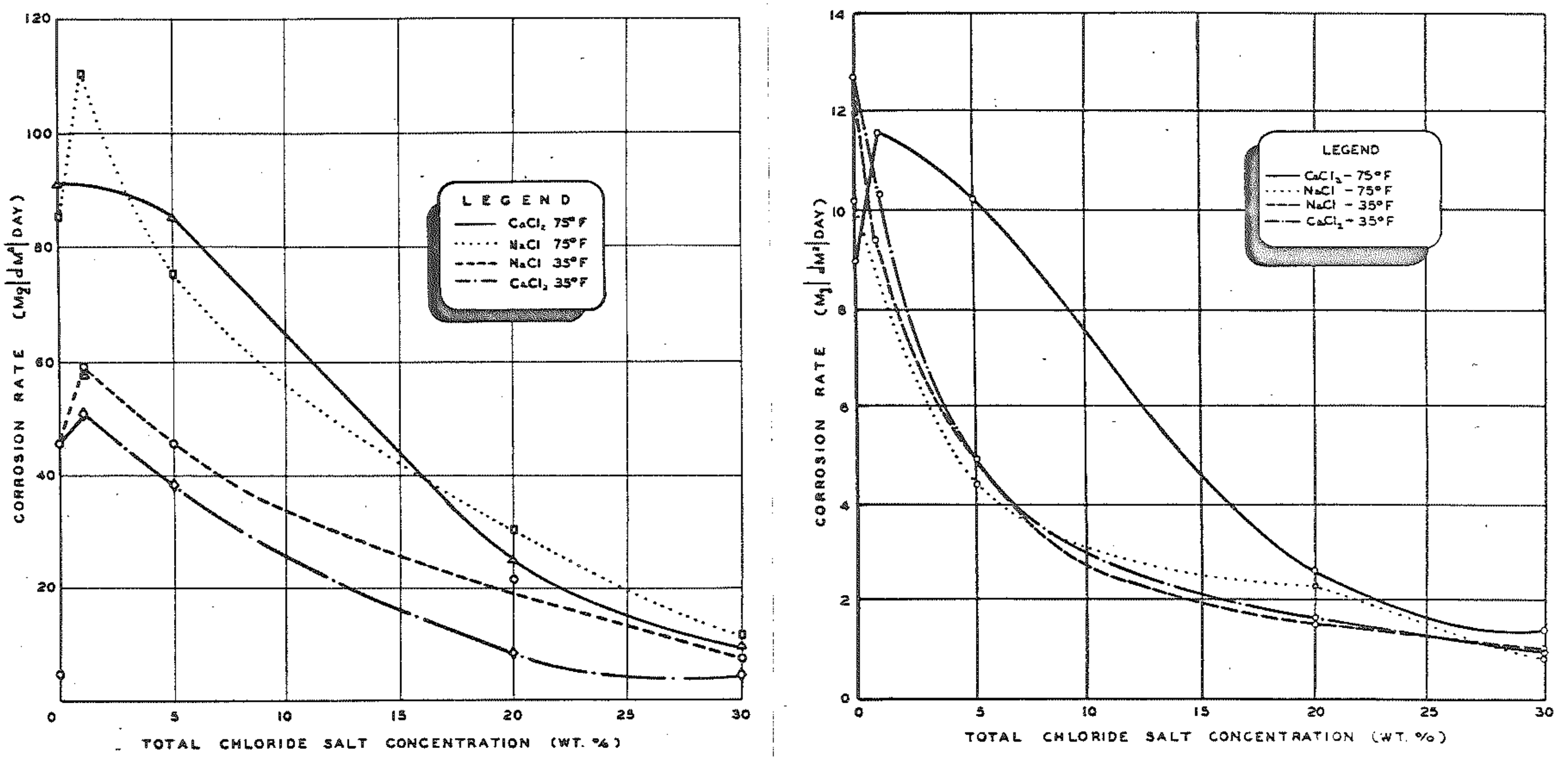
Figure II shows the effect of concentration of sodium chloride and calcium chloride on corrosion rate, both at room temperature (75± 5° F.) and refrigerated (35± 1° F.), with and without aeration. In the aerated tests it is noted that the corrosion rate in all cases is maximum at a concentration between 0 and 5 per cent by weight. It is also noted that distilled water at 75° F. caused more rapid corrosion than did any concentration of sodium or calcium chloride at 35° F. At any given concentration of either salt, corrosion was more rapid at 75° F. than at 35° F. In the studies where air was excluded, all cases show a maximum corrosion rate at zero or very dilute concentrations. The highest rate of corrosion observed in these stagnant solutions was only 13 mg./dm.^{2}/day, in in contrast to a high of 110 mg./dm.^{2}/day in the aerated solutions.

There appears to be no significant difference in the corrosive effects of sodium chloride and calcium chloride. However, it must be noted that calcium chloride is a deliquescent salt, that is, it tends to take on moisture from the atmosphere, while sodium chloride does not. Thus calcium chloride in mud under fenders will keep the mud from drying, and increase fender corrosion by keeping the fender wet after splashing.

Photographs of typical test plates at the end of a fourteen-day test period are shown in Figure III. The decrease in corrosive effects due to lower temperatures and to the exclusion of air is evident.

Concentration of Salt on Highways

Samples of slush and gutter drainage, collected several hours after salt application and analyzed, ranged in salt content from 0.24 to 1.52 per cent, by weight. Additional samples will be collected under various conditions during the forthcoming winter.



