

VALUE OF SALT SPRAY TEST

An Investigation of Heterogeneity Within the Chamber and
Other Factors Affecting the Reliability of the Salt-Spray Test for
Weathering Resistance of Coated Steel Sheet

by

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and

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Cambridge, Massachusetts
May, 1933

Professor Allyn L. Merrill
Secretary of the Faculty
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Cambridge, Massachusetts

Dear Sir:

We hereby submit a thesis entitled "Value of
Salt Spray Test" in partial fulfillment for the re-
quirements for the degree of Bachelor of Science in
Mining Engineering.

Respectfully submitted,

ABSTRACT

The conditions obtaining within the corrosion chamber of the salt spray test have been investigated, employing commercial coated steel specimens and salt solutions of different concentrations.

Evidences of distinct heterogeneity of vapor concentration have been found, and explanations are offered to explain its effect on the reliability of the results obtained. The fallacies attending the use of the gain in weight method of measuring corrosion have been outlined, and recommendations have been made towards possible improvements in the method, with special references to strength of solution, time of exposure, and the physical details of the apparatus.

THE VALUE OF THE SALT SPRAY TEST ON COATED STEEL SHEET

ACKNOWLEDGEMENTS

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Dr. R. S. Williams and Dr. V. O. Homerberg have contributed valuable comments throughout the investigation, while Mr. D. L. Edlund has aided greatly in the construction of the apparatus. To these gentlemen, we wish to extend our most hearty thanks.

The Continental Sheet Corporation of Canton, Ohio has been kind enough to furnish us with material for our tests.

INTRODUCTION

One of the most important problems facing the manufacturers of sheet steel coated for protection against atmospheric corrosion is the development of an accelerated laboratory test which will give reliable information with regard to the probable resistance of the product to weathering.

The salt-spray test in use in many laboratories is the most common test now employed for this purpose and by the use of this method, results can be obtained within a period of 100 hours.

Discussion of the reliability of this test in the various journals and textbooks together with private communications with the more important manufacturers using this test have pointed to the fact that there exists considerable distrust and doubt with regard to the reliability of the salt spray test as an indication of general weathering resistance of coated steel sheet.

One metallurgist₁ has criticized the method on the following points:

"(1) There has been no standard apparatus
₁ private confidential communication

accepted for making the test.

(2) The mechanical applications of producing the spray are subject to interruptions, both from mechanical failures, air pressure variations, and clogging due to salt accumulations on the apparatus.

(3) Evaporation causes the concentration of the salt solution to vary unless properly vented and the air conditioned.

(4) The orifices and spacing in the spray gun (nozzle) affect the quality of the spray as to whether fine or coarse, and the circulation."

We have undertaken an investigation of the actual conditions obtaining in the salt spray chamber using ordinary commercial coated steel sheets in an attempt to discover the fundamental sources of difficulty in salt spray testing. To this end, we have subjected different samples to salt spray conditions in a manner similar to that employed in practice today, varying the position in the tank and other conditions in an attempt to determine the existence of a relation between the rate of corrosion in the salt spray and the position of the sample within the chamber, and other relationships pointing to fundamental limitations of the method.

MATERIAL

The specimens used in the investigation were cut from standard coated steel sheet furnished through the courtesy of the Superior Sheet Steel Corporation of Canton, Ohio. The list of the different coatings with the designation assigned to each is given below:

- | | |
|---|----|
| (1) Commercial coat galvanized (28 gage) | GA |
| (2) Galvanized spelter tight coat (30 gage) | TC |
| (3) Long Terne 8 lb. coated (22 gage) | LT |
| (4) Galvannealed (24 gage) | GN |
| (5) Super Metal white Cu-bearing (24 gage) | SW |
| (6) Super Metal polished Cu-bearing (24 gage) | SP |
| (7) Pickled blue - not oiled (26 gage) | PB |
| (8) Galvanized extra-tight coat (30 gage) | ET |

To the best of our knowledge, the galvanized coatings were applied by the standard hot-dipping process. The different descriptions refer to differences in the thickness of the zinc coating.

The process of manufacture of the galvannealed and super-metal coatings is described by the manufacturers₁ as follows: " - from the coating pot, the sheets are individually transferred to a heat-treating furnace, where the temperature is higher than in the

₁ Superior Sheet Steel Corporation, Canton, Ohio.

coating pot: consequently the steel sheet expands, permitting the spelter to penetrate into the pores, thereby forming a perfect bond in the nature of a fusion between the coating and the base metal: this process also distributes the coating uniformly, and produces an etched or mat-like surface on the sheet."

The base metal in the galvanized samples is ordinary low carbon steel - in the super metal specimens, the base metal contains small percentages of copper, added for the purpose of increasing the corrosion resistance.

The pickled blue sample has an oxide coating over the base metal produced, as may be inferred, by a heat-treatment operation following the pickling operation.

Terne coatings are alloys of lead and tin of comparatively heavy thickness.

The specimens were cut to a 5" by 3½" size and a hole drilled close to the top of each sample for purposes of support in the chamber. The edges exposed in the cutting operation were coated to a depth of 1/2" with a special acid-proof paint, leaving an area of 20 square inches corroding surface.

APPARATUS

The chamber used in the investigation was made of soapstone ends and bottom, glass sides, and a removable glass roof. It is shown in figure one. At one end of the chamber, a glass tube dipping into

