# Effect of an Inhibitor on the Corrosion of Autobody Steel by De-Icing Salt

G. O. GRANT, *Commissioner of Roads, Municipality of Metropolitan Toronto, Canada*

The Council of Metropolitan Toronto became increasingly concerned with the corrosion of automobiles and the claims of individuals and organizations, such as labor groups and taxpayers, that it was caused by the salt used for de-icing roads during the winter months. Various claims were made by suppliers of inhibitors that this corrosion could be reduced to a reasonable amount. A review of a number of studies made on salt corrosion indicated a lack of complete data, and a research program was authorized by the Council to study this subject.

The study was undertaken as a joint venture with the Ontario Research Foundation, the Metropolitan Toronto Department of Roads, and the Ontario Department of Highway. Corrosion Service, a company acting as a consultant on corrosion problems, was also used in this study. Testing was done by means of mechanical rigs operating daily with test panels attached to the rigs, and the total project was designed to simulate, as closely as possible, the actual conditions existing on roads. It was possible, however, to accelerate the program by running the equipment daily and applying snow and chemicals to attain the final results.

The test coupons were removed periodically and weighed, to determine the loss of metal due to corrosion. The results indicated that (a) a reduction in loss of metal was obtained by the use of an inhibitor; (b) the test panels shaped to more closely resemble automobile body conditions showed the greater amount of corrosion; (c) the higher the corrosion rate, the lower the efficiency of the inhibitor; (d) the greatest corrosion caused by salt solution occurs when the vehicle is stored in a heated enclosure; (e) corrosion due to de-icing salt is dependent on time and not related to mileage traveled; and (f) the inhibitor and the de-icing salt tend to segregate, so a method of mixing to prevent this would be necessary.

On the basis of the results, a report was presented to the Council of Metropolitan Toronto, to the effect that there is insufficient justification for an expenditure of this nature, as the use of an inhibitor will not eliminate corrosion, but only retard that portion caused by salting, and the amount of retardation does not justify the cost. Also that the problems of corrosion in motor vehicles can be handled more economically and more thoroughly by the automobile manufacturers.

• THE ROADS and Traffic Committee of Metropolitan Toronto Council, in October 1960, approved a research project on the effect of an inhibitor on the corrosion of automobile body steel by de-icing salts used for snow removal on city thoroughfares. The program was planned and conducted by the Ontario Research Foundation, in association with the Metropolitan Department of Roads and the Ontario Department of Highways.

The problem of autobody corrosion has been recognized for many years and has been of considerable concern to urban and suburban car owners who must bear the burden of this form of attrition as it affects their vehicles. The use of sodium or calcium chloride to clear the roads of snow and to prevent road icing is a necessary practice to keep traffic moving and enable a large urban community to function efficiently during the winter months. It is most unlikely that despite the corrosion action of de-icing salts many city dwellers would favor the abandonment of its use for this purpose. Consequently, it is believed de-icing salts are here to stay, and means will be sought to minimize the deteriorating effect of de-icing salts on motor vehicles both by the auto manufacturers through design and application of better body coatings, and by the road authorities through constant improvement of methods to remove snow and ice with substances less corrosive than these salts, or through the use of additives to minimize their corrosive effects.

The corrosion occurring on autobodies has been studied by Holzwarth (*1*) of General Motors Laboratories with particular emphasis on corrosion in sheltered areas where a nonprotective iron oxide forms and corrosion is accelerated. Most of the salt corrosion testing involving automobiles has employed flat coupons located in well-exposed areas on the vehicle. In view of Holzwarth's work, the test procedure adopted in this program included a crevice-type coupon to simulate sheltered conditions. The crevice coupon was also paired with a flat coupon so that the corrosion loss in a given area could be compared.

In some large cities in the United States, the addition of inhibitors to de-icing salt has been and is being practiced. Also a special committee of the National Association of Corrosion Engineers has been established to study and correlate the problem of corrosion by de-icing salts. However, very few data are available that would provide a quantitative advantage for the use of inhibitors to de-icing salts, and the report of the NACE Committee T-4D, March 1959, indicated that the effect of adding inhibitors to de-icing salts was quite inconclusive. Examination of data from cities using an inhibitor (such as Rochester, Detroit, and Akron) did not provide convincing evidence in support of inhibitors, although Rochester's experience favors the continued use of an inhibitor though the data are not quantitatively substantiative.

In Metropolitan Toronto where some 80,000 tons of salt are used in a winter season, the use of an inhibitor presents a substantial item of expense. Consequently, because supporting data showing an inhibitor would be beneficial were lacking, this program was initiated to obtain quantitative evidence of corrosion of autobody steel in various environments.

The original plan was to employ vehicles fitted with corrosion panels, operating on portions of highways under construction that would not be used by normal traffic during the winter season. This plan was abandoned in favor of special rigs designed to operate on a circular asphalt pad under more controlled conditions. This decision proved wise as the low precipitation pattern, which began in the fall, continued into the winter months and would have made road operation difficult. By using the rigs, a snowfall could be created daily at will by accumulating at the test site truck loads of clean snow whenever sufficient snow occurred in the area. Later in the season, ice scrapings from the various operating skating rinks were secured, but finally in April city water was used on the rig pathways.

## CONCLUSIONS

1. Within the limits of the field tests carried out, it has been shown that the sodium hexametaphosphate inhibitor will definitely reduce corrosion of autobody steel due to de-icing salt solutions, the reduction of corrosion ranging from 10.5 to 77 percent if all samples are considered. The calculated average reduction of corrosion losses for all samples regardless of type was 55.7 percent.
2. Coupon shape had a major effect on corrosion in unsalted solutions and inhibited salt solutions. Corrosion of V- or crevice-type coupons was more severe than for the flat coupons, and this was due primarily to the formation and retention of dirt poultices in the V-coupons. It is felt that the V-coupon more closely represents automobile body conditions where sheltered corrosion occurs.
3. Apparently the higher the corrosion rate, the lower the efficiency of the inhibitor in general and vice versa.
4. Both rig and automobile test coupons showed that the greatest corrosion rate caused by salt solutions occurs when the car is stored in a heated enclosure or garage each night. The efficiency of the inhibitor is also erratic under these conditions and may be negligible.
5. Coupons placed on automobiles in normal use showed that corrosion due to de-icing salt is dependent on time and not related to mileage traveled.
6. Dry mixing of the fine inhibitor with coarse salt in a dry blender showed that there is a tendency for the inhibitor to segregate. If inhibitor is to be used on roads, a mixing method will be required to assure even mixing of salt and inhibitor at the point of application.
7. The only laboratory test that proved useful in evaluating the inhibiting effect was the intermittent or dip test. This test would be useful for comparing different inhibitor efficiencies, but the results obtained would not obviate the need for conducting field trials.

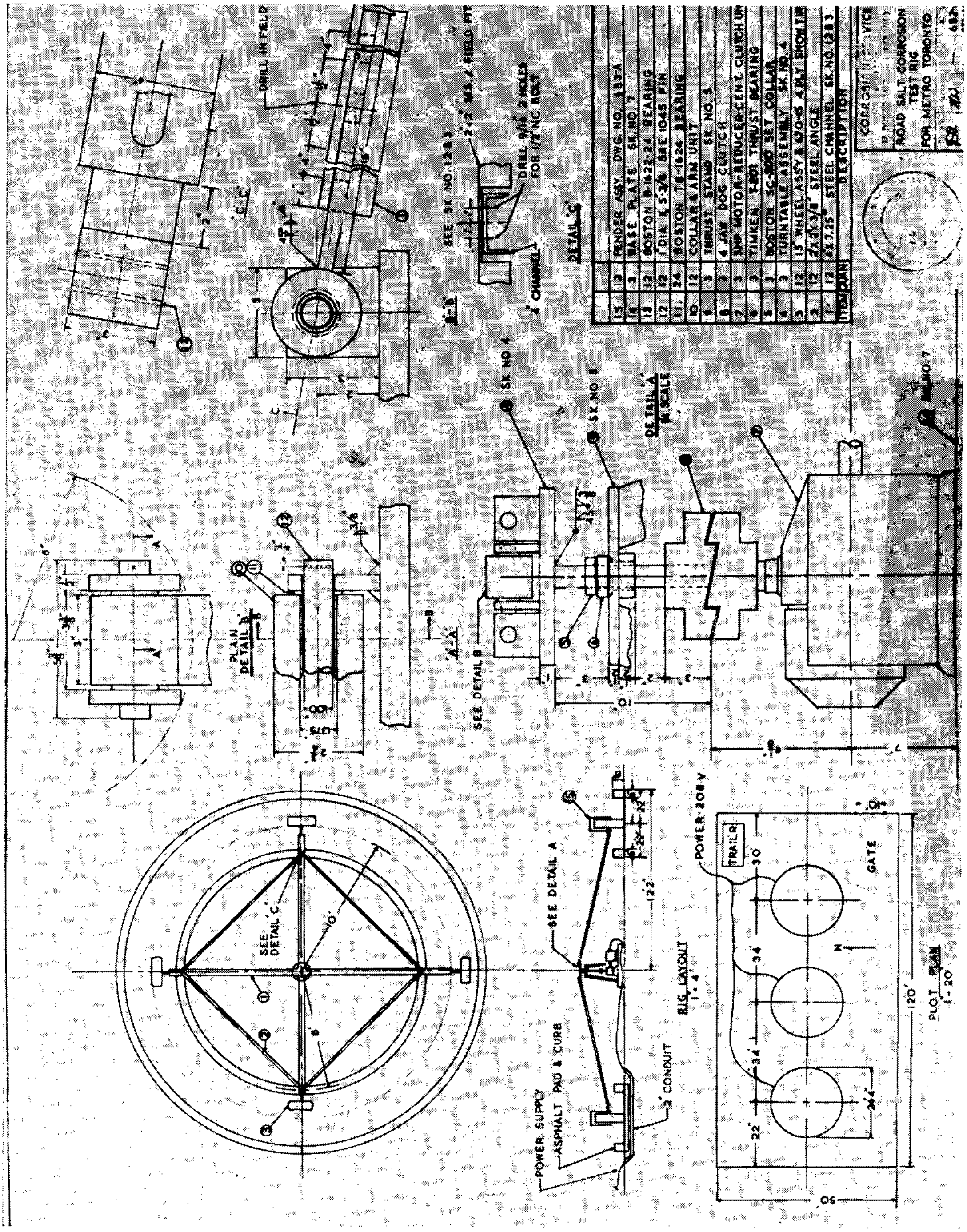
In assessing the conclusions the following should be noted:

1. The rig tests represented accelerated corrosion conditions and would compare to an extreme winter season when de-icing salt was used regularly throughout the winter.
2. The test period was not long enough to produce any major pitting corrosion, and therefore the efficiency of the inhibitor at this stage of corrosion was not illustrated.
3. All test coupons used were clean autobody steel, whereas in the great majority of automobiles, body surfaces would be dirty and in some cases corroded.

## DESIGN AND OPERATION OF TEST RIGS

The corrosion program was initiated late in the season, but the design and fabrication of the test rigs were executed to enable the test to start on February 1, 1961.

Three rigs were built to operate under three conditions: unsalted, salted, and inhibited salt. Figure 1 shows the design drawings of the rigs, and Figures 2 and 3 show the rigs operating on circular asphalt pads. The rigs were arranged with unsalted rig A to the west, salted rig B in the middle, and the inhibited salt rig on the east, so that the prevailing westerly winds would not blow spray


ROAD SALT CORROSION
TEST RIG
FOR METRO TORONTO
DETAIL A
SEE DETAIL A
DETAIL C
SEE DETAIL C
SEE DETAIL B
PLAN DETAIL B
RIG LAYOUT
POWER SUPPLY
ASPHALT PAD & CURB
3" CONDUIT
POWER 208 V
GATE
PLOT PLAN
DESCRIPTION

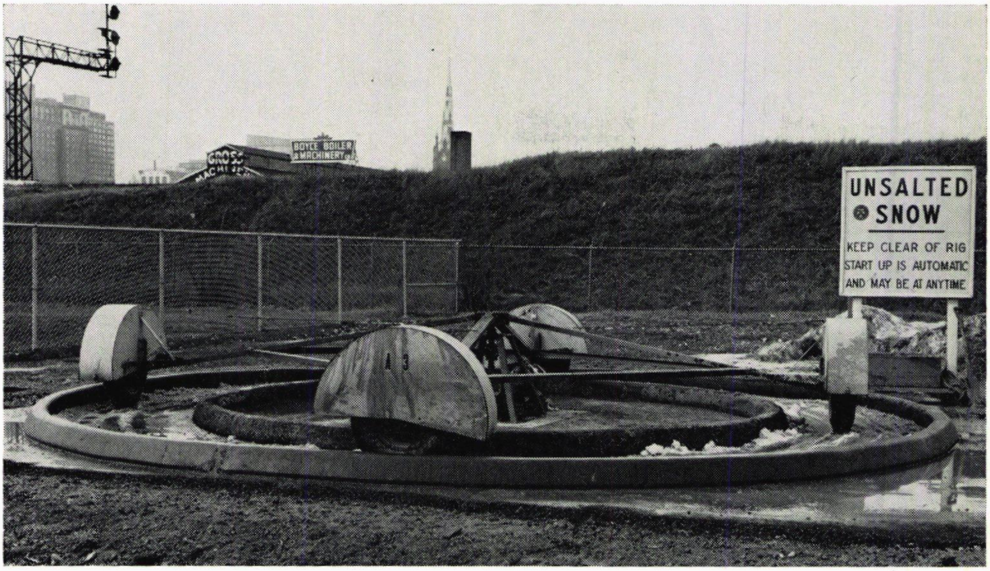



Figure 2. Rig operating on circular curbed asphalt pathway.


Figure 3. General view of the three rigs.

into the unsalted rig. Early in the test it was necessary to place polyethylene shields around the salted and inhibited rigs to prevent splashing and to retain the fluids in their respective tracks. Due to the centrifugal spray pattern caused by the circular motion of the test rig, the fluid splashed out of the wheelpath. In order to retain the fluids, the proposed distance of 50 mi per day was reduced to 25 by operating for 15-min periods. This, in addition to the plastic shield, made the operation more satisfactory, and the reduced time was less damaging to the rigs. It was not possible to reduce the speed without a drastic design change, although a lower speed (around 15 mph) would have been preferable.

This design of corrosion rig functioned quite well throughout the test, and equipment problems arising were not too serious. Repairs were quickly performed and the rigs were promptly restored to operation.