CONTINUOUSLY AERATED AND AGITATED

SERIES 14 & 15

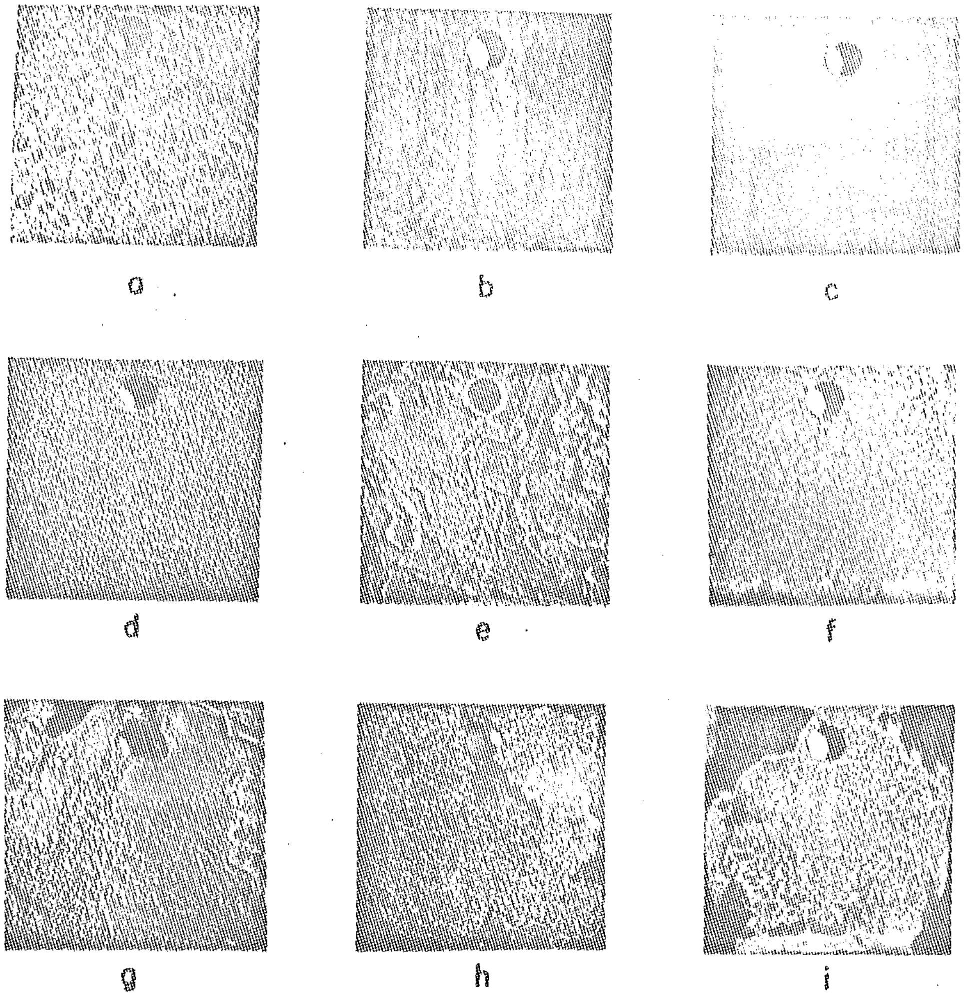
STAGNANT, LIMITED ACCESS TO AIR

SERIES 13 & 16

Figure II

EFFECT of TEMPERATURE on the CORROSIVENESS of $CaCl_2$ and NaCl BRINES

[illegible]



a b c

d e f

g h i

PLATE	CORROSIVE MEDIUM	AERATION	TEMPERATURE, °F
a	Distilled water	Aerated	75
b	Distilled water	Stagnant	75
c	Distilled water	Stagnant	35
d	1% $CaCl_2$	Aerated	75
e	1% $CaCl_2$	Aerated	35
f	1% $CaCl_2$	Stagnant	75
g	1% Rock salt	Aerated	75
h	1% Rock salt	Aerated	35
i	1% Rock salt	Stagnant	75

TYPICAL CORROSION TEST PLATES
after 14 DAYS

FIGURE III

Laboratory Study of Inhibitors

In a preliminary study of inhibitors, numerous chemicals were tried in aerated solutions, using a calcium chloride-magnesium chloride brine, such as is used for dust palliation, diluted so that the total chloride salts comprised 5 per cent of the solution, by weight. (In present tests more dilute solutions are being used, in order to approach more nearly the conditions actually found on highways). These tests resulted in the elimination of the following inorganic compounds: sodium tetraborate, sodium silicate, sodium nitrite, chrome alum, and chromic acid. Prior to their elimination, the above compounds were tested in conjunction with the following organic additives: mercaptobenzothiazole, formaldehyde, sodium salycilate, sodium benzoate, and hydroquinone. Selected as being worthy of further investigation were: sodium chromate, sodium dichromate, and various glassy phosphates.