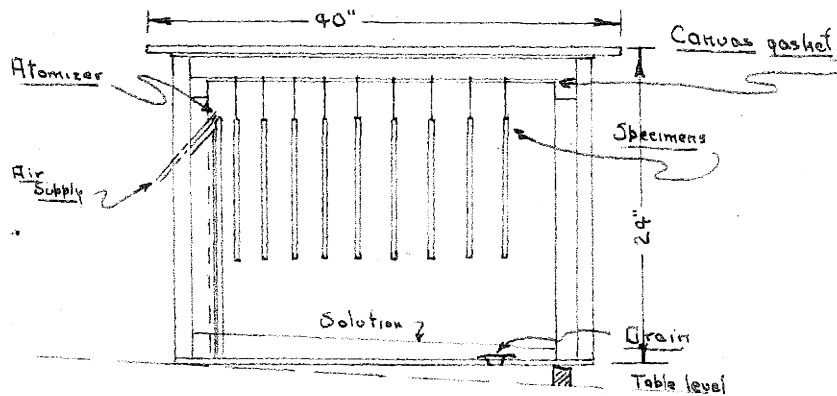
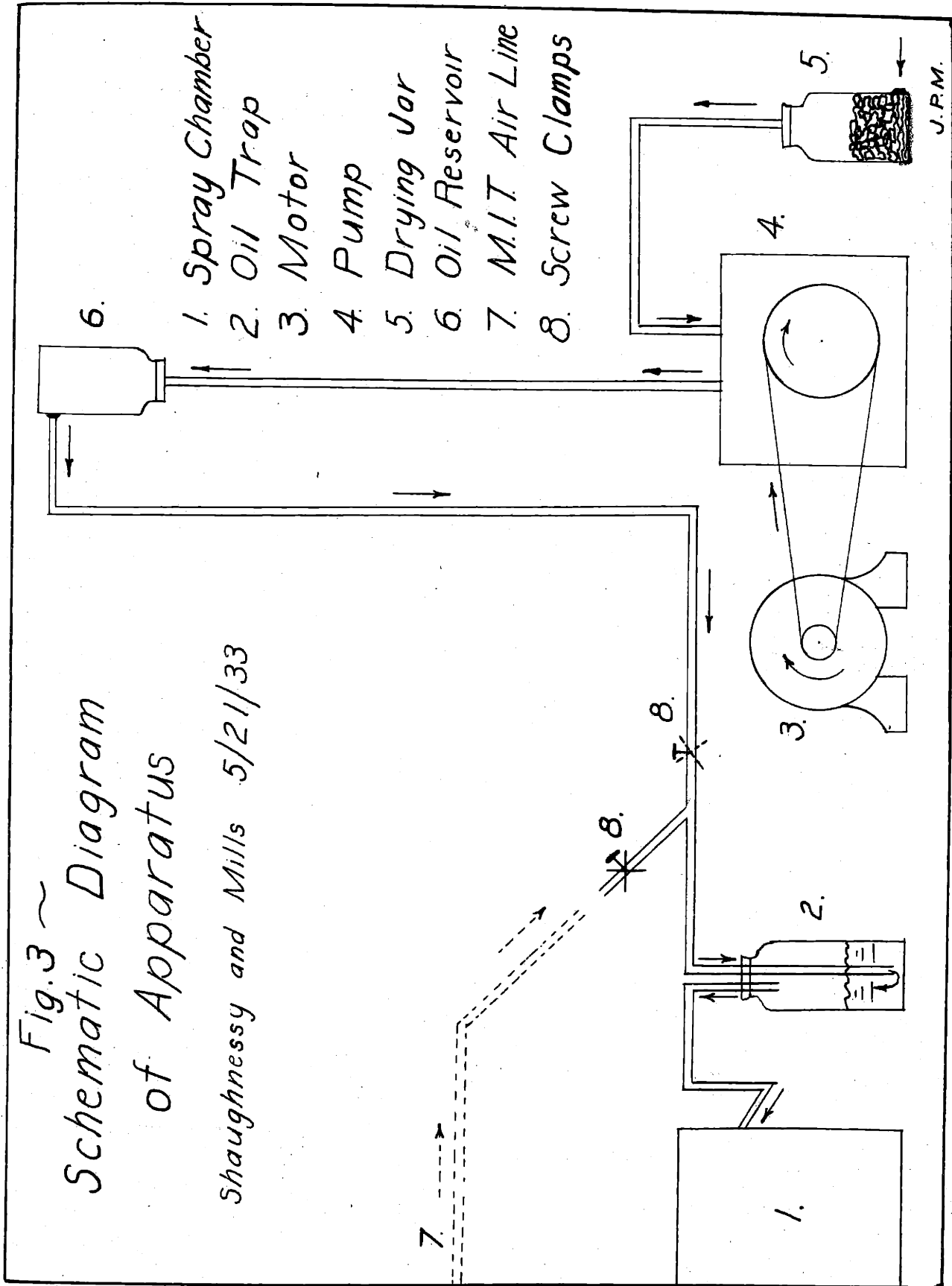


Figure One

the brine reservoir at the bottom of the tank, conducted the solution up into the path of the air jet, furnished by the pump and the Institute air-line, and introduced into the chamber by means of a glass tube passing through a hole in the soapstone end. The glass tube conducting the air and that leading the solution from the reservoir were both drawn to a small diameter of orifice and adjusted with relation to each other to give as fine a spray as possible. As will be brought out later, the size and relative position of the air jet, insofar as it affects the

Fig. 3 ~
Schematic Diagram
of Apparatus

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size of the particle of spray, has an appreciable effect on the corrosion rate, and care was taken to ensure the finest spray particle size possible.

At the end of the chamber opposite the spray nozzle, a hole was cut in the bottom of the tank in order to allow the solution to drain from the tank at the conclusion of the run. This hole was made water-tight by pouring molten paraffin around the stopper, and painting the paraffin with the same acid-proof paint used to coat the edges of the samples.

A canvas gasket, approximately $1/32$ " thick, was placed around the edges of the tank under the glass roof to prevent excessive leakage of spray from under the roof. This gasket acted also as an outlet for excess spray and prevented the constant influx of spray from establishing a pressure within the tank.

The samples were suspended vertically by hanging them from glass rods approximately $1/4$ " thick, extending the length of the tank. There were three glass rods holding three rows of samples, supported at the ends by wooden standards coated with the same acid-proof paint mentioned above. Glass hooks passed over the glass rods through $1/8$ " holes near the top of

the specimens and ensured the electrical insulation of the samples.

As shown in the sketch of the apparatus, figure two, the chamber was tilted slightly towards the nozzle end. The purpose of this inclination was to allow the drops of solution condensed on the roof of the chamber to run down the roof to the end of the chamber, and from there, down the end to the main body of solution.