To obtain conditions in the region of 40 F, comparable to those expected in garages heated directly, or by heat indirectly received through the dwelling walls as in an attached garage,

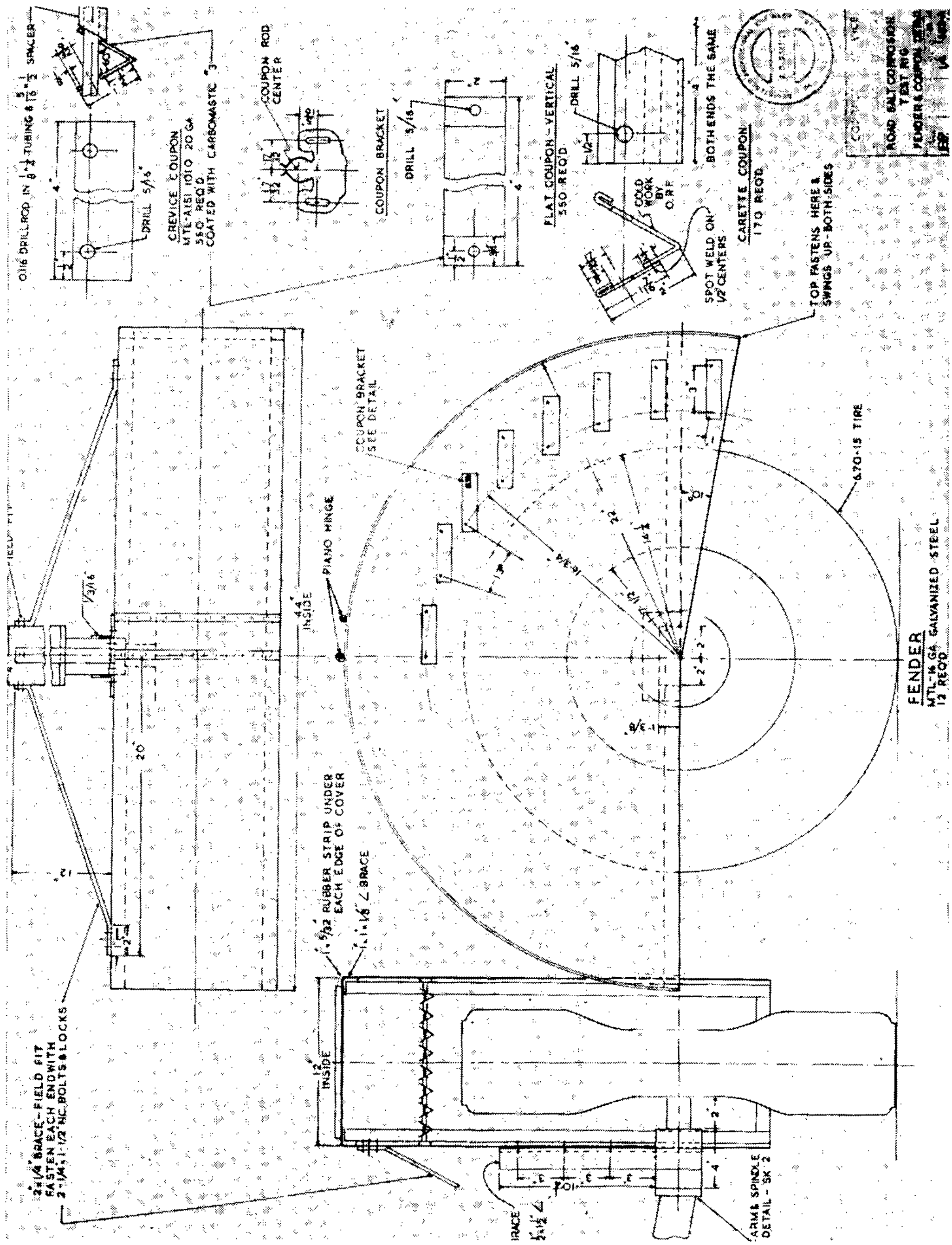



Figure 4. Design drawings of fender and coupons.

No. 4 fender of each rig was enclosed in a plastic envelope. During the down period, the fender was heated by a thermostatically controlled cal-rod unit. The heating of the No. 4 fenders was not begun at the start of the test, but was put in operation after a period of three weeks on February 21, 1961.

### FABRICATION AND PREPARATION OF CORROSION PANELS

The corrosion panels were made from autobody steel. The steel was aluminum killed and conformed to the following chemical analysis: C, 0.08 percent; Mn, 0.40 percent; P, 0.010 percent; S, 0.10 percent; Si, 0.018 percent; Cr, nil; Ni, nil; and Cu, 0.04 percent. The steel was in the cold-rolled, annealed condition with a hardness of Rockwell B-39-43. The metallographic structure consisted of fine grain ferrite in which the carbides were in the spheroidized condition. The sheet tested in the direction of rolling possessed the following physical properties, characteristic of deep drawing quality: tensile strength, 45,200 psi; yield strength, 23,900 psi; and elongation in 2 in., 43.0 percent.

Three types of corrosion coupons were selected—the V-type to approximate crevice conditions, the flat type to represent plain surfaces, and the caret type which was to be used only in a qualitative manner and not for weight loss measurements. The caret type was made similar to the V-type with the exception that 180° cold-worked beads were formed on the two edges; one side was overlapped and spot welded, and the other side was cold worked along the side by bending and straightening twice through a 90° angle increasing the hardness of the cold-worked zone to Rockwell B 59-61. Figure 4 shows the design drawings of the various coupons and of the fender inside which the coupons were fitted. Figure 5 shows a typical coupon rack composed of both V, flat, and caret coupons, mounted on a polyethylene-coated rod and insulated from one another with suitable polyethylene spacers. Figure 6 shows the arrangement of the rods in the fender, the inside region to the right.

The coupons were sheared from the sheet stock and fabricated to the required shape. Holes were punched in the coupons through which the polyethylene-coated rods passed. All test coupons were stamped according to the numbering system shown in Appendices A and B.

The V and flat coupons were sandblasted to ensure that the plastic coating applied to the panels would adhere, and both coupons were masked with suitable tape before plastic spraying. The V-coupons were masked in the crevice only covering an area of 26.3 sq cm. The flat coupons were masked in the midsection

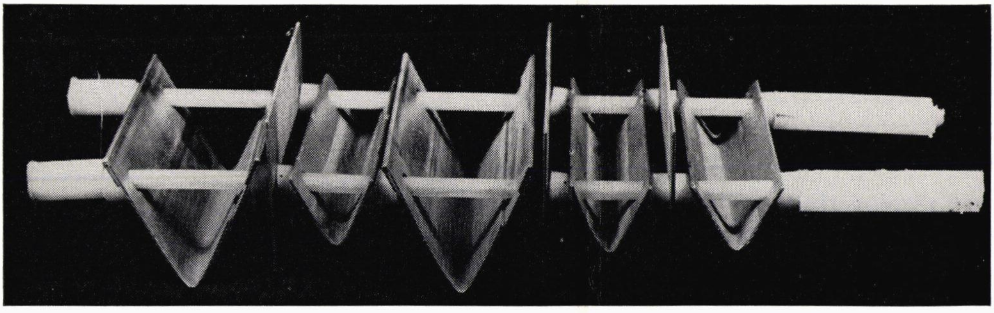


Figure 5. Set of coupons on polyethylene-coated rods.

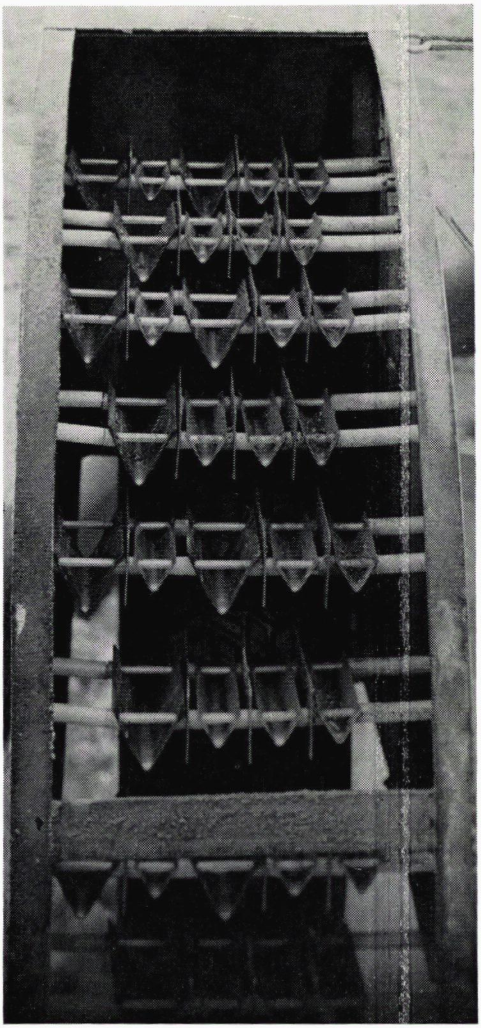


Figure 6. Fender and coupon rods. Inside location to right was sampled from top to bottom position.

covering an area of 64.0 sq cm. The caret coupons were not sandblasted or plastic coated and were placed on the rods following vapor degreasing in trichlorethylene. The V and flat coupons were sprayed with a thermal-setting, clear epoxy resin and baked at 200 F for 15 min between coats. Figures 7, 8 and 9 show the shape and appearance of the three types of corrosion coupons used. It is emphasized that the exposed surface of all the weight-loss coupons was sand-blasted, hence this surface would be more chemically active than the original cold-rolled surface. Plastic coating of the V-coupons was done to concentrate the crevice effect, whereas, in the case of the flat coupons, plastic coating eliminated crevice effects in the region of the punched holes.

The epoxy-coated coupons were stripped of masking tape and carefully cleaned in alcohol, dried, and weighed. The number of coupons required to load the rods and to take care of replacement samples is shown in Appendices A and B, which tabulate how the coupons were placed in rigs A, B, and C, and how they were removed at the end of the various periods. As coupons were removed, others were put on. This permitted obtaining data for the initial set of coupons, and also for those coupons placed on, starting two weeks later. For the program 1,300 coupons were prepared for the rigs and the sets of coupons placed on 10 automobiles traveling over the salted city streets for the period February to May 1961.

## DESCRIPTION OF INHIBITOR

Banox was chosen as the inhibitor for the program chiefly because it had been used by several cities in the United States in their studies of corrosion inhibitors added to de-icing salts. No attempt was made to evaluate other types of inhibitors, and the scope of this program did not include research to develop other types.

As previously mentioned, data pertaining to the use of inhibitors in road salt are not readily available. In the case of Rochester, where an inhibitor is used, the data were compared with Buffalo and Syracuse where an inhibitor is not used. These data were published in a report by NACE (*2*) and the corrosion rates in

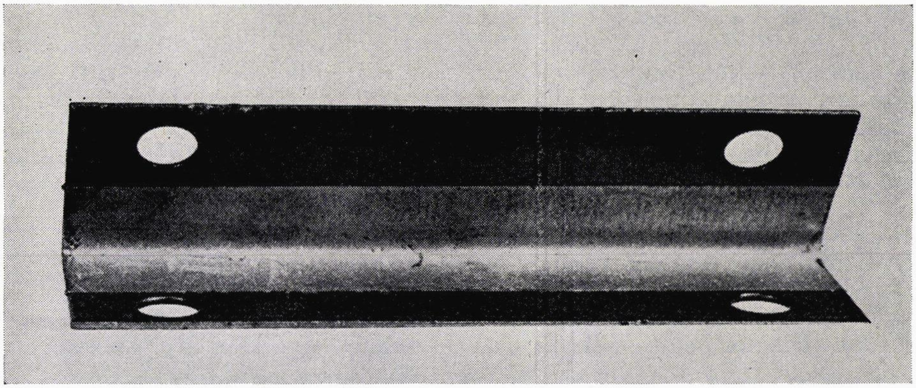


Figure 7. V-type coupon for crevice conditions. Bare portion sand blasted; full size.

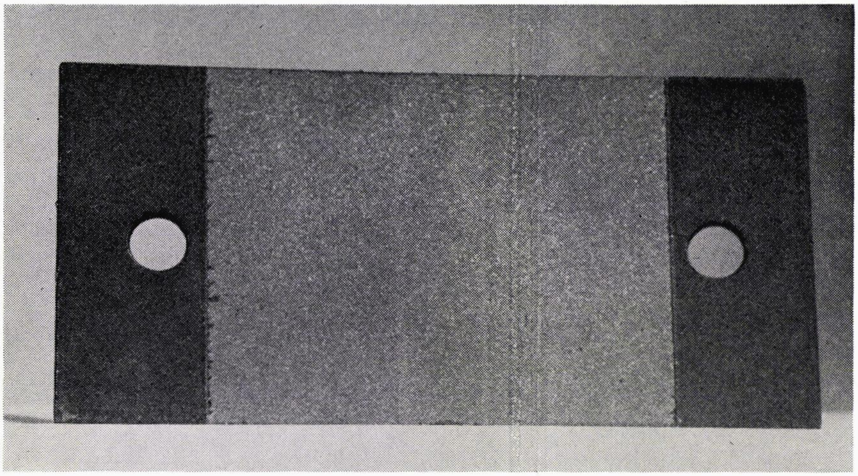


Figure 8. Flat-type coupon. Bare portion sand blasted; full size.

TABLE 1

| City | Condition | Corrosion Rate Uncorrected (mpy) | Average Weight Loss ($mg/dm^2/day$) |
|---|---|---|---|
| Rochester | Inhibited | 4.7 (spread 1.8—7.8) | 25.7 |
| Syracuse | Uninhibited | 4.1 (spread 1.4—9.1) | 22.4 |
| Buffalo | Uninhibited | 4.7 (spread 2.8—7.9) | 25.7 |

mills per year (mpy) only are shown (Table 1), with the corresponding average weight loss in brackets.

Table 2 shows the results of field tests in Cuyahoga County, Ohio (*3*), where polyphosphate inhibitors were used.

TABLE 2

| Salt | Rate of Corrosion ($mg/dm^2/day$) | |
|---|---|---|
| | Range | Average |
| Without inhibitor | 8.0—14.4 | 10.2 |
| With inhibitor | 5.0— 7.1 | 6.2 |

Most of the field experience employing inhibitors made use of a polyphosphate of which Banox is typical. Banox is chiefly composed of sodium hexametaphosphate with additives such as nitrites, compounds of zinc, and a small amount of calcium chloride. The inhibitor is believed to be of the cathodic type, forming a protective film on the metal surface reducing the strength of current that occurs during the action of corrosion. However, it is not proposed to discuss the subject of inhibitors here, as this subject has been well covered by Evan (*4*) and Putilova et al. (*5*). The inhibiting characteristics of sodium hexametaphosphate have been studied by Hatch (*6, 7*) in some detail.

The solubility of Banox was not examined thoroughly, but it was observed in the laboratory that, though most of the inhibitor dissolved readily in saline solutions, some of the crystals went into solution slowly at room temperature. The solution rate determination at various temperatures, particularly in the region of 32 F would be of value. The solubility factor, being related to the concentration of the inhibitor in the saline solutions, directly influences the ability of the inhibitor to retard corrosion rates.