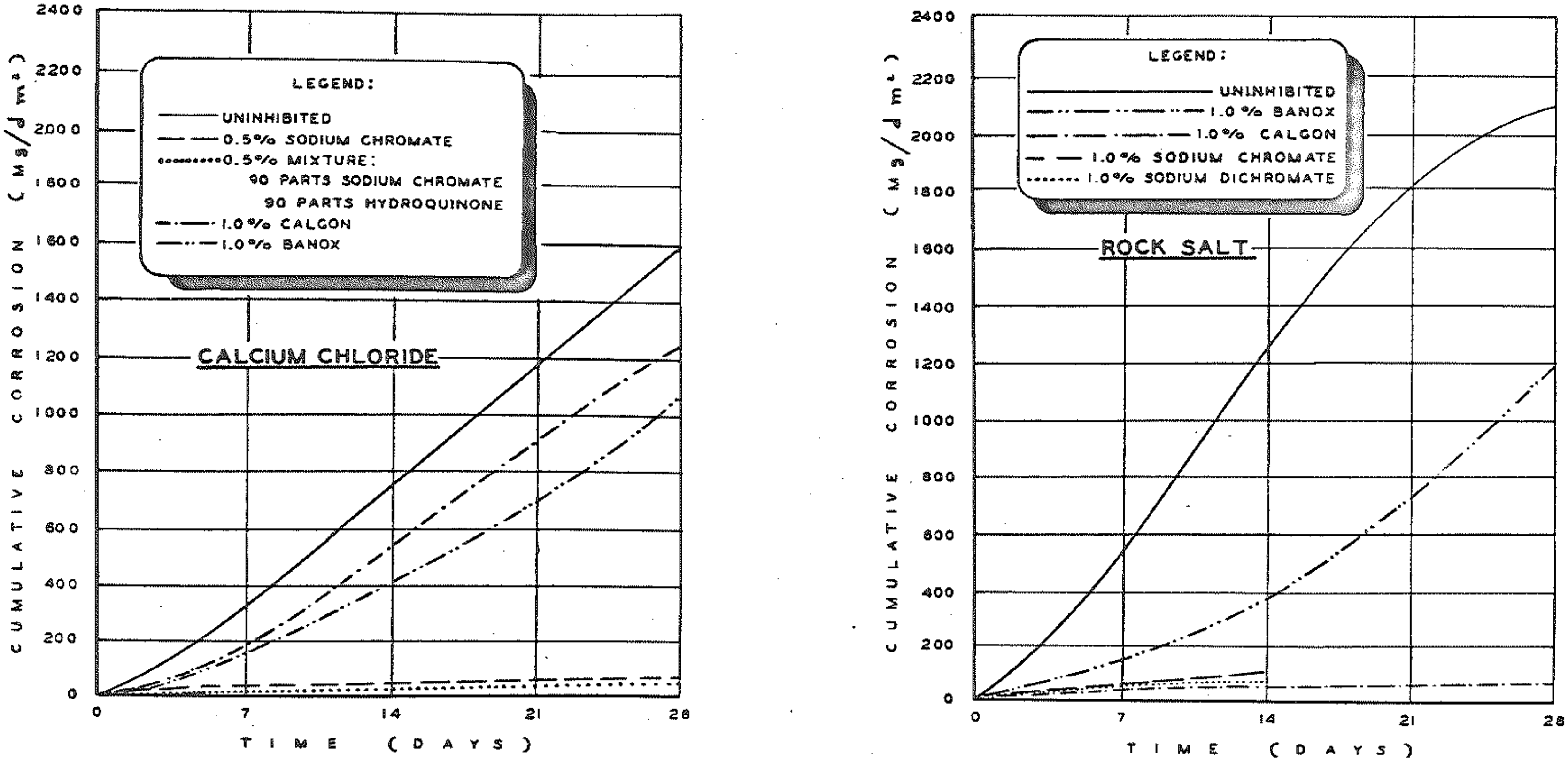
Now in progress or planned for the immediate future are detailed studies of three inhibitors being offered by vendors specifically for use on highways: Banox (a proprietary product manufactured by Calgon, Inc., Pittsburgh, Pa., consisting of sodium hexametaphosphate and certain calcium compounds said to be helpful in film formation, developed initially as a steel-treating process); Nalco 818-C (manufactured by the National Aluminate Corporation, Chicago, Illinois, consisting of a polyphosphate compound and several nitrites and nitrates that are said to be beneficial, developed for highway use); and a pre-treated rock salt to which potassium dichromate has been added by the Hardy Salt Co., Manistee, Michigan. (Chromate and dichromate salts of both sodium and potassium all behave similarly as inhibitors, and are commonly used in brines for refrigeration and air conditioning systems).

Figure IV shows graphically the amount of corrosion as a function of time over a four-week period for several inhibitors in 5 per cent calcium chloride and 5 per cent rock salt solutions aerated at room temperature. These indicate that the addition of 0.5 part of sodium chromate or a 90:10 mixture of sodium chromate and hydroquinone to 100 parts of calcium chloride or addition of 1 part of sodium chromate, sodium dichromate or Calgon (sodium hexametaphosphate) to 100 parts of rock salt, held corrosion down to less than 5 per cent of that in untreated brines. Addition of 1 part of Calgon or Banox to 100 parts of calcium chloride or 1 part of Banox to 100 parts of rock salt lowered the amount of corrosion slightly, but in no case held it below 50 per cent of the corrosion in untreated brines.

Figure V similarly shows the results of alternate immersion tests of three proprietary phosphates in 5 per cent calcium chloride and rock salt brines at room temperature. Added to the extent of 1 part inhibitor per 100 parts of calcium chloride, these inhibitors resulted in only a very slight decrease in corrosion. Similar quantities of inhibitor in the rock salt brine made a better showing, in the best case holding corrosion down to about 15 per cent of that in untreated brine.

Although studies of different inhibitor quantities are not yet complete, it is evident from Figures IV and V that addition of one part of certain inhibitors per 100 parts of salt is not sufficient to give good inhibition in 5 per cent brines. For the more dilute brines actually found on highways, a considerably higher ratio of inhibitor-to-salt may be necessary to form a solution with an inhibitor concentration high enough to establish a protective film.