Scarcity of time made it necessary to have the tests continuous. For a continuous supply of air, a York vacuum pump, belt-driven, powered by a G. E. 110 volt, 1/6 H. P. motor, was employed. The pump and motor were insulated from the test chamber in order that the vibrations of the pump would not shake corrosion product from the specimens under test. As shown in the sketch, precautions were taken to prevent the inclusion of oil globules in the air feed, the trap acting also as an air-humidifier. A drying bottle was placed in the air-feed to the pump to prevent moisture from entering the working cylinder of the pump.

PROCEDURE

The specimens, after cutting and painting, were cleaned with turpentine to remove excess paint, wiped with a towel saturated in CCl_4 , and weighed on a standard chemical balance.

The arrangement of the samples in the tank is shown in the sketch below, figure three.

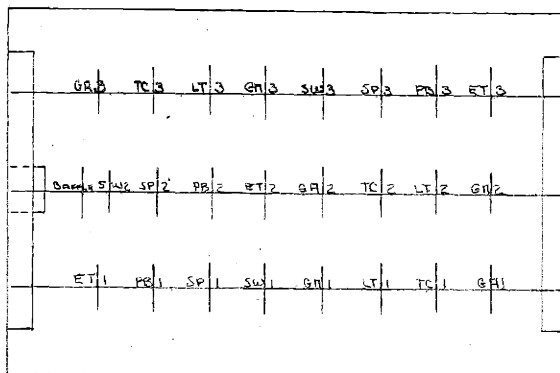


Figure Three

Six liters of brine containing, in the first run 1200 grams of commercial NaCl , and in the second, 300 grams of the salt were introduced in the bottom of the tank, and the spray adjusted. The samples were removed from the weighing dessicator and introduced immediately into the chamber.

After approximately 25 hours exposure, the spray

was turned off and the roof removed. The samples were allowed to dry in the tank, then placed in a dessicator and weighed, taking care not to lose any of the corrosion product formed on the surface.

After weighing, the samples were replaced in the tank, and the run continued for another 25 hours, followed by weighing. Final weights were taken at the end of 100 hours of exposure. At each weighing, the samples were inspected for signs of rust, and for the general appearance of the corrosion product.

At the conclusion of the first run, the tank was given a thorough cleansing and inspection, which include recaulking the drain. The pump and motor were inspected and oiled at regular intervals.

In the preliminary run, the samples were suspended in a single row down the center of the tank. In the subsequent runs, the samples were arranged in three rows in such a manner that any concentration of vapor in the tank would show up in the results. Also, in the second run, one of the rows of samples was depressed below the level of the other two rows, in order to determine if the height of the samples in the tank had an effect on the corrosion rate.

For the first run, the samples were cut to a size supposedly sufficient to give an area of surface exposed of 20 square inches, with a half-inch border of paint along the edges. Due to an error in the cutting operation (not discovered until after the samples were painted for the first run) the area exposed in the first run was only 12.14 square inches - for the second run, the size of the border was reduced to give the correct area of exposed surface. In the calculations, a correction was made for the error in area in the first run. The protection afforded by the paint on the edges was quite substantial - in suspending the samples from the glass hooks, however, the paint film must have been broken, for almost all of the samples showed evidence of localized corrosion around the suspending holes.

Weights of the samples were taken at convenient hours approximating as closely as possible the 25, 50, and 100 hour intervals desired, and are given as an appendix on pages

Previous experimenters have stressed the

importance of the size of spray and the effect of the fineness on the corrosion rate. Throughout our investigation, care has been taken to have the spray at all times of the same fineness. Unfortunately, after 40 hours of exposure in the first run, the tube leading the solution from the bottom of the tank cracked, and had to be replaced. The effect of this replacement on the results will be described later.

Some difficulty was experienced in adjusting the rate of flow of air through the humidifier and oil-filter. It was necessary, in order to prevent a back pressure from building up and bursting the bottle, to introduce an outlet in the line to by-pass some of the air to the atmosphere. This outlet was also used in changing from the pump to the Institute air line, a change made necessary by a tendency of the pump to overheat. It was found necessary also, to install an oil reservoir above the pump to take care of violent fluctuations in the oil level in the pump.

As received, the soapstone ends of the tank were higher than the glass sides. By filling these ends it was possible to adjust the level of the ends and sides. When assembled with the gasket in place, the

tank was practically air-tight, with just enough clearance to allow excess vapor to escape (thus preventing the pressure of the vapor from building up within the tank.)

As mentioned above, two different brine concentrations were used in the investigation in order to determine the effect of salt concentration on the rate of corrosion. The effect of the variation in concentration is discussed under results, but it will be well to mention at this point that checks were run on the solution concentration at regular intervals during the run, and no consistent divergence from the initial concentration was noticed. Though some vapor escaped through the gasket, it is reasonable to assume that this vapor was of the same salt concentration as the body of the corroding solution, and the only effect of this loss would be to decrease the total amount of solution available.

The tank was tilted, as mentioned above, in order to allow the drops of solution condensing on the roof of the chamber to run to the end and from there down the sides of the tank to the main body of the solution. Prolonged observation showed that

the angle of tilt was not sufficient, and some of the drops condensed on the roof actually evaporated in situ, leaving a deposit of salt. Due either to a subsequent solution of these deposits or to their insignificance in comparison with the total amount of salt in solution, these points could be considered negligible, as evidenced by the lack of divergence of concentration indicated by test.

Some of the drops condensing on the top of the tank agglomerated sufficiently so that they were able to drop from the roof onto the specimens.

Such an occurrence was inevitable with the tipping angle fixed by the other dimensions of the apparatus.

The effect of the drops falling from the roof, together with the solution that was able to condense on the samples themselves, was to wash some of the corrosion product from the samples to the floor of the chamber. This introduced an error in the work, and the effect of this error will be discussed in full under results.

The logical method for measuring the rate of corrosion would undoubtedly have been to remove as much of the corrosion product as possible and then

weigh the samples to determine the loss in weight. Due in part to the danger of removing some of the paint film along with the corrosion product, and also to the difficulty of removing the tightly-adherent zinc chloride product from the galvanized specimens, it was deemed advisable to conserve as much of the corrosion product as possible on the surface of the specimens, and measure the gain in weight. Such a method is responsible for more or less surprising results, and an explanation of this will be found under results.