The salt content desired in rigs B and C was approximately 5 percent. This value varied considerably, but this variation was more or less a parallel condition in both rigs. Solutions taken from various city thoroughfares following snow storms also showed a considerable degree of variation of salinity. In the case of the inhibited salt, the Banox addition was 2 percent of the salt, and the two materials were dry mixed in a twin dry blender. In this way, a uniform mixture was secured. However, it was observed that vibration caused a separation of the salt and inhibitor, which would be expected because of the wide difference in the particle size of the coarse salt and

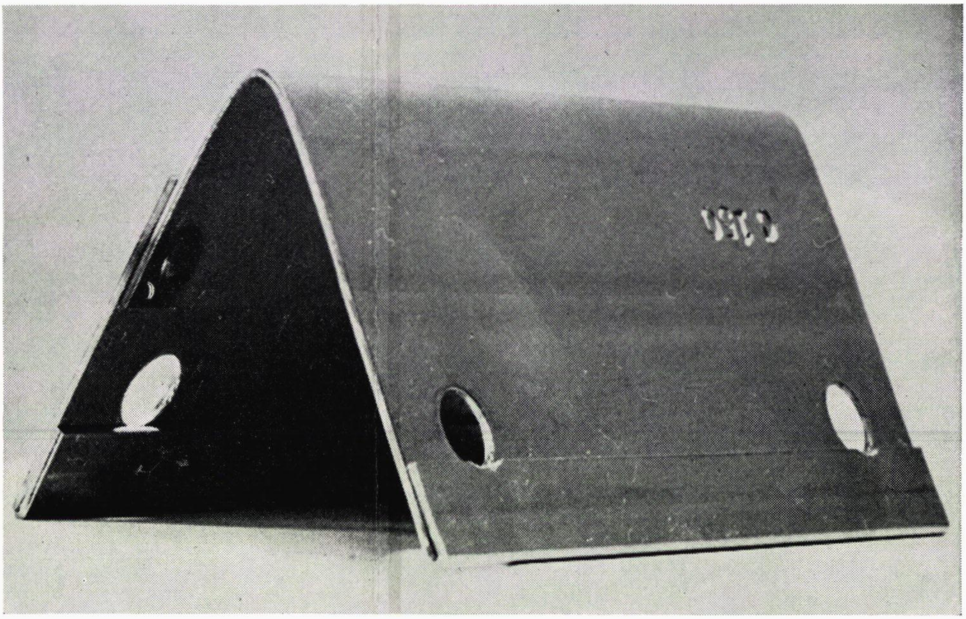


Figure 9. Caret-type coupon, not plastic coated. Surface cold rolled; full size.

fine Banox. The Banox consisted of coarse and fine particles, and it was noted that the fine particles tended to adhere to the salt crystals following the blending operation.

## EXPERIMENTAL PROCEDURE

The following outline of experimental procedures describes how the coupons were dealt with at the rigs, as well as how they were cleaned after removal. Certain coupons were assigned to special racks for placement on cars, and others were used for atmospheric corrosion tests. Road and rig solutions were checked for salt content and pH, and in the case of the inhibited salt, the amount of Banox was also determined. Laboratory corrosion tests on coupons exposed to saline and inhibited solutions were also carried out under different conditions to determine the effect of the inhibitor.

### *Test Rig Procedures*

All the fenders were fitted with rods carrying weighed, numbered, and cleaned coupons. Appendix A shows the coupon layout for each rig. On February 1, 1961, during the coldest period of the winter, operations were begun.

It was decided to remove specimens for weight loss every seven days. However, it was found that after the first week very little corrosion occurred, although both rigs B and C contained solution, while rig A contained dry snow. To all three rigs some clay soil was added to simulate road dirt. After the first week, which showed very little corrosion activity, it was decided to defer coupon removal until the fourteenth day. The weather moderated during the second week and corrosion activity increased quite noticeably. From the fourteenth day, coupons were then removed every consecutive seven days until the termination of the test.

Although the coupons were placed on in a consecutive manner, the method of removal was arranged to randomize the coupon selection. Starting on the side of the fender facing the motor drive and corresponding to rods 1—2, the method of removal was based on the latin square with A in the top position and D in the bottom position. One V and one flat coupon were taken from each wheel of each rig according to the removal plan of Appendix B for weight-loss determinations. To these positions additional V and flat coupons were placed on racks for removal at the end of the test, thus providing corrosion data under conditions differing from those experienced by the original coupons.

The conditions of the test involved running the vehicles for 15-min periods intermittently throughout the day for four periods and traveling a distance of 25 mi. In this way, the conditions of the test were held reasonably uniform during the run. Occasionally during a snow storm or heavy rain, this cycle could not be maintained. Time was also lost when the rigs failed mechanically and had to be shut down for repairs. Of the total scheduled 91 hr, the rigs operated some 78 hr, or 86 percent of the scheduled time.

### *Cleaning of Coupons*

Each removal period required cleaning of four V and four flat samples from each rig. All coupons were in pairs so that the corrosion of the V and flat coupons could be compared for the same location. The coupons were cleaned mechanically of all loose deposit and as much oxide as possible removed using a metal scraper. All coupons were washed, scrubbed, and dried, and the plastic was wiped with carbon tetrachloride to remove road tar. The coupons were finally cleaned by chemically dissolving the remaining oxide in a cold 6 N

HCl solution containing 2 percent by volume of rhodine 60 inhibitor (*8*), followed by thorough washing and drying with alcohol. Before weighing, the coupons were placed in a dessicator overnight to remove all traces of moisture. Blanks were cleaned for various periods of time in the inhibited acid, and the metal loss was considered negligible being within the limits of error for this method.

During cleaning of the coupons over the period of the test, the ease of cleaning was as follows: unsalted rig, most difficult; salted rig, most easily cleaned; inhibited rig, readily cleaned under the dirt poultice, more difficult where no poultice formed. It was also observed that the coupons removed from the No. 4 fender equipped with a heater to maintain 40 F during the nonoperating period were all more difficult to clean than the coupons from the unheated fenders.

The accumulation of dirt on the coupons built up during the test, and at the end of 21 days (Figs. 10 and 11) the poultice effect was well established, particularly in the case of rigs B and C. In rig A, due to lack of fluids during the cold periods the poultice build-up was slower. Toward the end of the test period, the dirt had bridged across the top of the coupons filling the V-type coupons almost completely. The flat coupons, which were in a vertical position, tended to be cleaner on the lower side due to washing by the wheel spray.

The weight losses found for the various coupons were determined in terms of milligrams per square decimeter, and the accumulated losses were later plotted to show the various trends encountered in each rig.

*Corrosion Coupons on Cars*

To obtain corrosion losses due to car operation on city streets, ten cars were selected on which were mounted coupon racks similar to those placed in the test rigs. These racks were mounted near the rear right wheels to be on the curb side of the car. In the case of eight cars, the location was well exposed to the spray from the wheels. In the case of two cars, it was found that the rack was not as exposed to road splash as the other eight.

A record of the mileage and conditions of the road was kept for each car, together with garage conditions. From time to time, coupons were removed from various cars during the test period and terminal samples were removed at the end of the run. The coupons were cleaned as outlined previously, and the corrosion rates in milligrams per square decimeter per day were determined.

*Atmosphere Tests*

To determine the corrosion losses due to atmospheric effects, a group of coupons were placed on the roof of a small building at the site. Flat coupons were used for this test, and only one side was exposed, the under side being coated entirely with epoxy resin. Most of the coupons were exposed with one flat side facing south inclined at an angle of 40°. Several flat coupons were exposed on edge with both sides to the weather in a manner similar to the way in which the flat coupons were mounted in the fenders of the rigs and under the cars.

Coupons were removed from the test site from time to time, and the weight losses due to industrial atmosphere were then determined.

*Solutions from Rigs and City Streets*

For purposes of checking, solutions were taken from rigs B and C from time to time and analyzed for salinity and pH, and, in the case of rig C, the amount of Banox present was also determined. Following snow storms in the city, solutions were collected from various locations and analyzed

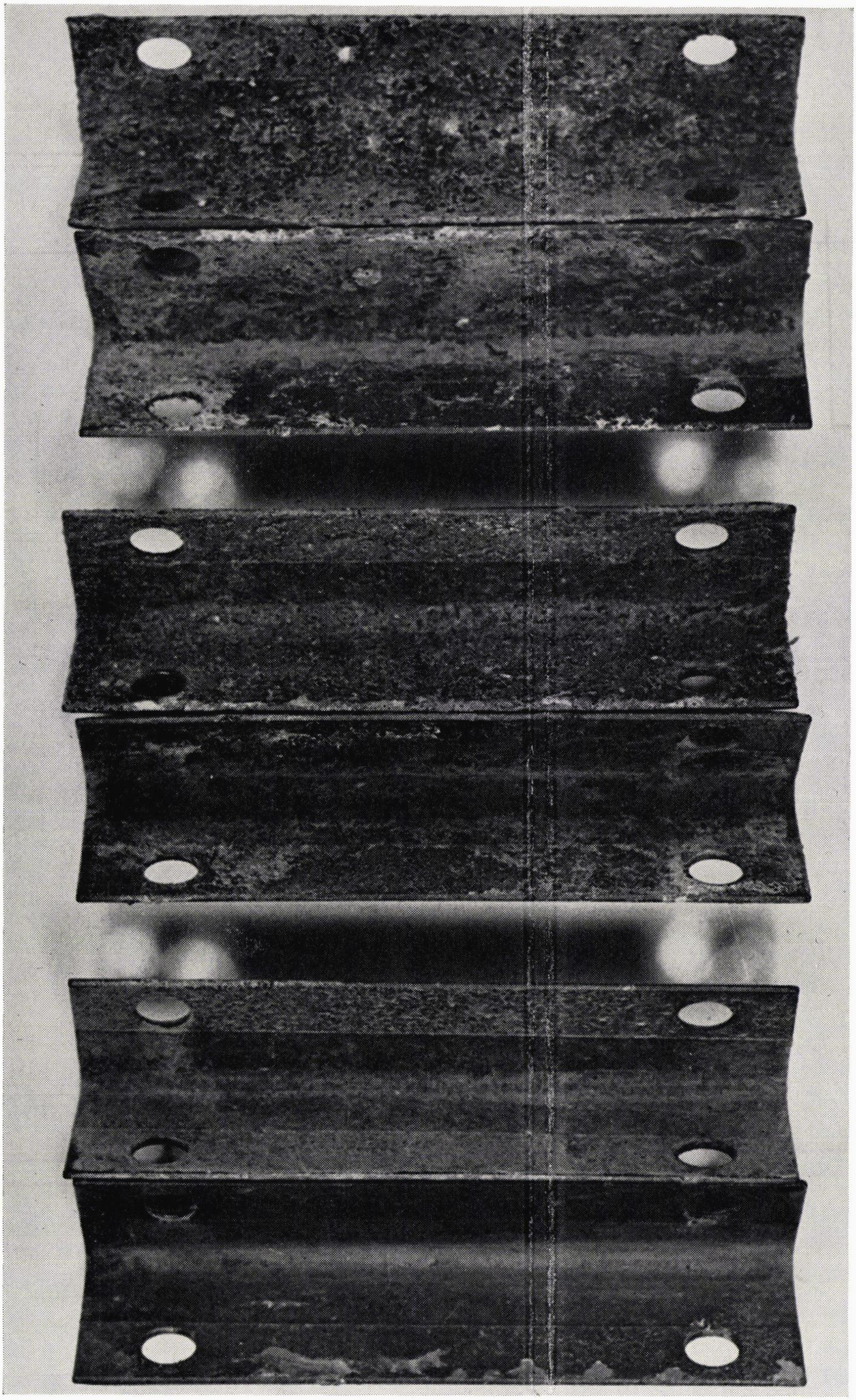


Figure 10. Poultice build-up at end of 21 days, V-type coupons; (left) no salt, (center) salted, (right) salt with inhibitor.

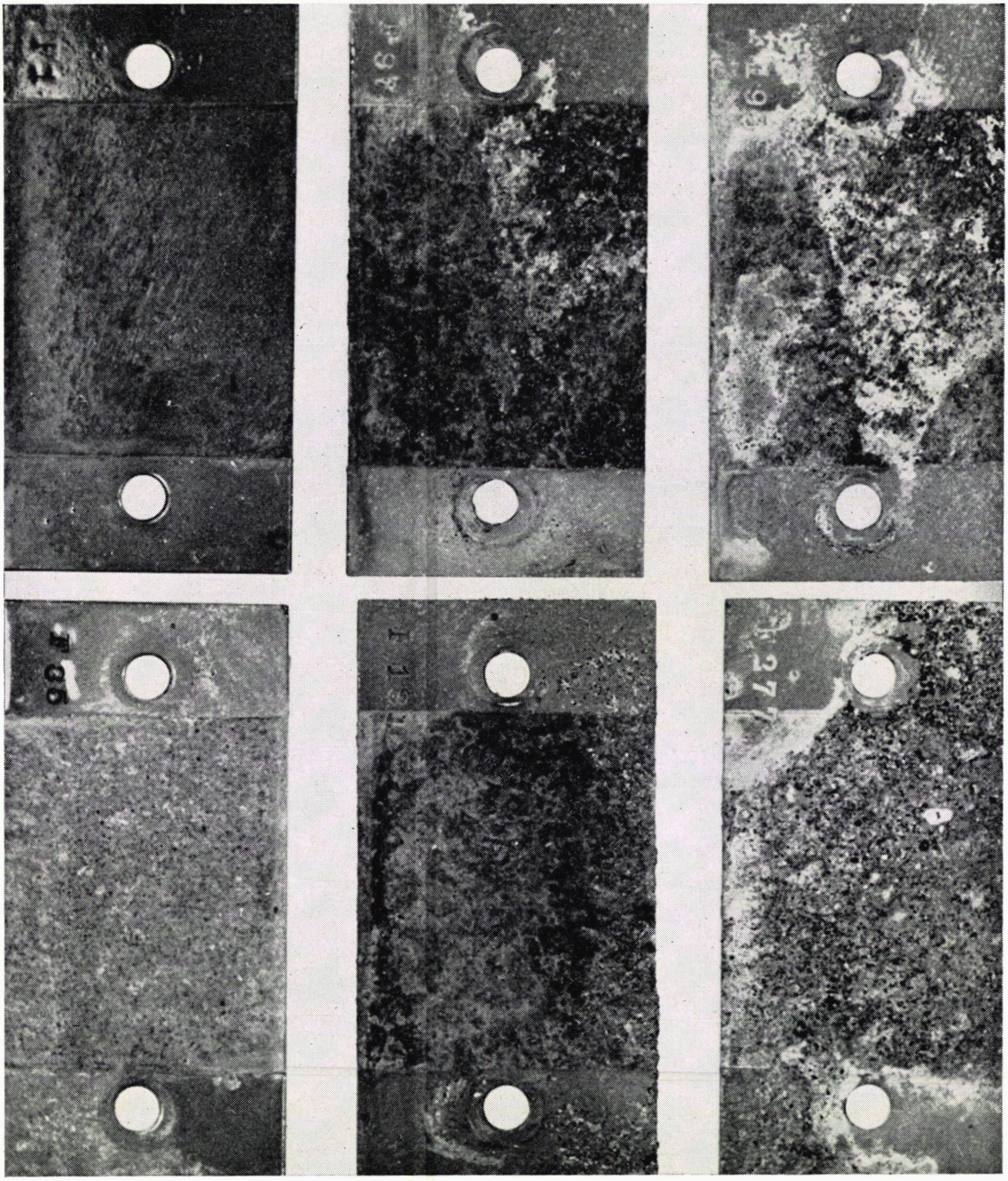


Figure 11. Poultice build-up at end of 21 days, flat-type coupons; (left) no salt, (center) salted, (right) salt with inhibitor.

for salt content and pH to determine the variation and concentration in several areas of the city and on the throughway.