A factor worthy of consideration is the fact that anodic inhibitors

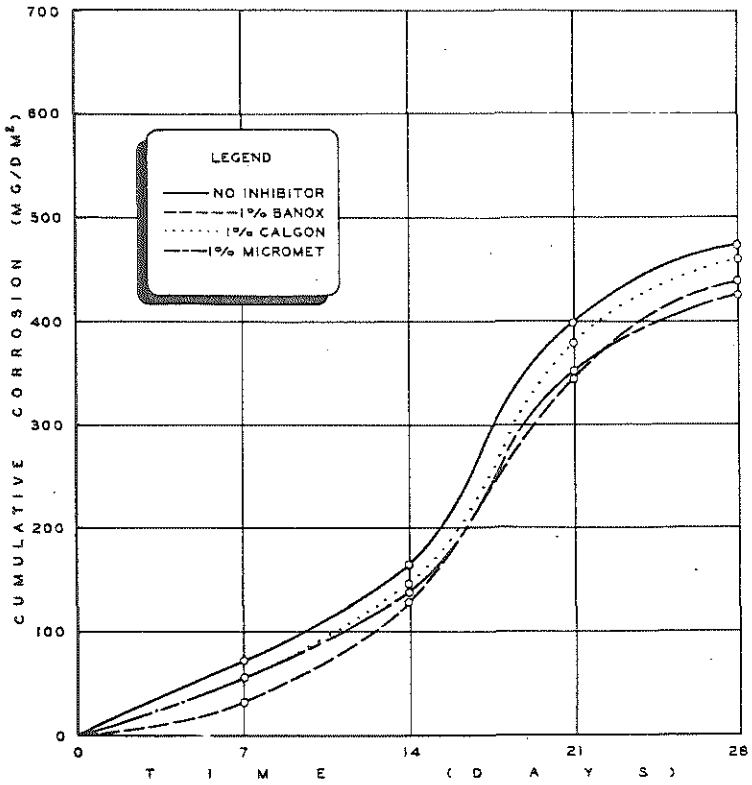


INHIBITOR CONCENTRATION EXPRESSED AS WEIGHT PER CENT OF TOTAL CHLORIDES PRESENT

AERATED AND AGITATED AT 75° F.
19 GAUGE SAE 1008 SHEET STEEL

EFFECT *of* CORROSION INHIBITORS *in* 5% BRINE

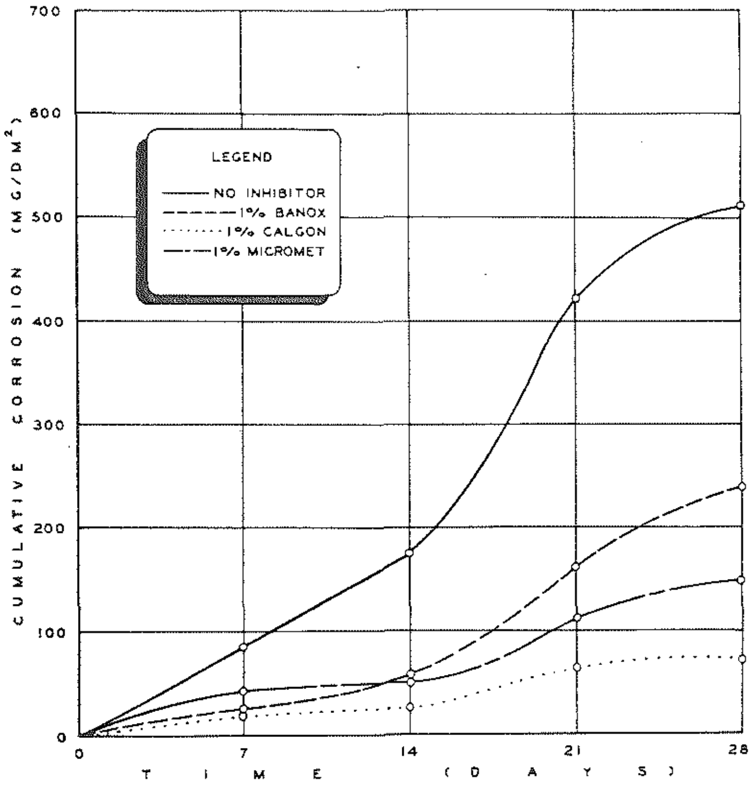
Figure IV



SERIES NO. 7

EFFECT of GLASSY PHOSPHATES as CORROSION INHIBITORS in 5% $CaCl_2$-$MgCl_2$ BRINE

ALTERNATE IMMERSION AT 75°F, 19 GAUGE SAE*1008 SHEET STEEL



SERIES NO. 7

EFFECT of GLASSY PHOSPHATES as CORROSION INHIBITORS in 5% ROCK SALT BRINE

19 GAUGE SAE*1008 SHEET STEEL, ALTERNATE IMMERSION AT 75°F

Figure V

--into which category both the chromates and the phosphates fall--when present in insufficient quantities, are known to cause pitting rather than overall corrosion.[3, 4] Although it takes place over a smaller area and does not cause as great a loss in weight, pitting corrosion constitutes an intensive attack on a small area, and can corrode completely through a steel sheet in a relatively short time. This pitting is illustrated in Figure VI, a photograph of plates after the fourth week of exposure to a 2 per cent calcium chloride solution containing 3 and 4 parts, by weight, of sodium chromate per 100 parts calcium chloride.

Current laboratory studies include investigation of corrosion rates in sodium and calcium chloride solutions of concentrations ranging from 0 to 4 per cent salt, by weight. To each brine concentration Banox or Nalco 818-C has been added in various ratios ranging from 0.25 to 4 parts of inhibitor per 100 parts of salt. Tests are also being made using Hardy Salt Co.'s dichromate-containing salt in solutions containing from 0 to 4 per cent of the mixture.