TABLE I
 DISTRIBUTION OF TOTAL CORROSION (EXPRESSED AS 100)
 ACCORDING TO TIME INTERVALS

RESULTS

20% Run

Symbol	0-25 hrs.	25-50 hrs.	50-100 hrs.
ET 1	25.9	25.7	48.4
ET 2	38.3	27.4	34.5
ET 3	31.4	23.7	44.9
PB 1	25.3	21.5	53.2
PB 2	37.7	29.6	32.7
PB 3	30.7	30.5	38.6
SP 1	22.2	25.9	51.9
SP 2	37.9	26.5	35.7
SP 3	31.4	31.3	37.3
SW 1	20.5	23.5	55.5
SW 2	31.0	24.7	42.4
SW 3	11.2	18.5	70.1
GN 1	23.6	24.5	51.9
GN 2	34.3	26.5	39.1
GN 3	32.2	31.3	37.1
LT 1	32.3	32.8	34.9
LT 2	29.2	49.4	21.5
LT 3	30.5	28.5	41.0

TABLE I
(continued)

Symbol	20% Run		
	0-25 hrs.	25-50 hrs.	50-100 hrs.
TC 1	29.5	30.4	40.1
TC 2	35.9	26.6	37.6
TC 3	26.8	27.9	44.1
GA 1	27.8	22.5	49.0
GA 2	33.0	26.1	40.9
GA 3	37.9	35.6	26.5
Average	29.5	28.2	42.1

TABLE I
 DISTRIBUTION OF TOTAL CORROSION (EXPRESSED AS 100)
 ACCORDING TO TIME INTERVALS

RESULTS

5% Run

Symbol	0-25 hrs.	25-50 hrs.	50-100 hrs.
ET 1	25.6	30.8	43.6
ET 2	26.6	35.0	38.4
ET 3	34.5	31.7	53.8
PB 1	20.5	26.8	52.7
PB 2	20.7	24.5	54.8
PB 3	24.9	31.8	43.3
SP 1	24.4	27.3	48.3
SP 2	28.8	35.4	35.8
SP 3	21.6	45.6	31.8
SW 1	31.6	31.7	36.7
SW 2	26.6	41.1	32.3
SW 3	39.1	38.9	22.0
GN 1	30.4	32.7	36.9
GN 2	38.2	35.7	26.1
GN 3	20.4	50.1	29.5
LT 1	61.4	2.1	36.5
LT 2	50.9	7.9	41.2
LT 3	56.4	4.1	39.5

TABLE I
(continued)

5% Run

Symbol	0-25 hrs.	25-50 hrs.	50-100 hrs.
TC 1	38.0	28.7	33.3
TC 2	30.2	38.3	31.5
TC 3	25.3	36.6	38.1
GA 1	30.7	30.9	38.4
GA 2	26.3	39.8	33.9
GA 3	32.4	34.9	32.7
Average	28.4	34.7	36.9

TABLE II
 WEIGHTED AVERAGES AND RELATIVE CORROSION IN THE VARIOUS ROWS
 (EXPRESSED IN GAIN IN WEIGHT AS MILLIGRAMS)

RESULTS

Symbol	20% Run			5% Run					
	Aver.	C.Aver.	ROW	Aver.	ROW	ROW			
ET	1289	2115	81	107	105	1694	104	98	101
PB	1158	1899	107	95	102	1722	106	96	101
SP	1085	1779	86	93	110	1599	137	88	87
SW	917	1503	89	117	76	1344	114	92	114
GN	937	1536	92	103	100	1459	104	96	76
LT	281	460	67	119	93	106	91	108	94
TC	1283	2104	101	115	68	1731	113	89	108
GA	1241	2035	97	100	102	1808	114	94	98

VISUAL EXAMINATION

No signs of rust were noticeable on either the 20% or the 5% set of zinc-coated samples (galvanized and galvanized) at the end of 50 hours exposure. At the end of 100 hours time, there was, on the 5% set, distinct evidences of rust, intermingled with residual zinc chloride. The 20% set showed very little if any rust associated with the zinc chloride on the surface of the sheet. All the samples, however, indicated the presence of small galvanic cells in the region of the supporting hole and at the edges of the samples, with localized areas of rust visible.

The oxide coating corroded quite badly from the start, and it was evident that the residual particles of iron oxide were acting cathodically towards the underlying base metal. It is to be noted that an appreciable amount of corrosion product from the oxide coated samples was found in the bottom of the tank.

The terne plate coating withstood the attack of the salt solution to a remarkable degree. As mentioned above, there was evidences of galvanic action in the region of the supporting hole and at the edges of the sample, and in addition to this, the surface of

the coating contained numerous pin-holes, at which points corrosion had proceeded at a reasonably rapid rate. The size and number of these pin-holes, however, were of such small magnitude that the total corrosion of the sample was not at all large.