From the various locations, about a quart of solution was collected in such a manner as to be representative of the road or rig mixture. In the case of road samples, to obtain a truly representative sample was not possible. The rig samples were more truly representative of conditions, and when the salinity was found to be high, corrections were made immediately with the aid of the conductivity meter.

### *Laboratory Corrosion Tests*

To examine the inhibiting effect of Banox in saline solution, laboratory tests were conducted by three procedures: (a) salt spray test, (b) modified Corrodcote test, and (c) intermittent immersion test.

Slush samples taken from Toronto roads were submitted for analysis for sodium chloride content and for pH determinations. Samples of slush from test rigs were submitted for sodium chloride and pH determinations, and, where applicable, for determination of inhibitor content. Several samples of deposits removed from test panel were submitted for determination of sodium chloride and pH determination.

## DISCUSSION OF RESULTS

The object of this corrosion test program was to evaluate quantitatively the effect of adding an inhibitor to de-icing salt on the corrosion of autobody steel under conditions similar to those encountered on salted streets. Although the test rig operation cannot be considered entirely comparable to street conditions, this method of testing was considered to be sufficiently valid to yield data of a significant nature.

The following discussion of the test results will deal first with the rig operation, followed by examination of data obtained from coupons mounted on cars, atmospheric corrosion tests, laboratory corrosion tests data, and solution analyses.

### *Corrosion Coupons on Rigs*

The weight losses for each removal period of the original coupons placed on February 1, 1961, for each rig are shown in Figure 12. The values up to February 21 represent the average value of four V-type coupons, and four flat coupons taken off in pairs according to the removal program in Appendix B. After February 21 the values for wheel 4 of each rig were excluded as this wheel was heated to 40 F after this date. This was done because the heating reduced the corrosion slightly in rig A (unsalted), increased corrosion very markedly in rig B (salted), and produced erratic corrosion in rig C (inhibited).

The corrosion of the salted rig is definitely more severe than the other two rigs, and at the end of the 91-day period, the rates were still ascending steeply. The curves for each coupon type are somewhat erratic, and one crosses the other at several points. By and large, the corrosion rate for both the V-coupon and the flat coupons does not differ to any great extent, although the poultice effect in the case of the V-coupon was much more severe than the flat coupon. It was previously pointed out that coupons from this rig were easily cleaned. The rust formation was loosely adhering and porous, consequently the saline solutions were able to penetrate the layer of dirt and rust to attack the underlying metal. Even after 91 days, the rate of attack appears to be undiminished.

In the unsalted rig A, the corrosion losses show a divergence as the test proceeds with the V-coupon showing a more severe loss than the flat coupons. Towards the end of the 91-day

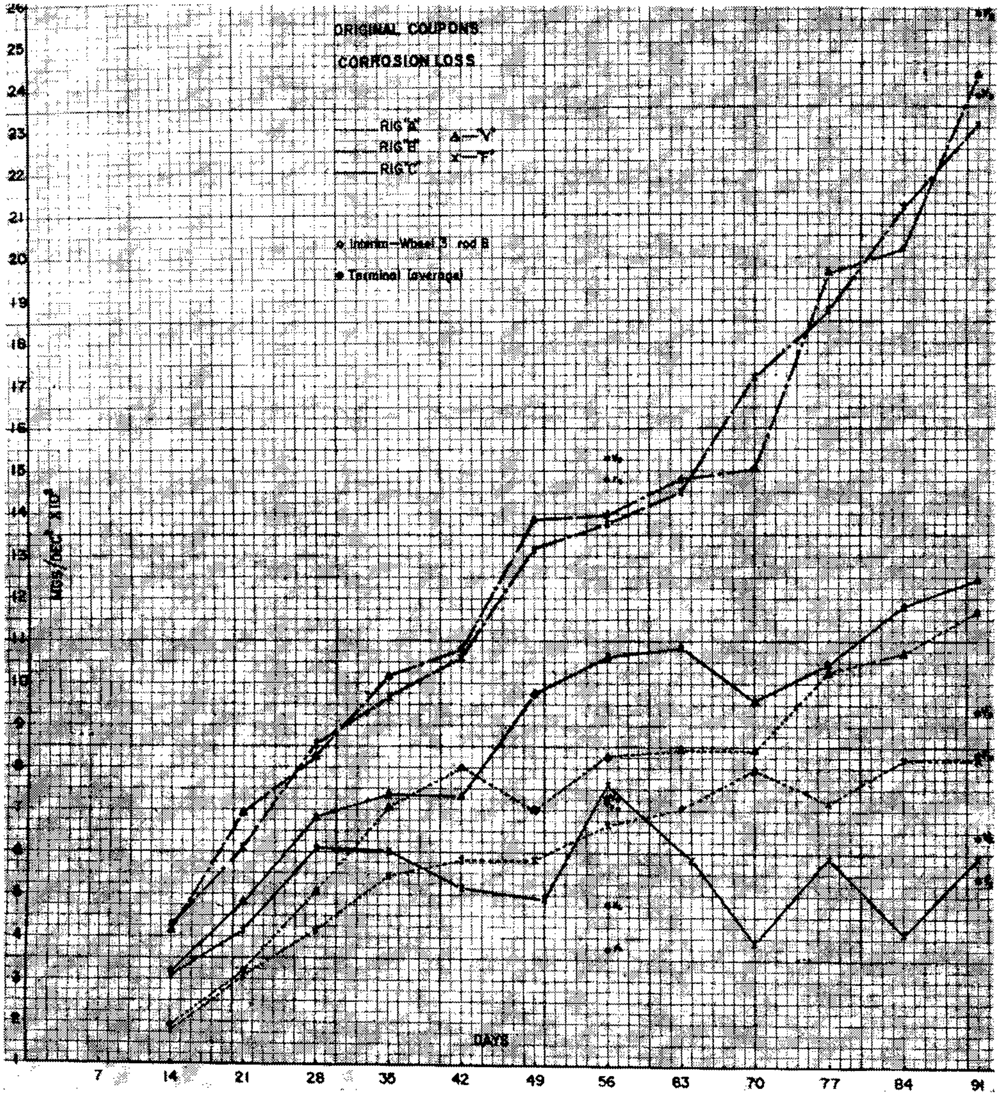



Figure 12. Corrosion losses of original coupons in the three rigs including interim losses from wheel 3 rod 8 and losses of terminal coupons.

period, the tendency was to approach a constant rate of attack. These curves show that the crevice type of surface represented by the V-coupon corrodes at a slightly higher rate than a plain surface represented by the flat coupon. The accumulation of dirt in the V-coupon acting as a poultice would contribute to the increase in corrosion in this instance.

In rig C, inhibited salt, the two curves are somewhat more erratic showing greater divergence. At the end of 91 days, there is also a tendency for the two rates to reach a constant value. The losses for the

V-coupons are above those for rig A, and the losses for the flat coupons reach a point below those for rig A. The inhibitor is tending to reduce corrosion losses from the salted level to the unsalted level. In the case of the flat coupons, the inhibited rig shows that the losses are lowered below those for the unsalted rig.

The results found in rig C showed considerable spread, no doubt due to some variation in the concentration of Banox in the saline solution in the rig, and also due to the effect of poulticing by the added soil in the rig pathway. The flat coupons particularly showed that where the top portions were poulticed, corrosion rates were high as deduced from the etched texture of this area of the coupon. The bottom faces being less poulticed were coated with a tight uniform oxide difficult to remove and under which the metal remained relatively smooth. Consequently, on the flat coupons the corrosion losses represent an average of areas where corrosion rates were high and low, a condition impossible to control, but which is very representative of conditions occurring on the under parts of an automobile body.

At the termination of the test, many of the original coupons were still in place. The losses for the terminal coupons were determined and the average values obtained. The terminal coupons from rig A were partially assessed. Terminal coupons from one wheel from rig B were examined, and all terminal coupons from rig C were examined. The average values are shown on the respective curves in Figure 12 as terminals. In rig A, they fall in the general region between the two types of coupons. In rig B, the terminals are reversed and above the position of their respective curves. In rig C, the greatest shift occurred in the V-coupon while the location of the terminal results for the flat coupon lies close to its respective curve.

The removal plan adopted selected coupons from the side of the fender facing inwards and from positions top to bottom. Examination of the data indicated that within the fender corrosion rates appeared high at the top inside, decreasing in the central region, and rising at the bottom inside. Also the rates appeared higher on the inside regions, decreasing midway across the fender, and flattening off toward the outside of the fender. Although the general results would remain the same had sampling included random removal across the fender as well as in the vertical direction, the curves for the three rigs would have altered their shape slightly in the case of rigs A and B, but more so in the case of rig C. This effect was attributed to the spray pattern. The wheels moving in a circular path would be unlike an automobile wheel because the spray would tend to angle vertically toward the outside of the fender. The spray distribution as visualized inside the rig fender would be less on the inside, greater in the central region, and maximum at the bottom outside. The spray pattern would affect rig C the most if proper coating of the coupons by the inhibited salt solution was not effective. However, examination at the site indicated that, although the above spray pattern existed, the fenders appeared to have been well covered over most of their internal surfaces.

This effect attributed to position was examined at the end of 56 days when the bottom rod was removed from No. 3 wheel of each rig. The weight loss data at this time showed samples from both rigs A and B to be on their respective curves (Fig. 12), whereas in the case of samples from rig C the weight losses were well below rig A and considerably below the curve for rig C. This position effect points out that the inhibited salt solution must have free access to the areas to be protected in order to be effective in reducing corrosion.

The corrosion rates in milligrams per square decimeter per day (mdd) over the period of the test are shown in Figure 13. Included on the chart are the corrosion rates for No. 4 wheel which had been heated to 40 F from February 21 to May 2. From this chart the corrosion rates for the three rigs can be compared; these rates pertain only to the original coupons placed on the rigs February 1. The interesting aspect of these data is the increase in corrosion rate of the heated wheel on rig B where the chemical activity of the salt solutions has been increased by raising the temperature of this fender when not operating. Heating tends to reduce the rate of the unsalted rig, whereas the condition in the inhibited rig C is somewhat erratic. The V-coupons in rig C show wide variation possibly related to the poultice effect reducing the efficiency of the inhibiting process.

It was pointed out earlier that the poultice effect appeared to be most noticeable on the flat coupons of rig C. Under the poultice area at the top, the corrosion rate was higher as judged by the etching effect. On the lower surface a tighter oxide coating was evident and here the corrosion rate appeared lower. Figures 14, 15, and 16 show photomacrographs of the surface of flat panels from each rig after the full period of 91 days. The surface of the sample from rig A (Fig. 14) is still relatively smooth. In this case pit-type corrosion is developing at the dark spots but the surface is not severely etched. Figure 15 showing a sample from rig B indicates severe etching more or less uniformly over the entire surface. Figure 16 (rig C) shows some area of etching at the top whereas at the bottom there are smooth patches. The rough patches were located under the dirt poultice and here the scale was very similar to that formed on the coupons from rig B. The flat coupons from rig C showed the greatest variation of attack ranging in appearance similar to Figures 14 through 16.

The appearance of Figure 14 (rig A) indicates the onset of pit-type corrosion. Although not too well established at the end of 91 days it would be expected that, had the test continued, pit-type corrosion would be more evident a few weeks later.

Analyses were also made of the weight losses and corrosion rates of the replacement coupons over most of the test period. It will be recalled that these coupons were placed on the rods two weeks following the start of the test on February 14. The first coupons placed on remained on until May 2. Thus the replacement coupons have different exposure conditions than the original coupons, and corrosion conditions were much more active on February 14 than they were on February 1, when the temperature was around 0 F. Although the replacement coupons occupied the same locations as the originals, they were exposed in reverse time to the originals.

The replacement coupon weight losses for each rig appear in Figure 17, and it can be readily seen that, although the curve for each rig occupies a similar location to those in Figure 12, the losses are somewhat higher, and there is little or no tendency to level off. Rig C, the inhibited rig, shows some retardation of corrosion, but after 49 days the corrosion losses remained above those for rig A (unsalted).

Figure 18 shows the corrosion rates for the replacement group. In this case the values for rig A and B are the average of the V and the flat coupons. This average was taken as the rates for each type of coupon were not too widespread. In the case of rig C the rates for each type of coupon are shown, as there was a considerable spread in their rates.