Since the formation of a protective inhibitor film depends upon the presence and availability of a finite amount of inhibitor per unit of metallic surface area, it is desirable to establish the quantity, as well as the concentration, of inhibitor-containing solutions required to provide protection to a given metallic area. This aspect has apparently been overlooked by the manufacturers and vendors of inhibitors to date, and may explain the failure of the field tests discussed below to correlate highly with laboratory studies. The actual determination of the amount of inhibitor

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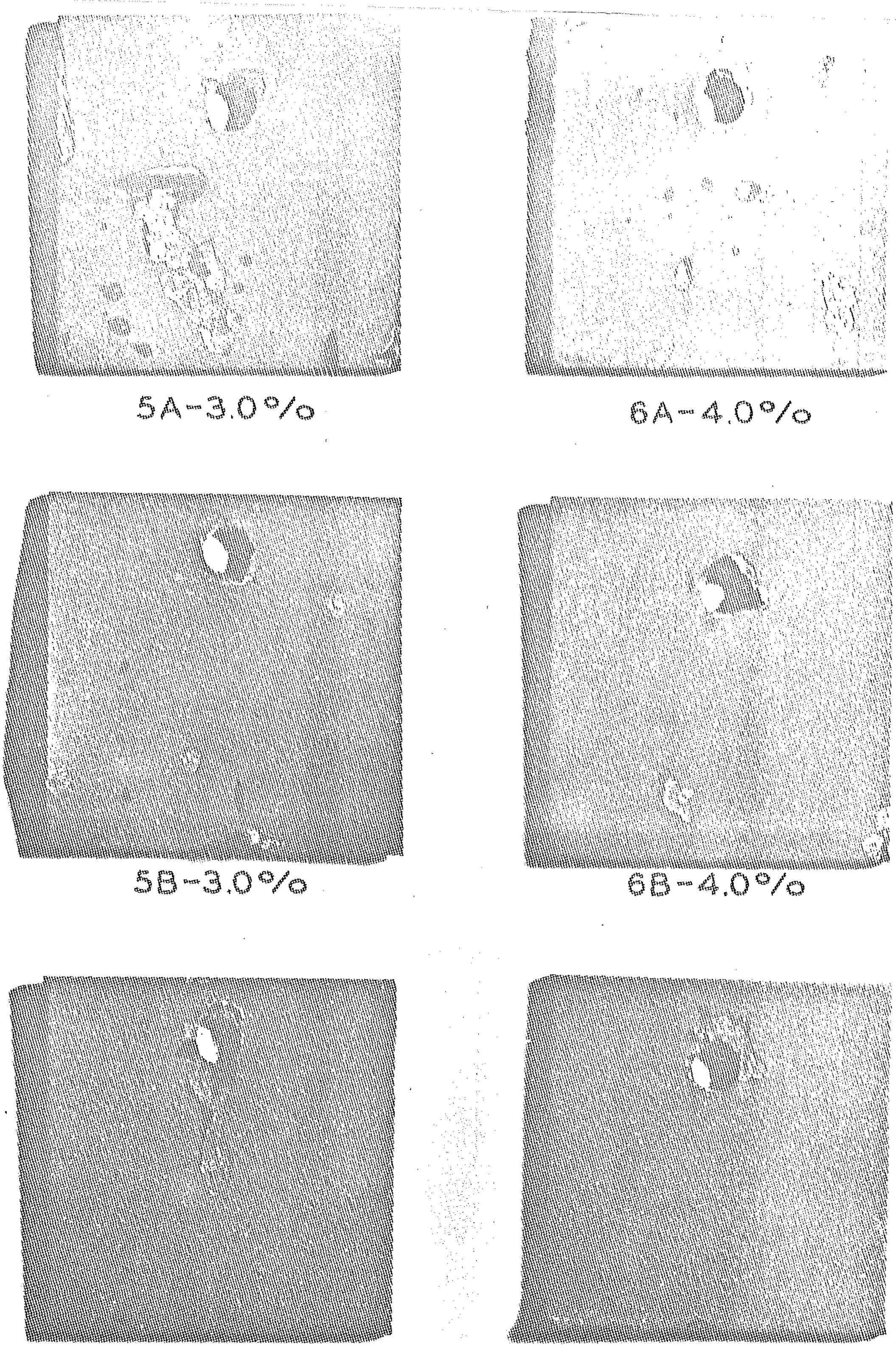
[3] H. H. Uhlig, op. cit.

[4] Evans and Hoar, "The Passivity of Metals, Part VII, The Specific Function of Chromates," Journal Chem. Soc., London, 2476 ff. (1932).



5A-3.0% 6A-4.0%

5B-3.0% 6B-4.0%

5C-3.0% 6C-4.0%

SERIES 18

EFFECT OF VARIOUS Na_2CrO_4 CONCENTRATIONS ON CORROSION OF 19-GAUGE SAE 1008 SHEET STEEL IN A CONTINUOUSLY AERATED & AGITATED 2% $CaCl_2$ SOLUTION AT 75°F

FIGURE VI

adsorbed on a steel surface presents certain technical difficulties, and may not be possible; National Aluminate Corp. states that it has been unable to devise a satisfactory method. However, the Research Laboratory is now developing a procedure which may give valid results. The possibility that inhibitors might be withdrawn from solution by adsorption onto the road surface or onto soil particles will also be investigated if suitable methods can be developed.