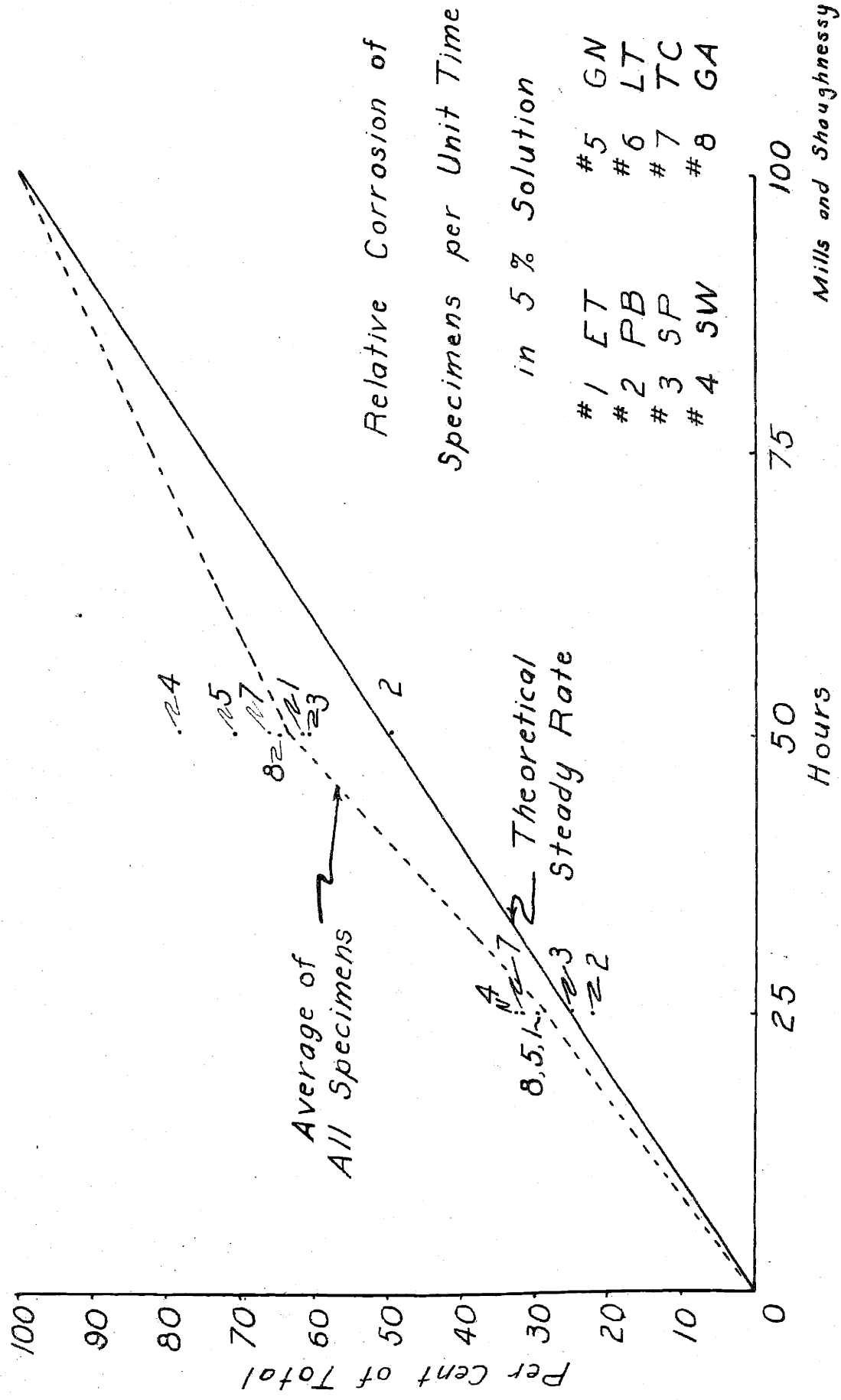
CALCULATIONS

After determining the amount of corrosion for the different intervals of time used in the experiment, these amounts were multiplied by a factor consisting of the number of hours actually under test over the desired base number of hours to give the amount of corrosion for the assumed base number of hours. The sum of these amounts gives the total corrosion for 100 hours which is used as a base for calculating the relative amount of corrosion on the basis of 100 units for 100 hours of exposure.

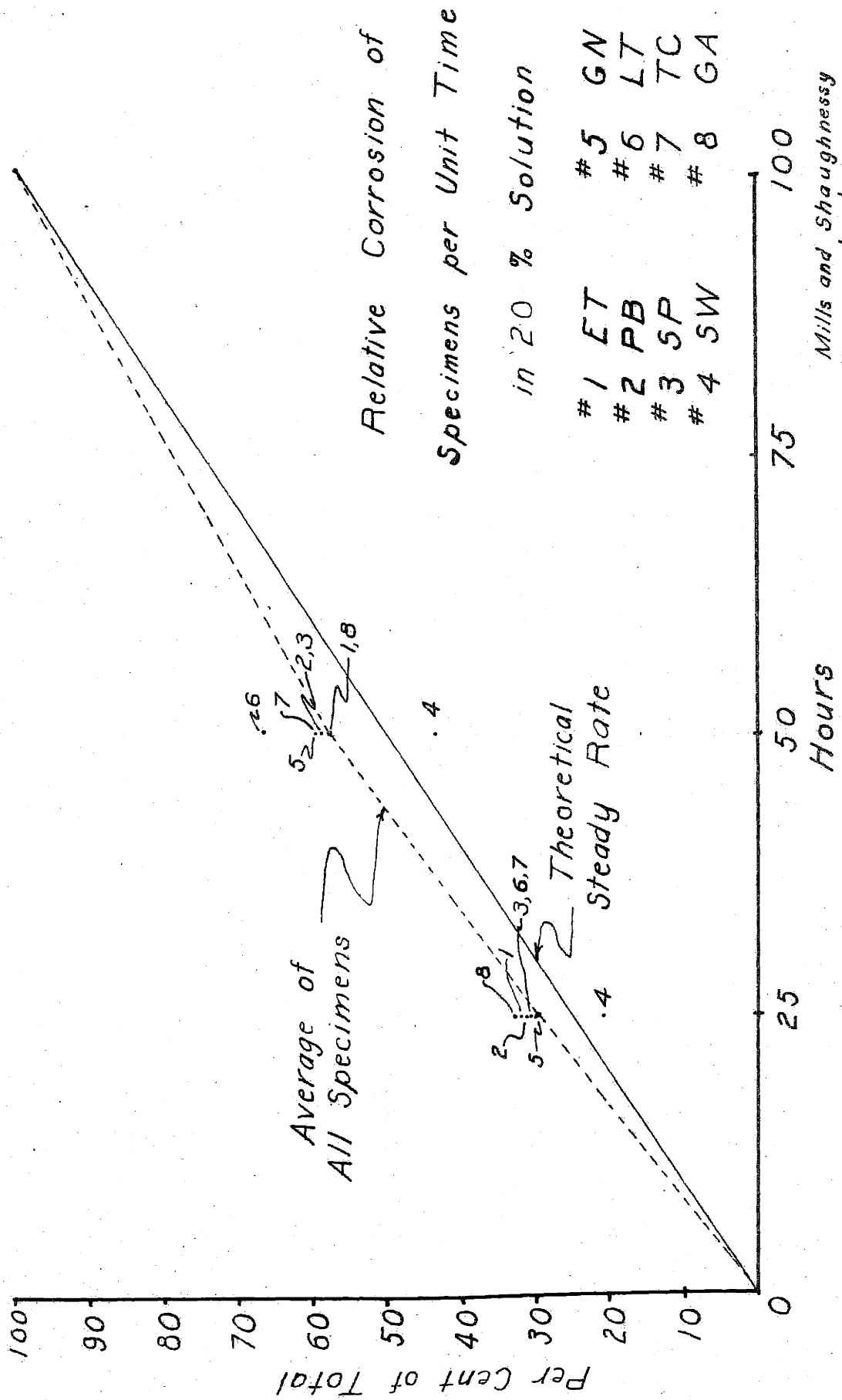
Since there is reason to believe that the condition of the vapor in the middle of the tank is different from that on the sides, it would not be quite justifiable to take the usual arithmetical average of these three totals. In order to bring out the relative importance of the middle row, a weighted average of the totals was used, in which the middle row was taken twice.