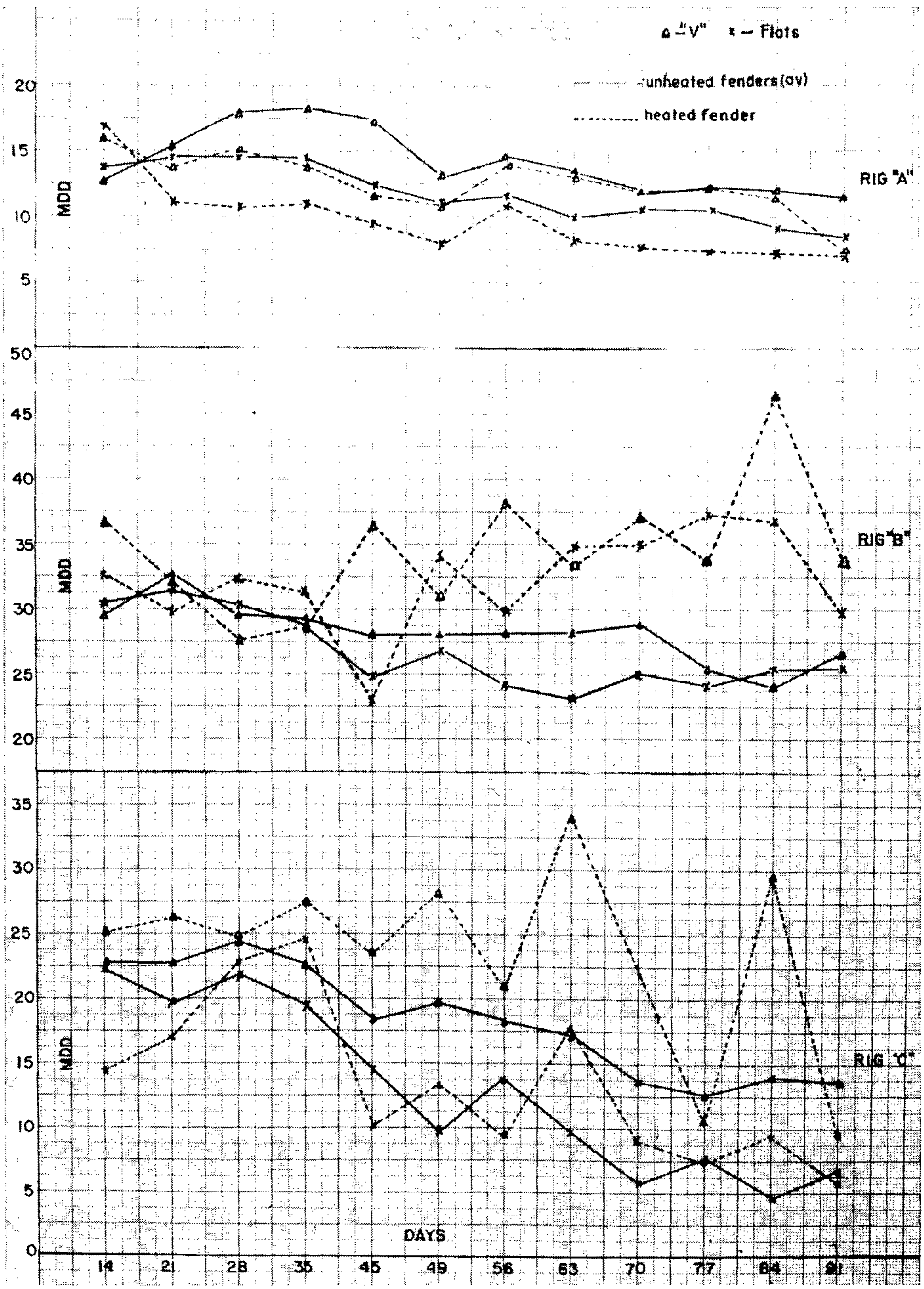



Figure 13. Corrosion rates for coupons in the three rigs and in the heated fender.

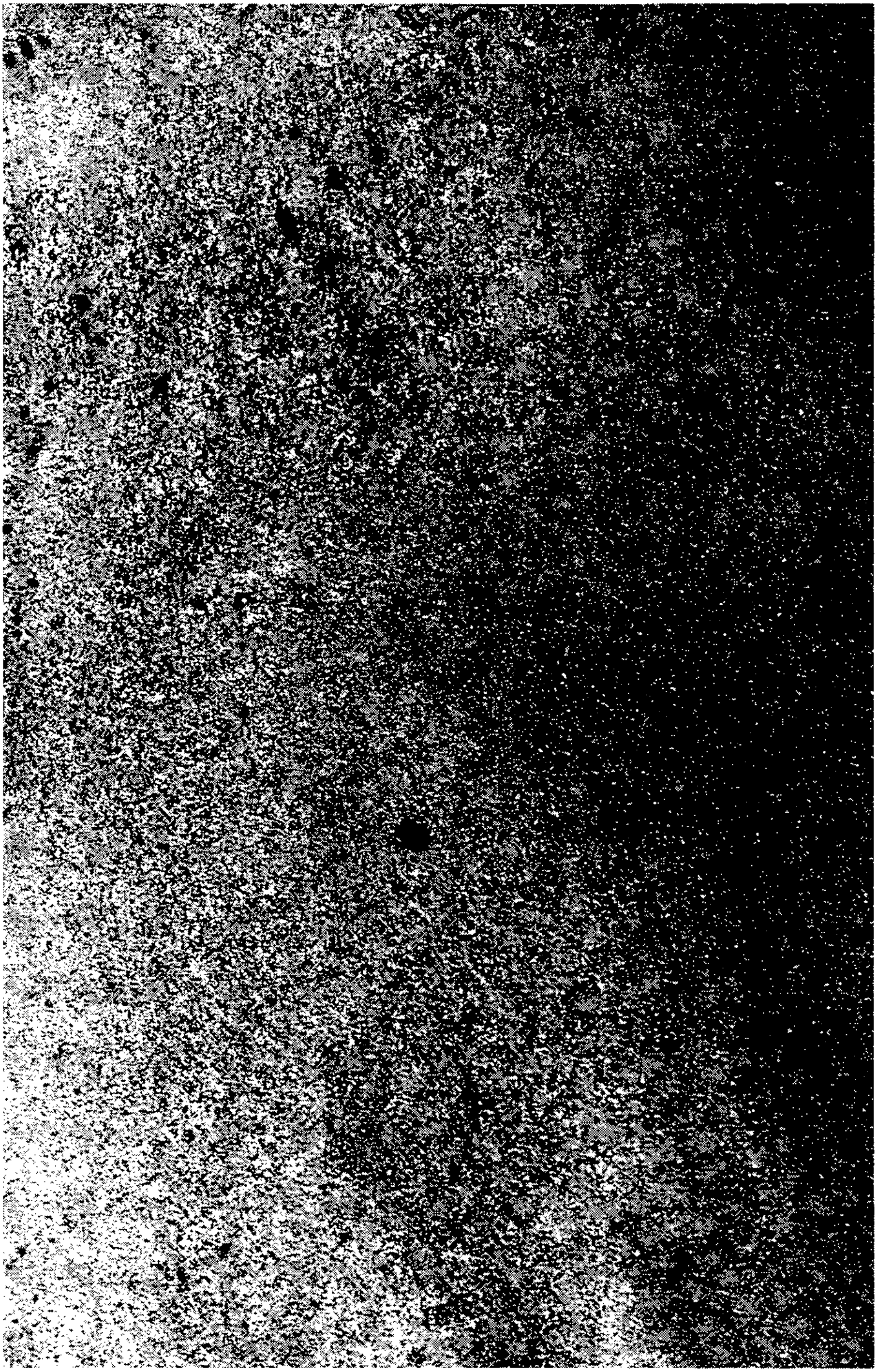


Figure 14. Photomacrograph of flat-type coupon after 91 days, rig A (unsalted). Pitting just beginning. (Mag. × 3¼)

Figure 15. Photomacrograph of flat-type coupon after 91 days, rig B (salted). Surface generally etched. (Mag. × 3½)

Figure 16. Photomacrograph of flat-type coupon after 91 days, rig C (inhibited salt). General etching under poultice at top; lower unpoulticed areas less attacked. (Mag. × 3¼)

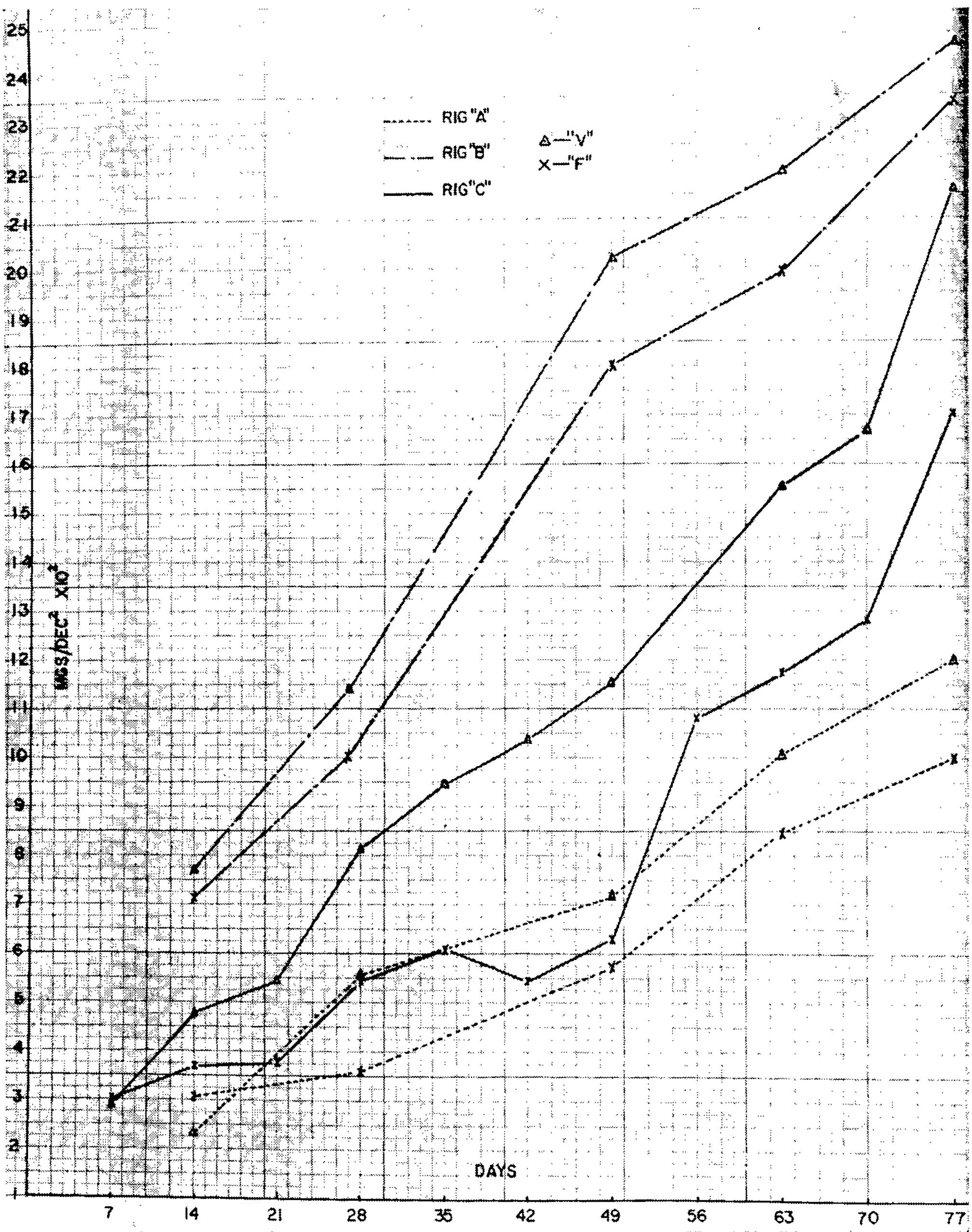



Figure 17. Corrosion losses of replacement coupons.

The rates for the flat-type coupons of rig C appear very close to those shown for rig A.

From these data it is apparent that the different period of placing on additional coupons has resulted in a higher corrosion activity of the replacement coupons. This could be due

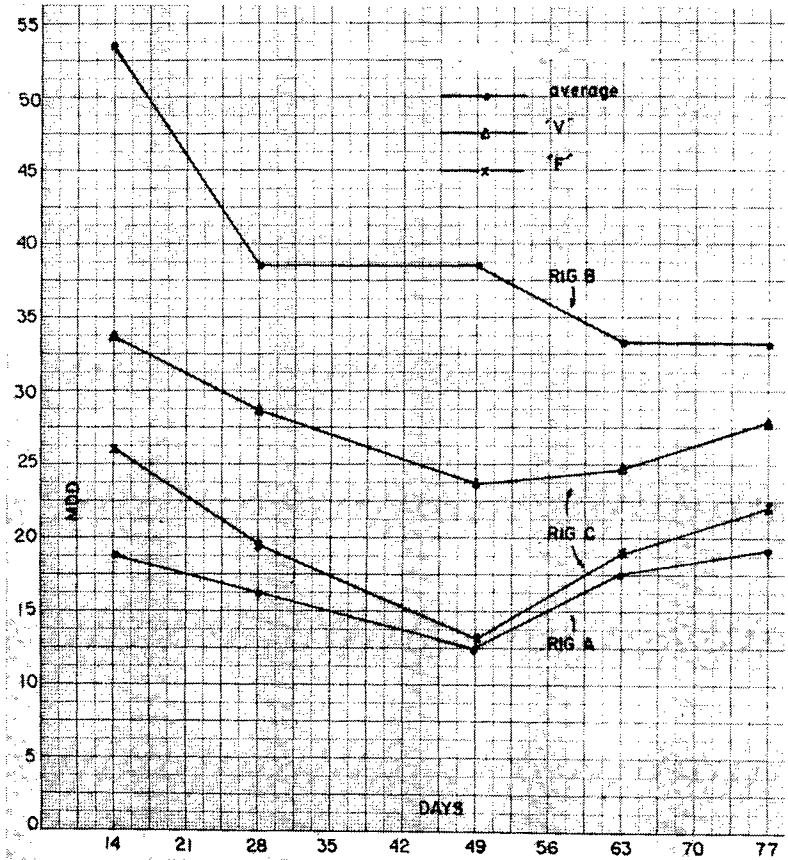



Figure 18. Corrosion rates of replacement coupons.

to a higher temperature environment at the time of placement, and also due to a faster poultice formation during this period. These two conditions were absent in the case of the original coupons when the temperature was lower and poultice rate appeared slower.

The caret-type coupons, it will be recalled, were placed on the rods for a qualitative examination only. It was found that these coupons did not exhibit any significant corrosion under the beads, under the spot welded lap joint, or along the cold worked area. The period of 91 days was too short to develop undue corrosion in these areas, and consequently no time was devoted to any specific examination of the caret coupons.

The foregoing discussion has dealt with the corrosion in the three rigs as measured by two types of corrosion coupons. Comparison of coupons placed on at different periods was also made. From the data presented, it is evident that the inhibitor employed in this test has tended to reduce the corrosion rate of the coupons in rig C to values equivalent to, and lower than, those in rig A. The replacement coupons show the same tendency, though not as markedly. It is evident in rig B that saline solutions corrode autobody steel very actively. The effect of heating influences the corrosion rates, leading to increased corrosion for the salted rig, and a diminished rate in the unsalted rig. In the case of the inhibited salt, it is believed that the rate would be diminished if poulticing by the road dirt were absent.

If the rigs had continued to operate through the summer and fall under atmospheric conditions, as would a car, the corrosion effects can only be a matter of conjecture. Under these conditions, the rainfall would eventually flush away the saline solution in rigs B and C. Corrosion in all the rigs would proceed at different rates for a time, possibly all three reaching a common level later in the summer. In the case of rig C, the corrosion would depend on the stability of the inhibited areas on the coupons. If maintained, the corrosion in rig C would be retarded. If the protection broke down, corrosion would proceed in much the same manner as the other two rigs. With the return of winter, the coupons would have an entirely different surface condition built up to begin the next winter cycle, when compared with the first winter cycle. How the coupons in rig C would respond to these new conditions cannot be answered by the data of this program as it is not possible to extrapolate such short-term data through the following seasons, but which is an important consideration in the use of an inhibitor to protect an automobile. In view of the results obtained for the replacement coupons (Fig. 17), it is probable that in rig C the degree of protection during the second winter season would not be as high as that achieved in the first.