Field Studies

During a 63-day test period from January 31 to April 4, 1949, small bare steel plates were installed under the fenders of city police cars in Lansing, Saginaw, and Detroit by Calgon, Inc., with the counsel and assistance of the Highway Department, to compare corrosion in Lansing, where Calgon's "Banox" was being added to rock salt, with that in Saginaw and Detroit, where no inhibitors were being used. The Detroit cars were, regrettably, on reserve status and were not in regular daily use as were those in Lansing and Saginaw; hence Detroit data are being completely disregarded. Lansing had intended to add 1 per cent Banox (the minimum recommended by Calgon, Inc.) to rock salt for 17 miles of selected streets, and only 0.5 per cent to salt for an additional 63 miles. However, during the season Lansing used 8,235 pounds of Banox and 944.5 tons of rock salt on these streets for an overall average of only 0.46 pound of Banox per 100 pounds of salt, indicating that some of this salt had little or no Banox in it. The results of these tests are presented in Table I with other pertinent data. Weight loss data on winter tests were provided by Calgon, Inc., and are not to be construed as being certified by the Michigan State Highway Department.

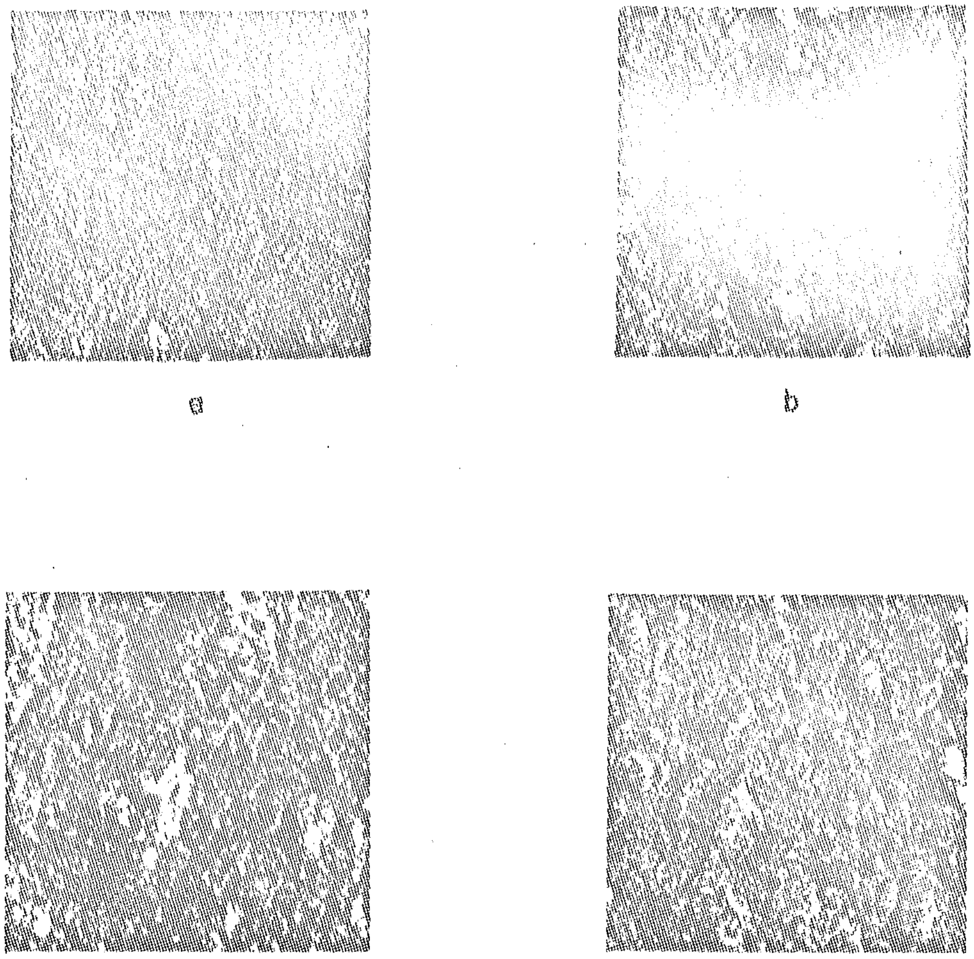
In an effort to determine how much of the difference in corrosion rates at Lansing and at Saginaw might be attributed to factors other than the use of Banox, the Research Laboratory installed plates on Lansing and Saginaw police cars for a 42-day period from April 14 to May 27, 1949. During this period, there were no salt or inhibitor applications in either city. The results of these tests are also shown in Table I.

TABLE I

	Winter Tests by Calgon, Inc.		Spring Tests by M.S.H.D.	
	Lansing	Saginaw	Lansing	Saginaw
Average weight loss, grms.	1.5920	2.0130	0.7269	0.8250
Area of plates, dm.^{2}	1.20	1.20	1.20	1.20
Duration of test, days	63	63	42*	42*
Average corrosion rate, mg/dm.^{2}/day	20.7	26.2	14.4	16.4
Average mileage of cars	12979.	8016.	7141.	7015.
Total precipitation, as water, in.	5.11	4.92	4.17	3.63
Mean temperature, °F.	31.0	29.3	58.8	53.8
Salt applied, tons/mile	10.53	0.85	0	0
Type salt coverage	Full Coverage	Intersections Only		

* Tests discontinued after 42 days because Lansing cars were being turned in for new ones.