From the totals as determined, and this weighted average, the relative corrosions in each row listed on page 24 are determined by simple division.

The values plotted are the averages of the relative corrosion of the three specimens of the same material for the different periods of exposure, and the average curve is plotted from the average of all of these values. The average corrected for the difference in area in the two runs, is listed as the corrected average.



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- Specimens per Unit Time in 20% Solution
- # 1 ET
 - # 2 PB
 - # 3 SP
 - # 4 SW
 - # 5 GN
 - # 6 LT
 - # 7 TC
 - # 8 GA

Mills and Shaughnessy
5/21/33

DISCUSSION OF RESULTS

We imagine the process of corrosion to be (1) a deposition, on the surface of the specimen, of a thin film of salt solution followed by a solution of the coating in this film, at least in the case of the zinc coatings, followed by (2) a replacement of this film, rich in zinc chloride by fresh brine, with consequent removal of some zinc chloride, by dripping from the bottom of the specimen, and solution of more of the coating. This process of solution and removal continues until the coating is entirely dissolved, whereupon the film of salt commences to attack the iron base. It is not to be inferred that the entire zinc coating must, of necessity, be removed, before attack of the base metal can begin. As a matter of fact, as brought out in the statement of the visual examination, in the case of the 5% run samples, there was unmistakable evidence of zinc chloride and rust present on the same specimen. This might be accounted for by variations in the thickness of coatings on the sheet.

Corrosion in the case of the pickled blue samples commenced with an attack of the oxide coating by the

film of solution - on the breakdown of the film, examination of the corroded sheet indicated the establishment of many small galvanic cells (between the remnants of the oxide film and the iron base) with the production of small piles of corrosion product in addition to the general solution action of the salt film.

Evidence points out the ability of the tin-lead (terne) coating to withstand the action of the salt film to a remarkable degree. It is the authors' belief that the entire corrosion in the case of the terne coating consisted in localized attack around the pin-holes, coupled with galvanic corrosion around the edges and the supporting hole.

RELATIVE CORROSION OF DIFFERENT SPECIMENS

The order of corrosion of the different specimens for the two runs is given below.

20%	5%
(1) Extra Tight	(1) Commercial
(2) Commercial	(2) Tight Coat
(3) Tight Coat	(3) Pickled Blue
(4) Pickled Blue	(4) Extra Tight

20%

- (5) Super Metal Polished
- (6) Galvannealed
- (7) Super Metal White
- (8) Long Terne

5%

- (5) Super Metal Polished
- (6) Super Metal White
- (7) Galvannealed
- (8) Long Terne

We may state, from the results as outlined above, that zinc coatings are least resistant to the corrosive action of salt vapor, followed in order by oxide coatings, treated zinc coatings, and lastly, terne coatings. The scope of the test was not large enough to attempt to draw an analogy between the rates of corrosion in salt spray conditions and general atmospheric corrosion, which might lead to some conclusions with regard to the inherent value of the salt spray test.

RELATIVE CORROSION VERSUS TIME OF EXPOSURE

The graph on page 29 shows the relation between the relative amount of corrosion and the time of exposure. We may infer from the degree of correspondence of the two curves with the straight line rate and the general distribution of the individual points on each side of the average curve that there existed no such thing as an initial rate of corrosion

as distinguished from a long time rate, or in any event, no such differentiation appeared in the time of exposure adopted in these runs. The unfortunate accident to the delivery tube during the first run might account for the difference in the ratio of the 25 to the 50 hour figure in the two runs - though it is to be expected that a different size of spray was the result of changing tubes, the difference is evidently not great enough to cause a serious difference in the total amount of corrosion.

CORROSION VERSUS STRENGTH OF SOLUTION

Gain in weight measurements indicate that the attack of a 20% brine solution is more severe than that of a 5% solution. Visual examination, on the other hand, shows presence of rust (and therefore, complete penetration of the coating) only on the 5% solution. We believe, trusting our visual examination, that the corroding power of a 5% brine solution is greater than that of a 20% solution, and imagine the apparent anomaly of the gain in weight measurements to be due to the following cause.

Assuming that the amount of brine deposited as a film on the surface of the specimens was roughly

the same in the two runs, the concentration of salt in the 5% solution is only one-fourth the salt concentration in the 20% solution. As a consequence, the 5% solution was able to dissolve zinc chloride to a greater degree and at a faster rate than the 20% solution. The effect of losing corrosion product at this faster rate is to cause an actual loss in weight which, in the case of the 5% solution, is sufficient enough to cause the final weight to fall below the final weight of the 20% solution run, even though the actual rate of corrosion is greater.

The effect of salt condensing on the specimens (and being included in the weighing operation) is to introduce an error, the gravity of which is much less than might be imagined. There is no reason to believe that the amount of salt condensed on one sample of a number of specimens will be different than that on any other sample of the same run.