### *Corrosion Coupons on Cars*

The corrosion losses were obtained from coupons placed on cars that operated in the city during the winter months. The test racks mounted near the right rear wheel were well exposed to road solutions except in two cases. Figure 19 is a photograph of the well-poulticed rack representative of eight cars, and Figure 20 is representative of the two cars that did not receive the same build-up of road dirt. A record of distance traveled was maintained and also the garage conditions, if not parked outside. These data are shown in Table 3, with the results in terms of corrosion rates for the several periods of sample removal.

Two significant points were noted from these data:

1. The corrosion is independent of mileage, being chiefly time dependent.
2. The car parked in a heated garage showed a higher corrosion rate than all the others, which were left outside or in an unheated attached garage.

It was also observed that the flat coupons on the car racks showed more attack than the V-type. This may be due to the flat panel being more exposed to the wheel spray than the V-type and receiving a mild sand blast on the lower side of the coupons.

The corrosion rates of the car coupons were found to be lower than those rates for the unheated fenders in rig B. The coupons from car No. 9 which had been parked in a heated garage showed a higher rate of corrosion comparable to conditions found in the heated fender of rig B, although the values for car No. 9 were slightly lower than the results from the heated fender.

The conditions of these tests, of course, differed somewhat from the rig operation. However, the results and comparison of the data derived from each car proved interesting and informative. The reason for the lower corrosion losses experienced by the coupons on the cars when compared with those in rig B is at-

TABLE 3
CORROSION OF CAR TEST COUPONS

| Car | Corrosion Rate: First Period Days | First Period Mdd | | Second Period Days | Second Period Mdd | | Mileage (mi) First Period | Mileage (mi) Second Period | Condition of Rack | Parking |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 25 | V-20.8 | F-23.8 | 90 | V-20.2 | F-20.9 | 402 | 1,451 | Heavy poultice | Outside |
| 2 | 25 | V-23.6 | F-23.2 | 90 | V-20.5 | F-20.1 | 804 | 2,573 | Heavy poultice | Attached garage, unheated |
| 3 | 22 | V-24.6 | F-24.2 | 87 | V-18.7 | F-22.6 | 640 | 4,084 | Heavy poultice | Outside |
| 4 | 21 | V-23.7 | F-27.1 | 85 | V-24.0 | F-25.0 | 967 | 3,571 | Heavy poultice | Outside |
| 5 | 46 | V-22.6 | F-22.6 | 98 | V-21.6 | F-21.6 | 1,675 | 3,522 | Heavy poultice | Outside |
| 6 | 44 | V-20.4 | F-17.8 | 85 | V-21.4 | F-20.2 | 812 | 2,021 | No poultice | Outside |
| 7 | 43 | V-18.9 | F-21.2 | 86 | V-17.3 | F-21.0 | 1,259 | 2,268 | Heavy poultice | Inside, unheated |
| 8 | 64 | V-10.1 | F-15.3 | 86 | V-15.8 | F-13.8 | 1,683 | 2,058 | No poultice | Outside |
| 9 | 64 | V-28.7 | F-30.0 | 85 | V-31.7 | F-32.0 | 1,523 | 2,055 | Heavy poultice | Heated garage |
| 10 | 64 | V-16.5 | F-15.9 | 85 | V-18.7 | F-18.0 | 1,852 | 2,463 | Heavy poultice | Outside |

tributed to the fact that, during mild periods, slight snowfall or rain would occur and, inasmuch as salting would not be needed, the car coupons would be then rinsed of salt solution periodically slowing down the corrosion rate. In rig B the tendency would be to have the salt solution up to strength most of the time, thus maintaining the corrosion conditions for all periods of exposure. Thus, in the rig test the exposure conditions

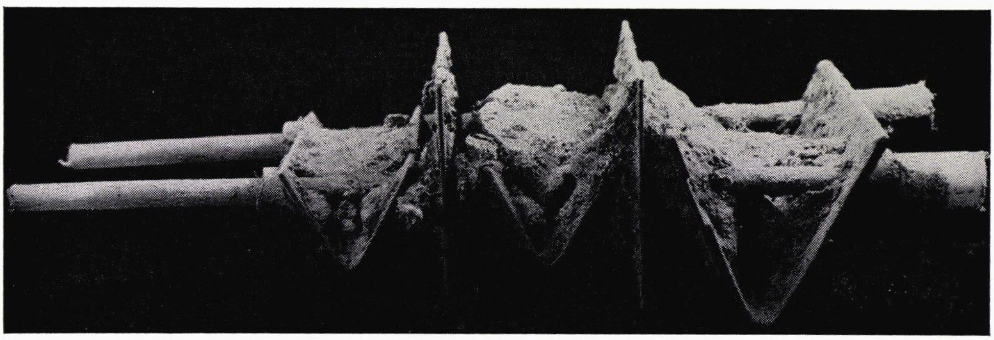


Figure 19. Poultice build-up typical of 8 cars (Table 3).

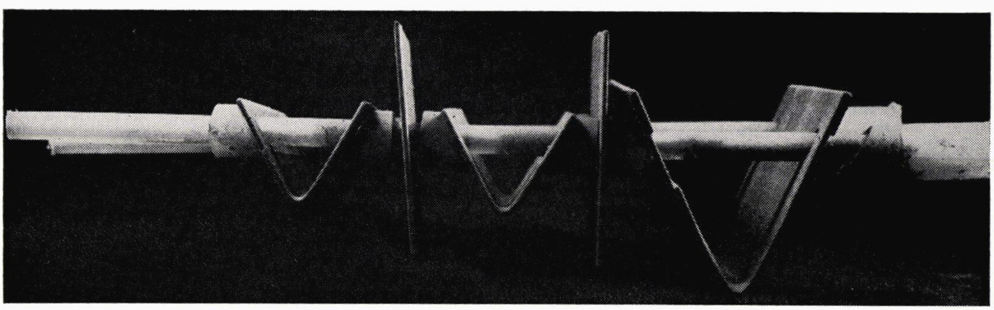


Figure 20. Light poultice build-up on 2 cars (Table 3).

would represent the worst condition of a severe winter, whereas in the car test the conditions were equivalent to a moderate winter season.

*Atmospheric Corrosion Tests*

To measure the effect of corrosion by the industrial-type atmosphere at the site, suitable coupons set up as described previously were evaluated from time to time. The corrosion losses were higher for these exposed coupons than for the more sheltered coupons in the unsalted rig A. The data for the atmospheric coupons are given in Table 4, together with a few points comparing the panels mounted in a flat and vertical position. Over a long period the losses on the vertical samples would be slightly higher than those mounted in the flat position.

The atmospheric corrosion of the exposed coupons is considerably higher than that found under the fender of rig A. The values lie more nearly in the area slightly above the V-coupons in rig C. These losses are somewhat comparable to those incurred by the test coupons mounted on cars in Table 3. It would be expected that the losses in the well-exposed area would be greater than those in rig A protected as they are by the fender and thus being able to dry off between exposures and to build up a more protective coating. The corrosion loss in the type of atmosphere at the site corresponds to about 9 g per sq dec per year, which is normal for industrial atmospheric corrosion. It is pointed out, however, that the short-term results of this test may not extrapolate to this total loss for the long-term exposure.

QUANTITATIVE CONSIDERATION OF THE CORROSION DATA

The foregoing discussion of results of the corrosion tests in the rigs, on the cars and atmospheric tests related the data somewhat qualitatively by means of graphs and tables. In order to provide a numerical relation of the effect of the inhibitor and the relation of corrosion weight losses of the car coupons and atmosphere tests to the losses found in the salted rig, the following data will serve to show the magnitude of these differences.

*Reduction of Corrosion Loss in Salt Solutions Due to Inhibitor*

Dealing with the effect of adding an inhibitor to the salt solutions in rig C, the percentage reduction of the corrosion losses for the three groups of data obtained from rig B (salt) and C (salt and inhibitor) is given in Table 5.

For the 91-day period, the effect of the inhibitor is very marked in the case of the original coupons and terminals with the flats showing a lower loss than the V-coupons. This was not the case for the replacement coupons, although they occupied the same locations as the originals. In this instance, as was pointed out previously, the replacements were put on at a different period during which temperature and poulticing conditions

TABLE 4
ATMOSPHERIC CORROSION TESTS

| Period | | Corrosion Loss (mg/dec²) | Corrosion Rate (mdd) | | |
|---|---|---|---|---|---|
| Days | Dates | | | Flat | Vertical |
| 25 | 2/3/61 - 2/28/61 | 630 | 25.2 | — | — |
| 46 | 2/3/61 - 3/21/61 | 1,082 | 23.6 | — | — |
| 74 | 2/3/61 - 4/18/61 | 1,462 | 19.8 | — | — |
| 88 | 2/3/61 - 5/2/61 | 1,652 | 18.8 | — | — |
| 21 | 3/21-22/61 - 4/11/61 | — | — | 25.5 | 21.6 |
| 42 | 3/21-22/61 - 5/2/61 | — | — | 24.8 | 27.4 |

TABLE 5

| Data Group | % Red. of Wt. Loss $\left(\frac{\text{rig B-rig C}}{\text{rig B}} \times 100\right)$ V-Coupons | Flat Coupons | Remarks |
|---|---|---|---|
| Original coupons | 48.5 | 74.4 | For 91-day period |
| Original coupons plus terminals | 61.0 | 77.0 | For 91-day period |
| Replacement coupons | 10.5 | 25.4 | Extrapolated to 91 days |

were believed to influence the action of corrosion in the initial stages promoting higher corrosion rates and a faster poultice rate which interfered with the action of the inhibitor.

The reduction of losses shown when the original take-off coupons were combined with the originals left on as terminals is greater than that for the original take-offs only. This result is due to the original take-offs being located at the inner side of the fender where corrosion rates were the highest. The results of the terminals indicated that other regions not sampled during the test period had lower losses due to more efficient coverage from the wheel spray. Thus the combination of all the losses for the original coupons showed lower average loss. This position effect was not as pronounced in rig A and rig B as shown by the location of the terminals in Figure 12.

An attempt was made to summarize the reduction of corrosion losses due to the inhibitor in rig C by calculating the average reduction of losses for both the V-type coupon and the flat-type coupon. The resulting percent reduction of the corrosion losses, thus calculated, was found to be as follows: originals, 62.2 percent; terminals, 76.5 percent; replacements, 17.7 percent; originals plus terminals, 76.3 percent; and originals plus terminals plus replacements, 55.7 percent.

In this case the spread ranges from 17.7 to 76.5 percent for the reduction of the combined losses of both types of coupons. For the test conditions prevalent in rig C probably the best representative figure for the over-all reduction of corrosion losses would be the general average for all the coupons, 55.7 percent.

### *Comparison of Corrosion Losses With Those of Rig B (Salted)*

Based on the corrosion weight losses of the coupons from rig B, the percentage differences for the original and terminal coupons and the replacements of rig A (unsalted) were calculated. In addition, a similar comparison was made of the corrosion losses of the car tests and the atmosphere test. The percentage difference for each of the previous test conditions is given in Table 6 with the foregoing data for rig C included for comparison.

For the 91-day term of the various test conditions, the figures in Table 6 show the weight losses found under these conditions when related to the salted rig B. There is a substantially lower loss in rig A in which the coupons were protected under the fender than for the atmosphere coupons which were boldly exposed to the weather. The losses on the car coupons were lower than those in the salted rig indicating that the conditions in the rig were more severe than on the salted streets.

## ROAD AND RIG SOLUTION DATA

To obtain data for salt content of road solutions, samples were collected

TABLE 6

| | | Wt. Loss, % Diff., V-Coupons | (Rig B — WL)/Rig B Flat Coupons | Remarks |
|---|---|---|---|---|
| Rig C (salt plus inhibitor) | Original coupons | 48.5 | 74.4 | For 91 days |
| | Original coupons plus terminals | 61.0 | 77.0 | For 91 days |
| | Replacements | 10.5 | 25.4 | Extrapolated to 91 days |
| Rig A (unsalted) | Originals | 51.6 | 64.4 | For 91 days |
| | Originals plus terminals | 58.5 | 65.6 | For 91 days |
| | Replacements | 50.5 | 56.7 | Extrapolated to 91 days |
| Car test coupons (salted streets) | | 24.0 | 27.5 | Extrapolated to 91 days; 10 cars tested |
| Atmospheric test coupons (industrial) | | | 26.4 | Extrapolated to 91 days; flat coupons with underside coated |

from four sites in the city following snow storms and after the streets had been salted. The four locations were as follows:

| *Code* | *Location* |
|---|---|
| 1 | Mount Pleasant at Cemetery |
| 2 | Yonge at Dundonald |
| 3 | Bloor at Church |
| 4 | Queen's Park at Ontario Research Foundation |

Several locations in the Metro area were also included to compare the salting within the city limits and the Metro area.

| *Code* | *Location* |
|---|---|
| A | Gardiner Expressway |
| B | Eglinton at Weston Road |
| C | Sheppard at Kennedy Road |
| D | Danford at Birchmount |
| E | Highway 27 |
| F | Kingston Road West at Victoria Park |
| G | Kingston Road East at Victoria Park |
| H | Dufferin at Lawrence |

The salt content and pH-value of the solutions determined in the Service Laboratory are given in Table 7. There was a considerable variation in the salt content taken at various periods during the program.

Solutions were collected from rigs B and C from time to time, and analyzed for Banox content. Some of the laboratory results show a high salt content, and it is pointed out that when this condition appeared it was possible to make immediate correction at the site to reduce the salt to

TABLE 7
SALT CONTENT OF ROAD SOLUTIONS

| Date Collected | Location | Salt (%) | pH |
|---|---|---|---|
| 12/21/60 | 1 | 1.24 | 7.40 |
| | 2 | 2.19 | 7.40 |
| | 3 | 3.69 | 7.32 |
| | 4 | 2.16 | 7.39 |
| 1/4/61 | 1 | 1.75 | 7.39 |
| | 2 | 2.01 | 7.19 |
| | 3 | 3.01 | 7.32 |
| | 4 | 1.93 | 7.58 |
| 1/26/61 | 1 | 4.42 | 7.10 |
| | 2 | 7.33 | 6.70 |
| | 3 | 2.40 | 7.60 |
| | 4 | 4.83 | 7.50 |
| 1/27/61 | 1 | 3.63 | 7.20 |
| | 2 | 3.62 | 6.95 |
| | 3 | 5.27 | 7.10 |
| | 4 | 3.80 | 7.10 |
| 2/5/61 | 1 | 3.82 | 6.30 |
| | 2 | 6.83 | 7.05 |
| | 3 | 1.28 | 7.32 |
| | 4 | 0.56 | 7.45 |
| 2/16/61 | 1 | 0.18 | 8.36 |
| | 2 | 0.08 | 8.34 |
| | 3 | 1.90 | 9.32 |
| | 4 | 1.67 | 8.02 |
| 3/9/60 | 1 | 0.50 | 8.11 |
| | 2 | 0.30 | 8.01 |
| | 3 | 0.55 | 8.71 |
| | 4 | 0.43 | 7.85 |
| 2/4/61 | A | 7.61 | 7.03 |
| | B | 5.03 | 7.00 |
| 3/9/61 | C | 2.31 | 8.31 |
| | D | 1.07 | 8.20 |
| | E | 1.68 | 7.85 |
| | F | 0.99 | 8.22 |
| | G | 0.43 | 8.15 |
| | H | 1.31 | 8.11 |

the operating range, by the aid of the conductivity meter.