Photomicrographs (Figure VII) of pitted areas of representative plates from both tests show less pitting of the Lansing plates from the winter test than of Saginaw winter plates or the spring plates from either city. This observation implies that the inhibitor had beneficial effects. But on the other hand, the microscopic appearance of the plates from the spring test, after only 42 days of exposure compared to 63 days for the winter plates, indicates that considerable damage may be done to fenders in warmer weather, even with no salt on the roads. This indication substantiates the every-day



a

b

c

d

PLATE	CITY	EXPOSURE PERIOD	STREET TREATMENT
a	Lansing	Jan. 31 - April 4, 1949	Salt and Banox
b	Saginaw	Jan. 31 - April 4, 1949	Salt only
c	Lansing	April 14 - May 27, 1949	None
d	Saginaw	April 14 - May 27, 1949	None

PHOTOMICROGRAPHS *of* PITTED AREAS *of* REPRESENTATIVE PLATES *from* FIELD TESTS

MAGNIFIED 31 DIAMETERS

B 761

FIGURE VII

observation of corrosion of automobile doors, side panels, and trunks caused by rain or dew which can neither be blamed on salt nor controlled by treating the salt.

Comparison of Laboratory and Field Tests

The results of laboratory tests indicate that corrosion in dilute salt solutions is only slightly more rapid than in pure water at the same temperature, and that in either case, it is more rapid at higher temperatures. The field tests, however, do not agree with the laboratory results in these respects.

In Lansing, the corrosion rate in the spring tests was only 70 per cent of what it was in the winter tests; in Saginaw, only 63 per cent. Laboratory studies would predict a higher rate in the spring than in the winter. However, consideration of the Saginaw tests as valid leads to the conclusion that not more than half of the annual corrosion takes place during the four or five months when salt is used. The laboratory results imply that even less damage occurs during the cold season, regardless of salt application.

In the spring tests the corrosion rate in Lansing was only 88 per cent of what it was in Saginaw, despite the fact that Lansing had a higher mean temperature and more precipitation. This difference, however, is perhaps not large enough to be statistically significant, since the weight loss figures are the average of only 12 plates in each city, and the losses of individual plates deviate from the mean value as much as 61 per cent.

The fact that winter corrosion in Lansing was only 79 per cent of that in Saginaw may be significant, but this figure hardly compares with the degree of inhibition obtained in the laboratory, where corrosion was held to less than 5 per cent.

Several reasons can be advanced as to why the results of the field tests and laboratory tests do not agree. Calcium chloride and magnesium chloride might have been present as impurities in the rock salt. Although these salts have not raised corrosion rates much over that of pure water in the laboratory tests, if they were present in mud under a fender they would, by their deliquescent nature, tend to remain damp and keep the fender wet for a longer period of time after splashing, thereby leading to more corrosion. Roughening of the surface by pitting presents a larger surface for corrosion as the test continues, and might cause a long test to show a higher overall corrosion rate than a short test. It is possible that in warmer weather more oil, bituminous material, etc., were splashed on the test plates, affording them a certain amount of protection from moisture. The frequency and thoroughness of car washings are other variables over which no control was exerted.

Toxicity

Both sodium chromate and sodium dichromate are toxic when taken internally, a lethal dose of the dichromate being about 15 grams, according to McNally.[5] External skin contact with either of them frequently results in the formation of "chrome-holes"--deep, difficult-to-heal ulcers characteristic of chromate poisoning. Continued breathing of chromate and dichromate dust sometimes causes nasal ulcers and, occasionally, complete perforation of the nasal septum.[6, 7] The many cases of chromate injuries

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[5] W. D. McNally, Toxicology, Chicago, Industrial Medicine, (1937).

[6] A. Hamilton, Industrial Poisons in the United States, New York, MacMillan Co. (1925).

[7] F. J. Wampler, The Principles and Practice of Industrial Medicine, Baltimore, Williams and Wilkins Co., (1943).

on record are, however, those of workers in industries using large quantities of chromates. It is difficult to predict whether or not the use of chromates to form very dilute solutions upon application to streets and highways would constitute a hazard to the health of persons applying the salt-chromate mixture, service station attendants, children playing in gutters and drains, small animals, etc.

There appear to be no such hazards involved in the use of phosphates.[8]

The Michigan State Stream Control Commission has expressed the opinion that neither chromates nor phosphates, applied in amounts of one or two per cent of the salt applications, would cause appreciable stream pollution---even in urban areas---because of the great dilution.

Approximate Cost of Inhibitors

At currently quoted prices, the minimum cost of inhibitors is of the order of $280 per ton, delivered in carloads, or slightly over $300 per ton in lesser quantities, due to differences in both prices and freight rates. At $280 per ton, the addition of 1 per cent of inhibitor would cost $2.80 per ton of salt used, exclusive of any costs of handling, storage, and mixing. During the last three years the Highway Department has used an average of 39,070 tons of sodium and calcium chloride each year on the state trunk line system. The annual cost of adding even 1 per cent inhibitor to such an amount of salt would be $109,396.

Other Investigations

The following quotation is from a paper "Corrosion Problems of the Automotive Engineer," presented at the June 5-10, 1949, meeting of the Society of Automotive Engineers at French Lick, Indiana, by F. L. LaQue and E. J. Hergenroether, both of the Development and Research Division of the International Nickel Company, Inc.:

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[8] F. J. Wampler, *op. cit.*

"There has been considerable discussion of the possibly adverse effects on corrosion of the sodium or calcium chloride sprinkled on roads to melt ice or lay dust. There seems to be little question that chlorides can aggravate corrosion - at the same time, one should not reach the conclusion that chlorides encountered from this source are the most important factor in the deterioration of automobiles or that in the localities where they are used corrosion of cars would cease if the use of the salts were to be discontinued.

"The technical background is, to say the least, confusing. For example, when a series of sodium chloride solutions varying from pure water to concentrated brine are used for a conventional salt spray test, the greatest corrosion of bare steel occurs with a very small percentage of chloride and the pure water is more corrosive than all concentrations beyond about 1 or 2% sodium chloride. The explanation is based on the fact that the solubility of oxygen in sodium chloride solutions decreases as the chloride concentration increases and the lack of oxygen in the more concentrated solutions more than compensates for the corrosion aggravating effect of the chloride ion.