If time had permitted, the authors had intended to weigh the samples before and after a washing operation. Tests conducted by the British Iron and Steel Institution Corrosion Committee¹ along this line

¹ British Iron and Steel Corrosion Committee - First Report, 1951, page 118

proved conclusively that the effect of condensed salt was of distinctly minor importance.

Rust falling from the specimens introduces a troublesome error, especially in tests (such as ours) conducted with coatings of different types where the amount of the rust falling from each is likely to be quite variable. As far as the authors are aware, no convenient method of retaining the rust on the specimens has yet been devised. Attempts to catch and weigh the fallen rust are not in harmony with the general theme of simplicity and rapidity which characterizes this test.

The reader will doubtless recall that the middle row of the specimens was placed almost directly in the path of incoming spray, protected only by a baffle plate. The results, when analyzed, indicate that there is a heterogeneity of spray in different portions of the tank. If we distinguish between the center section and the outside section (consisting of the rows on both sides of the center row) the center section in the case of the 20% solution in general corroded more, and in the case of the 5% solution in general corroded less than the outside section.

If we imagine the spray, as it leaves the nozzle, penetrating through the spray already present, to the rear of the tank where it spreads out and returns along the sides, there are two conditions at work that may produce the above mentioned heterogeneity (1) the entering spray, meeting that already present, tends to concentrate along the middle row, and the samples in this row will be subjected to more spray in a given time than those in the outer section, and (2) the spray particles on leaving the nozzle tend to agglomerate as time goes on, and it is reasonable to postulate that the coalescing effect is more pronounced in the spray that has reached the outer section than that in the middle section not as far removed from the nozzle. To sum up, then, there is present in the middle section, spray of relatively fine particle size, and relatively denser than that present in the outer section. Now spray of a certain particle size will not corrode as rapidly as spray of finer particle size, and in addition, the more dense the spray, the thicker the film on the specimen is likely to be, and for this reason, the greater the corrosion rate.

We have, therefore, two opposing tendencies - in the center region, a denser spray tends to promote

relatively greater corrosion in that area, while a coarser particle size in the outer region tends to promote relatively greater corrosion in that section.

From the facts at hand, it is evident that in the case of the 20% solution, the density of the spray was the more important factor, while in the case of the 5% solution, the particle size had the greater effect. The authors are unable to explain this observation, and offer it for purposes of discussion and comment.

CORROSION VERSUS POSITION IN THE TANK

In addition to the heterogeneity across the tank discussed above, differences in corrosion rate from the rear to the front (near the nozzle end) of the tank and differences in a vertical direction were investigated.

As discussed under procedure, triplicate samples of each coating were arranged to bring out heterogeneity in a lengthwise direction. The results of the 20% solution run were not at all conclusive, but in the 5% run, the results showed unmistakably a greater corrosion rate in the rear of the tank. An analysis

analogous to that offered above in the case of heterogeneity across the tank is inadequate. We may say, in a general way, however, that since there is no reason to suspect a larger particle size of spray at one end of the tank than at the other, there exists a larger concentration of spray at the rear end of the tank, which would explain the greater amount of corrosion at that end.

Heterogeneity in a vertical direction has been also well established. As outlined under PROCEDURE, the first row of samples (PBl, TCl etc.) were depressed approximately 10 cm. below the level of the other two rows, and in very nearly every case showed less corrosion than the corresponding samples in the other rows. As in the previous discussion, since there is little reason to suspect a difference in particle size from top to bottom of the tank, the concentration of vapor seems to be less at the bottom than at the top of the tank.

CONCLUSIONS

There exists within the salt spray chamber used, at least under the conditions of the test, definite evidences of heterogeneity in density and particle size of salt spray, as shown by relative corrosion rates of triplicate samples of the different coatings.

The rate of corrosion, per time interval, over a period of 100 hours seems almost constant for the materials under test.

The gain in weight method of measuring extent of corrosion is of doubtful value when used with specimens coated by different processes and of different composition.

A 5% solution of NaCl is a more severe corroding agent than a 20% solution of the same material.

In the case of coated steel sheet specimens subjected to the action of a salty atmosphere, the order of corrosion is as follows: (1) galvanized coatings, (2) oxide coatings, (3) treated galvanized coatings, and (4) (most resistant) terne coatings.

RECOMMENDATIONS

We recommend for the use of salt spray testing in industrial practice

(1) - the support of specimens from the bottom (possibly placing them in grooves cut in wooden holders) to eliminate exposure of the base metal required in forming the supporting hole,

(2) - the use of a 5% solution as opposed to a 20% solution, inasmuch as the rate of corrosion is greater, and for this reason, comparable results, fully as reliable, may be obtained in a shorter period of exposure,

(3) - the arrangement for introduction of spray through several nozzles situated at various points around the chamber in an effort to counteract heterogeneity in the vapor,

(4) - the presence of adequate cleansing apparatus for incoming air, in order to prevent entrance of oil into the corrosion chamber,

(5) - the painting of edges of specimens exposed in the cutting operation,

(6) - the use of adequate baffling arrangement in front of the spray nozzle to prevent direct impingement of the spray on specimens.

We recommend for further investigation of the salt spray test

(1) - the determination of the effect of addition of more nozzles on the heterogeneity of the spray within the chamber,

(2) - the use of uncoated specimens, since there is much more data on the atmospheric corrosion of uncoated sheets than coated material,

(3) - the development of efficient means of removing corrosion product in preparation for measuring loss in weight. The use of the gain in weight method in the case of materials with different coating composition, is to be discouraged,

(4) - unless accuracy consumes no more time in weighing, the authors feel it unnecessary to carry the weights of specimens beyond the second decimal point, especially when the magnitude of some of the unavoidable errors is contemplated.