The analysis of the solutions from rigs B and C are shown in Table 8. The interesting point is the variation of the Banox content. Although it was added in the amount of 2 percent of the salt, at no time did the Banox reach the 2 percent mark in the solution, with the exception of that period when the solution was prepared in drums using city water. The value of 2.5 percent Banox in the April 25 test was believed due to using the inhibited salt toward the bottom of the container where excess Banox had concentrated by handling and jarring causing the Banox to settle out toward the lower parts of the container. This possibility was pointed out under the section dealing with inhibitors.

TABLE 8
SALT AND INHIBITOR CONTENT OF RIG SOLUTIONS

| Date | Rig | Salt (%) | Meter [1] | pH | Banox (%) |
|---|---|---|---|---|---|
| 2/1/61 | B | 6.14 | | 7.50 | |
| | C | 6.98 | | 6.62 | 0.5 |
| 2/2/61 | | | | | |
| AM | B | 15.4 | | 7.35 | |
| | C | 17.0 | | 5.88 | 1.7 |
| PM | B | 7.71 | | 7.13 | |
| | C | 9.67 | | 6.02 | 1.9 |
| 2/4/61 | | | | | |
| AM | B | 6.23 | | 7.37 | |
| | C | 6.32 | | 5.92 | 1.8 |
| PM | B | 4.79 | | 7.20 | |
| | C | 5.20 | | 6.20 | 1.7 |
| 2/5/61 | | | | | |
| AM | B | 4.29 | | 7.30 | |
| | C | 4.87 | | 6.30 | 1.7 |
| 2/12/61 | B | 3.00 | 3.4 | | |
| | C | 2.07 | 2.7 | | |
| 2/16/61 | C | 3.68 | (Solution 2 PM) | | 1.9 |
| | | 3.65 | (Solution 4 PM) | | 1.65 |
| | | 2.07 | (Slush 2 PM) | | 1.07 |
| | | 1.32 | (Slush 4 PM) | | 1.7 |
| 3/16/61 | B | 11.8 | | | |
| | C | 11.7 | | | 0.67 |
| 3/25/61 | B | 7.37 | 7.0 | | |
| | C | 5.20 | 5.2 | | 0.52 |
| 3/26/61 | B | 6.29 | 5.5 | | |
| | C | 3.99 | 4.0 | | 0.26 |
| 3/27/61 | B | 2.72 | 2.8 | | |
| | C | 2.49 | 2.5 | | 1.1 |
| 4/2/61 [2] | B | 3.8 | | 8.00 | |
| | C | 3.37 | | 7.51 | 2.5 |

[1] Michi-Mho conductivity meter.

[2] City water used for rig solutions during this period and to May 2, 1961.

LABORATORY CORROSION TESTS

The corrosion tests employed to evaluate the inhibitor were (a) salt fog test, (b) modified Corrodcote test, and (c) intermittent immersion test. The first two tests indicated that under these conditions the inhibiting effect of Banox was found to be negligible. Both these test procedures are carried out under conditions of saturated humidity, and at no time did the coupons undergo a drying period. Under the conditions of these tests the inhibitor was unable to establish a protective film capable of reducing the corrosion activity of the saline solutions.

The conditions of the intermittent immersion test established protection to the extent that the corrosion loss in the Banox solution was one-tenth that of the salt solution. This test procedure which involves drying between exposures to the corroding environment is more representative of conditions established in the test rigs, although the results are not comparable quantitatively. This method of testing would be useful to obtain data for evaluating the inhibiting characteristics of inhibitors to qualify such compounds for further investigation. This test would by no means indicate inhibiting efficiency as applied to rig testing, but would assist in selecting other compounds for field tests.

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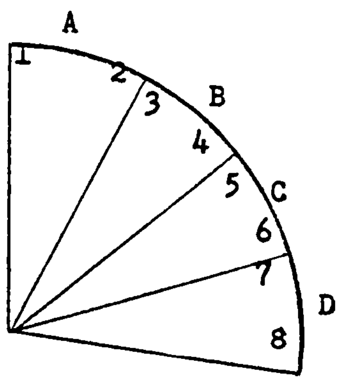
## Appendix A
## Sample Location Plan

| Rig | Wheel | Position on Rod | A Rod 1 | A Rod 2 | B Rod 3 | B Rod 4 | C Rod 5 | C Rod 6 | D Rod 7 | D Rod 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 1 | V 1 | V 2 | V 7 | V 8 | V 13 | V 14 | V 19 | V 20 |
| | Inside dia. | 2 | F 1 | F 2 | F 7 | F 8 | F 13 | F 14 | F 19 | F 20 |
| | | 3 | V 3 | V 4 | V 9 | V 10 | V 15 | V 16 | V 21 | V 22 |
| | | 4 | F 3 | F 4 | F 9 | F 10 | F 15 | F 16 | F 21 | F 22 |
| | | 5 | C 1 | V 6 | C 4 | V 12 | C 7 | V 18 | C 10 | V 24 |
| | | 6 | V 5 | F 6 | V 11 | F 12 | V 17 | F 18 | V 23 | F 24 |
| | | 7 | F 5 | C 2 | F 11 | C 5 | F 17 | C 8 | F 23 | C 11 |
| | | 8 | C 3 | | C 6 | | C 9 | | C 12 | |
| Condition—No salt, no inhibitor | 2 | 1 | V 25 | V 26 | V 31 | V 32 | V 37 | V 38 | V 43 | V 44 |
| | | 2 | F 25 | F 26 | F 31 | F 32 | F 37 | F 38 | F 43 | F 44 |
| | | 3 | V 27 | V 28 | V 33 | V 34 | V 39 | V 40 | V 45 | V 46 |
| | | 4 | F 27 | F 28 | F 33 | F 34 | F 39 | F 40 | F 45 | F 46 |
| | | 5 | C 13 | V 30 | C 16 | V 36 | C 19 | V 42 | C 22 | V 48 |
| | | 6 | V 29 | F 30 | V 35 | F 36 | V 41 | F 42 | V 47 | F 48 |
| | | 7 | F 29 | C 14 | F 35 | C 17 | F 41 | C 20 | F 47 | C 23 |
| | | 8 | C 15 | | C 18 | | C 21 | | C 24 | |
| | 3 | 1 | V 49 | V 50 | V 55 | V 56 | V 61 | V 62 | V 67 | V 68 |
| | | 2 | F 49 | F 50 | F 55 | F 56 | F 61 | F 62 | F 67 | F 68 |
| | | 3 | V 51 | V 52 | V 57 | V 58 | V 63 | V 64 | V 69 | V 70 |
| | | 4 | F 51 | F 52 | F 57 | F 58 | F 63 | F 64 | F 69 | F 70 |
| | | 5 | C 25 | V 54 | C 28 | V 60 | C 31 | V 66 | C 34 | V 72 |
| | | 6 | V 53 | F 54 | V 59 | F 60 | V 65 | F 66 | V 71 | F 72 |
| | | 7 | F 53 | C 26 | F 59 | C 29 | F 65 | C 32 | F 71 | C 35 |
| | | 8 | C 27 | | C 30 | | C 33 | | C 36 | |
| | 4 | 1 | V 73 | V 74 | V 79 | V 80 | V 85 | V 86 | V 91 | V 92 |
| | Outside dia. | 2 | F 73 | F 74 | F 79 | F 80 | F 85 | F 86 | F 91 | F 92 |
| | | 3 | V 75 | V 76 | V 81 | V 82 | V 87 | V 88 | V 93 | V 94 |
| | | 4 | F 75 | F 76 | F 81 | F 82 | F 87 | F 88 | F 93 | F 94 |
| | | 5 | C 37 | V 78 | C 40 | V 84 | C 43 | V 90 | C 46 | V 96 |
| | | 6 | V 77 | F 78 | V 83 | F 84 | V 89 | F 90 | F 95 | F 96 |
| | | 7 | F 77 | C 38 | F 83 | C 41 | F 89 | C 44 | V 95 | C 47 |
| | | 8 | C 39 | | C 42 | | C 45 | | C 48 | |

Sample Positions on Rods

| Position | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Rod 1 | V | F | V | F | C | V | F | C |
| Rod 2 | V | F | V | F | V | F | C | |

Section and Rod Positions



| Rig | Wheel | Position on Rod | A Rod 1 | A Rod 2 | B Rod 3 | B Rod 4 | C Rod 5 | C Rod 6 | D Rod 7 | D Rod 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| B | 1 | 1 | V 97 | V 98 | V103 | V104 | V109 | V110 | V115 | V116 |
| | | 2 | F 97 | F 98 | F103 | F104 | F109 | F110 | F115 | F116 |
| | Inside dia. | 3 | V 99 | V100 | V105 | V106 | V111 | V112 | V117 | V118 |
| | | 4 | F 99 | F100 | F105 | F106 | F111 | F112 | F117 | F118 |
| | | 5 | C 49 | V102 | C 52 | V108 | C 55 | V114 | C 58 | V120 |
| | | 6 | V101 | F102 | V107 | F108 | V113 | F114 | V119 | F120 |
| | | 7 | F101 | C 50 | F107 | C 53 | F113 | C 56 | F119 | C 59 |
| | | 8 | C 51 | | C 54 | | C 57 | | C 60 | |
| | 2 | 1 | V121 | V122 | V127 | V128 | V133 | V134 | V139 | V140 |
| | | 2 | F121 | F122 | F127 | F128 | F133 | F134 | F139 | F140 |
| | | 3 | V123 | V124 | V129 | V130 | V135 | V136 | V141 | V142 |
| | | 4 | F123 | F124 | F129 | F130 | F135 | F136 | F141 | F142 |
| | | 5 | C 61 | V126 | C 64 | V132 | C 67 | V138 | C 70 | V144 |
| Condition—Salt | | 6 | V125 | F126 | V131 | F132 | V137 | F138 | V143 | F144 |
| | | 7 | F125 | C 62 | F131 | C 65 | F137 | C 68 | F143 | C 71 |
| | | 8 | C 63 | | C 66 | | C 69 | | C 72 | |
| | 3 | 1 | V145 | V146 | V151 | V152 | V157 | V158 | V163 | V164 |
| | | 2 | F145 | F146 | F151 | F152 | F157 | F158 | F163 | F164 |
| | | 3 | V147 | V148 | V153 | V154 | V159 | V160 | V165 | V166 |
| | | 4 | F147 | F148 | F153 | F154 | F159 | F160 | F165 | F166 |
| | | 5 | C 73 | V150 | C 76 | V156 | C 79 | V162 | C 82 | V168 |
| | | 6 | V149 | F150 | V155 | F156 | V161 | F162 | V167 | F168 |
| | | 7 | F149 | C 74 | F155 | C 77 | F161 | C 80 | F167 | C 83 |
| | | 8 | C 75 | | C 78 | | C 81 | | C 84 | |
| | 4 | 1 | V169 | V170 | V175 | V176 | V181 | V182 | V187 | V188 |
| | | 2 | F169 | F170 | F175 | F176 | F181 | F182 | F187 | F188 |
| | | 3 | V171 | V172 | V177 | V178 | V183 | V184 | V189 | V190 |
| | Outside dia. | 4 | F171 | F172 | F177 | F178 | F183 | F184 | F189 | F190 |
| | | 5 | C 85 | V174 | C 88 | V180 | C 91 | V186 | C 94 | V192 |
| | | 6 | V173 | F174 | V179 | F180 | V185 | F186 | V191 | F192 |
| | | 7 | F173 | C 86 | F179 | C 89 | F185 | C 92 | F191 | C 95 |
| | | 8 | C 87 | | C 90 | | C 93 | | C 96 | |
| C | 1 | 1 | V193 | V194 | V199 | V200 | V205 | V206 | V211 | V212 |
| | | 2 | F193 | F194 | F199 | F200 | F205 | F206 | F211 | F212 |
| | Inside dia. | 3 | V195 | V196 | V201 | V202 | V207 | V208 | V213 | V214 |
| | | 4 | F195 | F196 | F201 | F202 | F207 | F208 | F213 | F214 |
| | | 5 | C 97 | V198 | C100 | V204 | C103 | V210 | C106 | V216 |
| | | 6 | V197 | F198 | V203 | F204 | V209 | F210 | V215 | F216 |
| | | 7 | F197 | C 98 | F204 | C101 | F209 | C104 | F215 | C107 |
| | | 8 | C 99 | | C102 | | C105 | | C108 | |
| | 2 | 1 | V217 | V218 | V223 | V224 | V229 | V230 | V235 | V236 |
| | | 2 | F217 | F218 | F223 | F224 | F229 | F230 | F235 | F236 |
| | | 3 | V219 | V220 | V225 | V226 | V231 | V232 | V237 | V238 |
| | | 4 | F219 | F220 | F2225 | F226 | F231 | F232 | F237 | F238 |
| | | 5 | C109 | V222 | C112 | V228 | C115 | V234 | C118 | V240 |
| | | 6 | V221 | F222 | V227 | F228 | V233 | F234 | V239 | F240 |
| | | 7 | F221 | C110 | F227 | C113 | F233 | C116 | F239 | C119 |
| | | 8 | C111 | | C114 | | C117 | | C120 | |
| | 3 | 1 | V241 | V242 | V247 | V248 | V253 | V254 | C259 | V260 |
| Condition—Salt + Inhibitor | | 2 | F241 | F242 | F247 | F248 | F253 | F254 | F259 | F260 |
| | | 3 | V243 | V244 | V249 | V250 | V255 | V251 | V261 | V262 |
| | | 4 | F243 | F244 | F249 | F250 | F255 | F256 | F261 | F262 |
| | | 5 | C121 | V124 | C124 | V252 | C127 | V258 | C130 | V264 |
| | | 6 | V245 | F246 | V251 | F252 | V257 | F258 | V263 | F264 |
| | | 7 | F245 | C122 | F251 | C125 | F257 | C128 | F263 | C131 |
| | | 8 | C123 | | C126 | | C129 | | C132 | |
| | 4 | 1 | V265 | V266 | V271 | V272 | V277 | V278 | V283 | V284 |
| | | 2 | F265 | F266 | F271 | F272 | F277 | F278 | F283 | F284 |
| | | 3 | V267 | V268 | V273 | V274 | V279 | V280 | V285 | V286 |
| | Outside dia. | 4 | F267 | F268 | F273 | F274 | F279 | F280 | F285 | F286 |
| | | 5 | C133 | V270 | C136 | V276 | C139 | V282 | C142 | V288 |
| | | 6 | V269 | F270 | V275 | F276 | V281 | F282 | V287 | F288 |
| | | 7 | F269 | C134 | F275 | C137 | F281 | C140 | F287 | C143 |
| | | 8 | C135 | | C138 | | C141 | | C144 | |

| | Samples V | Samples F | Samples C |
|---|---|---|---|
| Per wheel | 24 | 24 | 12 |
| Per rig | 96 | 96 | 48 |
| 3 rigs total | 288 | 288 | 144 |