"This observation helps explain why steel specimens exposed to atmospheric corrosion without contact with brine were corroded twice as much as duplicate specimens attached under a test car driven over a salt-treated road and garaged in a humid atmosphere. Also, field surveys have shown almost as much corrosion of cars in areas where salt treatments of roads are never employed as in regions where they are used regularly. Furthermore, surfaces located where they are shielded from salt splashed from the road have been found to suffer as much damage as those freely exposed to such splash.

"Apparently the humidity of the atmosphere where a car is kept or parked is a more important factor than salt treatment of roads in determining the extent of corrosion of automobile underbodies. In this connection, however, it is important to note that salt that may adhere to the car will have an indirect adverse effect through keeping the metal moist as a result of the hygroscopic properties of the salts - calcium chloride being worse than sodium chloride in this respect. This means, in effect, that corrosion will occur at a lower relative humidity when there is salt on the metal than when salt is absent.

"Efforts are being made to relieve the situation re possible corrosive effects of salts used for road treatment by the addition to the salts of corrosion inhibitors, and especially polyphosphates and chromates. The car users'can help themselves most by keeping or parking their cars where they will have a chance to dry quickly and by washing them often enough to get rid of accretions which may accelerate corrosion.

"In summary, it seems reasonable to conclude that the danger of accelerated corrosion from the use of salts for road treatment - and expecially if the salts contain inhibitors - is not great enough to recommend the discontinuance of these treatments which are so valuable in preventing accidents on icy roads and in increasing the comfort of travel on dusty ones."

LaQue and Hergenroether also suggest designing cars so that warm air from under the hood is directed by vanes and channels to undercar surfaces to hasten drying, and comment on the possibility of adding very slight amounts of copper or nickel, or both, to body steel to give a greater corrosion resistance.

The National Aluminate Corporation has announced results of a field test, claiming a corrosion rate of 22 mg./dm.^{2}/day for panels mounted under cars in Rochester, New York where their product, "Nalco 818-C", was added to ice-control salt, compared with rates of 34, 34, and 37 mg./dm.^{2}/day in three other un-named cities using no inhibitors. (Nalco 818-C has only recently been introduced, and will be tested by this laboratory in the near future.)

Summary

(1) In continuously aerated solutions, maximum corrosion occurred at concentrations of between 0 and 5 per cent by weight, for both sodium and calcium chloride solutions, at either 75° or 35° F. The maximum corrosion rate in solutions of either of these salts was only slightly higher than in distilled water at the same temperature.

At any concentration of sodium or calcium chloride, corrosion was faster at 75° F. than at 35° F. Corrosion in distilled water at 75° F. was faster than in any concentration of either salt at 35° F.

There was no significant difference in corrosion rates in sodium and calcium chloride solutions, but it must be noted that calcium chloride, by virtue of its deliquescent tendency, would retard drying under fenders and accordingly lengthen the time during which the corrosion takes place.

(2) When air was excluded, both sodium and calcium chloride showed maximum corrosion rates at zero or very dilute concentrations, at both 75° F. and 35° F. Corrosion rates were much lower than in aerated solutions.

(3) The salt content of slush and gutter drainage samples ranged from 0.24 to 1.52 per cent by weight.

(4) Under laboratory conditions it was possible to hold the corrosion

rate of body steel down to about 5 per cent of that in uninhibited brines by the addition of certain phosphates and chromates to chloride solutions. In brines containing 5 per cent, by weight, of sodium or calcium chloride, addition of 1 part inhibitor per 100 parts salt was in some cases sufficient to give good inhibition, in some cases not. In the more dilute salt solutions encountered on highways, it is doubtful if this 1 part inhibitor per 100 parts salt (the ratio recommended by both Calgon, Inc. and National Aluminate Corp. for their respective inhibitors) would be adequate. More complete studies are in progress to determine required inhibitor concentrations and quantities.

In some cases, deep pitting might cause damage altogether out of proportion to the overall corrosion rate evidenced by loss in weight.

(5) In the field tests, corrosion occurred more rapidly in both cities during the winter months than in the spring months. This relationship apparently conflicts with the results of laboratory tests as to the effect of temperature. The corrosion rate in the city using Banox, a phosphate inhibitor, was 79 per cent of that in a simultaneous test in the city using no inhibitor.

(6) The field tests indicate that not more than half the annual automobile body corrosion takes place during the four or five months that salt is used on highways. Laboratory tests indicate that even less than half is to be expected during those cold months, since corrosion is more rapid at higher temperatures.

(7) The use of chromate inhibitors may be questionable from the standpoint of public health. The extent of any danger resulting from the concentrations contemplated has not been established as yet.

3 10.25

29.

(8) The cost of adding inhibitors is at least $2.80 per ton of salt

for each 1 per cent of inhibitor added. If only 1 per cent were to be used, the annual cost to the Highway Department would be of the order of $109,000. (based on average total salt consumption for the past three years).

(9) Vehicle operators can probably reduce corrosion damage considerably by keeping the underside of their vehicles clean. Automobile manufacturers can help by design improvements so that a smaller area gets splashed and so that the underside dries more rapidly, and possibly by the use of improved steels.

Conclusion

Until such time as it may be conclusively demonstrated that the corrosion of automobile bodies and fenders taking place during the period in which chloride salts are applied to highways can be inhibited to such an extent that the total annual corrosion is appreciably reduced, a costly large-scale program of adding inhibitors to those salts used by the Department on the state trunk line system does not seem to be justified.