OBSERVATIONS

WEIGHT OF SPECIMENS, 20% RUN

Symbol	Orig Wt.	41 hr.	48 hr.	96 hr.
ET 1	35.640	36.090	36.163	36.759
ET 2	35.803	36.663	36.693	37.150
ET 3	35.542	36.258	36.276	36.747
PB 1	40.192	40.709	40.765	41.407
PB 2	40.229	40.908	40.955	41.299
PB 3	40.997	40.671	40.773	41.215
SP 1	58.095	58.434	58.520	58.984
SP 2	58.190	58.953	58.954	59.364
SP 3	58.270	58.792	58.880	59.243
SW 1	58.350	58.621	58.687	59.126
SW 2	58.320	58.867	58.910	59.348
SW 3	58.845	59.073	59.155	59.603
GN 1	65.440	65.775	65.837	66.268
GN 2	65.700	66.248	66.282	66.647
GN 3	66.100	66.597	66.660	66.993
LT 1	72.000	72.099	72.118	72.181
LT 2	73.490	73.650	73.658	73.727
LT 3	73.650	73.486	73.507	73.610
TC 1	40.555	41.183	46.300	41.798
TC 2	40.100	40.970	41.012	41.544
TC 3	40.440	40.827	40.900	41.272

OBSERVATIONS

Symbol	WEIGHT OF SPECIMENS, 20% RUN			
	Orig. Wt.	41 hr.	48 hr.	96 hr.
GA 1	43.885	44.635	44.680	45.257
GA 2	44.635	45.310	45.358	45.846
GA 3	44.150	44.935	45.048	45.470

OBSERVATIONS

Symbol	WEIGHT OF SPECIMENS, 5% RUN			
	Orig. Wt.	24 hr.	49 hr.	110 hr.
ET 1	35.109	35.540	36.080	37.014
ET 2	33.273	33.697	34.275	34.952
ET 3	37.036	37.603	38.145	38.852
PB 1	40.361	40.720	41.210	42.380
PB 2	40.112	40.443	40.850	41.860
PB 3	39.762	40.180	40.635	41.555
SP 1	59.113	59.625	60.222	61.508
SP 2	58.029	58.420	58.920	59.536
SP 3	56.866	57.143	57.790	58.332
SW 1	57.849	58.316	58.805	59.493
SW 2	57.746	58.060	58.565	59.050
SW 3	58.459	58.735	59.331	59.743
GN 1	65.910	66.350	66.845	67.525
GN 2	64.860	65.376	65.878	66.326
GN 3	64.855	65.073	65.640	66.040
LT 1	70.886	70.943	70.945	70.988
LT 2	73.391	73.350	73.359	73.416
LT 3	72.379	72.433	72.437	72.485
TC 1	40.697	41.413	41.975	42.770
TC 2	40.078	40.525	41.123	41.710
TC 3	39.637	39.995	40.683	41.500

OBSERVATIONS

Symbol	WEIGHT OF SPECIMENS, 5% RUN			
	Orig. Wt.	24 hr.	49 hr.	110 hr.
GA 1	43.200	43.808	44.443	45.413
GA 2	45.988	46.414	47.088	47.788
GA 3	44.818	45.273	45.895	46.603

OBSERVATIONS

CHANGES IN WEIGHT

Symbol	41	48	96	Total	24	49	110	Total
ET 1	450	73	483	1006	431	540	934	1905
ET 2	863	30	457	1350	424	578	777	1779
ET 3	696	38	584	1318	567	542	707	1816
PB 1	517	54	634	1205	359	490	1170	2019
PB 2	679	47	344	1070	331	407	1110	1848
PB 3	326 ^o	102	442		418	555	920	1893
SP 1	339	86	464	889	512	597	1286	2395
SP 2	743	21	410	1174	391	500	616	1507
SP 3	522	88	363	973	287	647	542	1476
SW 1	271	66	439	776	467	489	688	1644
SW 2	547	43	438	1028	314	505	485	1304
SW 3	128	62	468	658	576	596	412	1584
GN 1	335	62	431	828	440	495	680	1615
GN 2	548	34	365	947	516	502	448	1466
GN 3	497	73	333	903	218	557	400	1175
LT 1	99	19	63	181	57	2	43	102
LT 2	160	8	69	237	41 ^o	9	57	
LT 3	164 ^o	21	103		54	4	48	106
TC 1	628	117	498	1243	716	562	795	2073
TC 2	870	42	532	1444	447	598	587	1632
TC 3	387	73	372	832	458	688	871	2017

^o indicates loss in weight

OBSERVATIONS

CHANGES IN WEIGHT

Symbol	41	48	96	Total	24	49	110	Total
GA 1	550	45	577	1172	608	638	970	2216
GA 2	675	48	488	1211	426	674	700	1800
GA 3	785	113	322	1120	555	622	708	1885

OBSERVATIONS

ADJUSTMENT OF CHANGES IN WEIGHT

Symbol	20% Run				5% Run			
	25	50	100	Total	25	50	100	Total
ET 1	274	269	504	1047	449	540	765	1754
ET 2	526	375	476	1377	441	578	636	1655
ET 3	425	321	609	1355	590	542	580	1712
PB 1	315	271	660	1246	374	490	959	1823
PB 2	414	325	359	1098	344	407	909	1660
PB 3	365 ^o	363 ^o	461	1189 ^o	435	555	754	1744
SP 1	207	242	484	933	533	597	1052	2182
SP 2	453	317	427	1197	407	500	505	1412
SP 3	318	317	378	1013	299	647	442	1388
SW 1	165	191	458	814	486	489	564	1539
SW 2	334	268	457	1079	327	505	398	1230
SW 3	78	130	487	695	600	596	338	1534
GN 1	204	211	450	865	459	495	557	1511
GN 2	334	258	380	972	537	502	367	1406
GN 3	303	288	349	940	227	557	328	1112
LT 1	61	62	66	189	59	2	35	96
LT 2	98	166	72	336	58 ^o	9	47	114 ^o
LT 3	79 ^o	75 ^o	107	261 ^o	56	4	39	99
TC 1	383	395	520	1298	745	562	651	1958
TC 2	530	393	555	1478	465	598	481	1544
TC 3	236	245	388	879	476	688	714	1878

^o indicates adjusted figure

OBSERVATIONS

ADJUSTMENT OF CHANGES IN WEIGHT

Symbol	20% Run			Total	5% Run			Total
	25	50	100		25	50	100	
GA 1	336	272	601	1209	633	638	795	2066
GA 2	411	325	509	1245	444	674	574	1692
GA 3	479	451	336	1266	577	622	581	1780