# Appendix B
## Sample Removal and Replacement Plan

| Wk. | Rig | Wheel | Sect. | Rod No. | Pos. on Rod | Take off Pairs V-F | Put on Pairs RV-RF | Wk. | Rig | Wheel | Sect. | Rod No. | Pos. on Rod | Take off Pairs V-F | Put on Pairs RV-RF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | 1 | B | 3 | 1-2 | 7 | 351 | 4 | 1 | 1 | C | 5 | 1-2 | 13 | 387 |
| | | 2 | A | 1 | 1-2 | 25 | 352 | | | 2 | B | 3 | 1-2 | 31 | 388 |
| | | 3 | C | 5 | 1-2 | 61 | 353 | | | 3 | D | 7 | 1-2 | 67 | 389 |
| | | 4 | D | 7 | 1-2 | 91 | 354 | | | 4 | A | 1 | 1-2 | 73 | 390 |
| | B | 1 | B | 3 | 1-2 | 103 | 355 | | 2 | 1 | C | 5 | 1-2 | 109 | 391 |
| | | 2 | A | 1 | 1-2 | 121 | 356 | | | 2 | B | 3 | 1-2 | 127 | 392 |
| | | 3 | C | 5 | 1-2 | 157 | 357 | | | 3 | D | 7 | 1-2 | 163 | 393 |
| | | 4 | D | 7 | 1-2 | 187 | 358 | | | 4 | A | 1 | 1-2 | 169 | 394 |
| | C | 1 | B | 3 | 1-2 | 199 | 359 | | 3 | 1 | C | 5 | 1-2 | 205 | 395 |
| | | 2 | A | 1 | 1-2 | 217 | 360 | | | 2 | B | 3 | 1-2 | 223 | 396 |
| | | 3 | C | 5 | 1-2 | 253 | 361 | | | 3 | D | 7 | 1-2 | 259 | 397 |
| | | 4 | D | 7 | 1-2 | 283 | 362 | | | 4 | A | 1 | 1-2 | 265 | 398 |
| 2 | A | 1 | A | 1 | 1-2 | 1 | 363 | 5 | 1 | 1 | D | 8 | 1-2 | 20 | 399 |
| | | 2 | D | 7 | 1-2 | 43 | 364 | | | 2 | A | 2 | 1-2 | 26 | 400 |
| | | 3 | B | 3 | 1-2 | 55 | 365 | | | 3 | B | 4 | 1-2 | 56 | 401 |
| | | 4 | C | 5 | 1-2 | 85 | 366 | | | 4 | C | 6 | 1-2 | 86 | 402 |
| | B | 1 | A | 1 | 1-2 | 97 | 367 | | 2 | 1 | D | 8 | 1-2 | 116 | 403 |
| | | 2 | D | 7 | 1-2 | 139 | 368 | | | 2 | A | 2 | 1-2 | 122 | 404 |
| | | 3 | B | 3 | 1-2 | 151 | 369 | | | 3 | B | 4 | 1-2 | 152 | 405 |
| | | 4 | C | 5 | 1-2 | 181 | 370 | | | 4 | C | 6 | 1-2 | 182 | 406 |
| | C | 1 | A | 1 | 1-2 | 193 | 371 | | 3 | 1 | D | 8 | 1-2 | 212 | 407 |
| | | 2 | D | 7 | 1-2 | 235 | 372 | | | 2 | A | 2 | 1-2 | 218 | 408 |
| | | 3 | B | 3 | 1-2 | 247 | 373 | | | 3 | B | 4 | 1-2 | 248 | 409 |
| | | 4 | C | 5 | 1-2 | 277 | 374 | | | 4 | C | 6 | 1-2 | 278 | 410 |
| 3 | A | 1 | D | 7 | 1-2 | 19 | 375 | 6 | 1 | 1 | C | 6 | 1-2 | 14 | 411 |
| | | 2 | C | 5 | 1-2 | 37 | 376 | | | 2 | D | 8 | 1-2 | 44 | 412 |
| | | 3 | A | 1 | 1-2 | 49 | 377 | | | 3 | A | 2 | 1-2 | 50 | 413 |
| | | 4 | B | 3 | 1-2 | 79 | 378 | | | 4 | B | 4 | 1-2 | 80 | 414 |
| | B | 1 | D | 7 | 1-2 | 115 | 379 | | 2 | 1 | C | 6 | 1-2 | 110 | 415 |
| | | 2 | C | 5 | 1-2 | 133 | 380 | | | 2 | D | 8 | 1-2 | 140 | 416 |
| | | 3 | A | 1 | 1-2 | 145 | 381 | | | 3 | A | 2 | 1-2 | 146 | 417 |
| | | 4 | B | 3 | 1-2 | 175 | 382 | | | 4 | B | 4 | 1-2 | 176 | 418 |
| | C | 1 | D | 7 | 1-2 | 211 | 383 | | 3 | 1 | C | 6 | 1-2 | 206 | 419 |
| | | 2 | C | 5 | 1-2 | 229 | 384 | | | 2 | D | 8 | 1-2 | 236 | 420 |
| | | 3 | A | 1 | 1-2 | 241 | 385 | | | 3 | A | 2 | 1-2 | 242 | 421 |
| | | 4 | B | 3 | 1-2 | 271 | 386 | | | 4 | B | 4 | 1-2 | 272 | 422 |
| 7 | A | 1 | A | 2 | 1-2 | 2 | 423 | 10 | 1 | 1 | D | 7 | 3-4 | 21 | 459 |
| | | 2 | B | 4 | 1-2 | 32 | 424 | | | 2 | A | 1 | 3-4 | 27 | 460 |
| | | 3 | C | 6 | 1-2 | 62 | 425 | | | 3 | B | 3 | 3-4 | 57 | 461 |
| | | 4 | D | 8 | 1-2 | 92 | 426 | | | 4 | C | 5 | 3-4 | 87 | 462 |
| | B | 1 | A | 2 | 1-2 | 98 | 427 | | 2 | 1 | D | 7 | 3-4 | 117 | 463 |
| | | 2 | B | 4 | 1-2 | 128 | 428 | | | 2 | A | 1 | 3-4 | 123 | 464 |
| | | 3 | C | 6 | 1-2 | 152 | 429 | | | 3 | B | 3 | 3-4 | 153 | 465 |
| | | 4 | D | 8 | 1-2 | 188 | 430 | | | 4 | C | 5 | 3-4 | 183 | 466 |
| | C | 1 | A | 2 | 1-2 | 194 | 431 | | 3 | 1 | D | 7 | 3-4 | 321 | 467 |
| | | 2 | B | 4 | 1-2 | 224 | 432 | | | 2 | A | 1 | 3-4 | 219 | 468 |
| | | 3 | C | 6 | 1-2 | 254 | 433 | | | 3 | B | 3 | 3-4 | 249 | 469 |
| | | 4 | D | 8 | 1-2 | 284 | 434 | | | 4 | C | 5 | 3-4 | 279 | 470 |
| 8 | A | 1 | B | 4 | 1-2 | 8 | 435 | 11 | 1 | 1 | B | 3 | 3-4 | 9 | 471 |
| | | 2 | C | 6 | 1-2 | 38 | 436 | | | 2 | D | 7 | 3-4 | 45 | 472 |
| | | 3 | D | 8 | 1-2 | 68 | 437 | | | 3 | C | 5 | 3-4 | 63 | 473 |
| | | 4 | A | 2 | 1-2 | 74 | 438 | | | 4 | A | 1 | 3-4 | 75 | 474 |
| | B | 1 | B | 4 | 1-2 | 104 | 439 | | 2 | 1 | B | 3 | 3-4 | 105 | 475 |
| | | 2 | C | 6 | 1-2 | 134 | 440 | | | 2 | D | 7 | 3-4 | 141 | 476 |
| | | 3 | D | 8 | 1-2 | 164 | 441 | | | 3 | C | 5 | 3-4 | 159 | 477 |
| | | 4 | A | 2 | 1-2 | 170 | 442 | | | 4 | A | 1 | 3-4 | 171 | 478 |
| | C | 1 | B | 4 | 1-2 | 200 | 443 | | 3 | 1 | B | 3 | 3-4 | 201 | 479 |
| | | 2 | C | 6 | 1-2 | 230 | 444 | | | 2 | D | 7 | 3-4 | 237 | 480 |
| | | 3 | D | 8 | 1-2 | 260 | 445 | | | 3 | C | 5 | 3-4 | 255 | 481 |
| | | 4 | A | 2 | 1-2 | 266 | 446 | | | 4 | A | 1 | 3-4 | 267 | 482 |

| Wk. | Rig | Wheel | Sect. | Rod No. | Pos. on Rod | Take off Pairs V-F | Put on Pairs RV-RF | Take Off Carets |
|---|---|---|---|---|---|---|---|---|
| 9 | A | 1 | A | 1 | 3-4 | 3 | 447 | C 1 |
| | | 2 | C | 5 | 3-4 | 39 | 448 | C 19 |
| | | 3 | D | 7 | 3-4 | 69 | 449 | C 34 |
| | | 4 | B | 3 | 3-4 | 81 | 450 | C 40 |
| | B | 1 | A | 1 | 3-4 | 99 | 451 | C 49 |
| | | 2 | C | 5 | 3-4 | 135 | 452 | C 67 |
| | | 3 | D | 7 | 3-4 | 165 | 453 | C 82 |
| | | 4 | B | 3 | 3-4 | 177 | 454 | C 88 |
| | C | 1 | A | 1 | 3-4 | 195 | 455 | C 97 |
| | | 2 | C | 5 | 3-4 | 231 | 456 | C115 |
| | | 3 | D | 7 | 3-4 | 261 | 457 | C130 |
| | | 4 | B | 3 | 3-4 | 273 | 458 | C136 |

| Wk. | Rig | Wheel | Sect. | Rod No. | Pos. on Rod | Take off Pairs V-F | Put on Pairs RV-RF |
|---|---|---|---|---|---|---|---|
| 12 | A | 1 | C | 5 | 3-4 | 15 | 483 |
| | | 2 | B | 3 | 3-4 | 33 | 484 |
| | | 3 | A | 1 | 3-4 | 51 | 485 |
| | | 4 | D | 7 | 3-4 | 93 | 486 |
| | B | 1 | C | 5 | 3-4 | 111 | 487 |
| | | 2 | B | 3 | 3-4 | 129 | 488 |
| | | 3 | A | 1 | 3-4 | 147 | 489 |
| | | 4 | D | 7 | 3-4 | 189 | 490 |
| | C | 1 | C | 5 | 3-4 | 207 | 491 |
| | | 2 | B | 3 | 3-4 | 225 | 492 |
| | | 3 | A | 1 | 3-4 | 243 | 493 |
| | | 4 | D | 7 | 3-4 | 285 | 494 |
| 13 | A | 1 | D | 8 | 3-4 | 22 | 495 |
| | | 2 | B | 4 | 3-4 | 34 | 496 |
| | | 3 | C | 6 | 3-4 | 64 | 497 |
| | | 4 | A | 2 | 3-4 | 76 | 498 |
| | B | 1 | D | 8 | 3-4 | 118 | 499 |
| | | 2 | B | 4 | 3-4 | 130 | 500 |
| | | 3 | C | 6 | 3-4 | 160 | 501 |
| | | 4 | A | 2 | 3-4 | 172 | 502 |
| | C | 1 | D | 8 | 3-4 | 214 | 503 |
| | | 2 | B | 4 | 3-4 | 226 | 504 |
| | | 3 | C | 6 | 3-4 | 256 | 505 |
| | | 4 | A | 2 | 3-4 | 268 | 506 |
| 14 | A | 1 | A | 2 | 3-4 | 4 | 507 |
| | | 2 | D | 8 | 3-4 | 46 | 508 |
| | | 3 | B | 4 | 3-4 | 58 | 509 |
| | | 4 | C | 6 | 3-4 | 88 | 510 |
| | B | 1 | A | 2 | 3-4 | 100 | 511 |
| | | 2 | D | 8 | 3-4 | 142 | 512 |
| | | 3 | B | 4 | 3-4 | 154 | 513 |
| | | 4 | C | 6 | 3-4 | 184 | 514 |
| | C | 1 | A | 2 | 3-4 | 196 | 515 |
| | | 2 | D | 8 | 3-4 | 238 | 516 |
| | | 3 | B | 4 | 3-4 | 250 | 517 |
| | | 4 | C | 6 | 3-4 | 280 | 518 |
| 15 | 1 | 1 | B | 4 | 3-4 | 10 | 519 |
| | | 2 | C | 6 | 3-4 | 40 | 520 |
| | | 3 | A | 2 | 3-4 | 52 | 521 |
| | | 4 | D | 8 | 3-4 | 94 | 522 |
| | 2 | 1 | B | 4 | 3-4 | 106 | 523 |
| | | 2 | C | 6 | 3-4 | 136 | 524 |
| | | 3 | A | 2 | 3-4 | 148 | 525 |
| | | 4 | D | 8 | 3-4 | 190 | 526 |
| | 3 | 1 | B | 4 | 3-4 | 202 | 527 |
| | | 2 | C | 6 | 3-4 | 232 | 528 |
| | | 3 | A | 2 | 3-4 | 244 | 529 |
| | | 4 | D | 8 | 3-4 | 286 | 530 |
| 16 | 1 | 1 | C | 6 | 3-4 | 16 | 531 |
| | | 2 | A | 2 | 3-4 | 28 | 532 |
| | | 3 | D | 8 | 3-4 | 70 | 533 |
| | | 4 | B | 4 | 3-4 | 82 | 534 |
| | 2 | 1 | C | 6 | 3-4 | 112 | 535 |
| | | 2 | A | 2 | 3-4 | 124 | 536 |
| | | 3 | D | 8 | 3-4 | 166 | 537 |
| | | 4 | B | 4 | 3-4 | 178 | 538 |
| | 3 | 1 | C | 6 | 3-4 | 208 | 539 |
| | | 2 | A | 2 | 3-4 | 220 | 540 |
| | | 3 | D | 8 | 3-4 | 262 | 541 |
| | | 4 | B | 4 | 3-4 | 274 | 542 |