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Alternative Deicing Chemicals Research

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16. Abstract

The effectiveness of alternative deicers was evaluated in field and laboratory testing. The ice melt capacity, ice penetration, concrete compatibility, and corrosion properties of various deicers was tested in the laboratory.
The information gathered, in conjunction with field experience, will help maintenance managers determine the most cost effective deicing chemicals and practice.

Implementation:

This report recommends that the amount of sand contained in the current salt/sand mixture be reduced. The use of prewetting is recommended to enhance deicer performance. Sodium chloride remains the most cost-effective deicing chemical, however prewetting with magnesium or calcium chloride is recommended.

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1.0 Introduction

This research was begun in 1990 at the request of Section 8 Maintenance which is responsible for snow and ice control in the Denver-metropolitan area. Section 8 has responsibility for approximately 3130 lane miles in the Denver area and typically spends $1.9 to $2.2 million per year to perform snow and ice removal. In order to provide traction and melt snow and ice, the Section 8 uses a mixture of 18% salt (NaCl) and 82% hard aggregate less than 3/8 inch.

In recent years, the use of road sand to provide traction during storms has become an issue. Sand used in snow and ice control is a 10-15% contributor to the winter air pollution problem (brown cloud) and is a component in the geologic particulates under 10 microns which constitute approximately 35-45% of PM-10s in winter [1]. Sand actually decreases traction once pavements are bare, breaks windshields and chips paint on motorist's cars when kicked up by vehicles, decreases the life of pavement markings, and clogs drainage structures along the roadway. In addition, the disposal of used road sand is becoming a problem in the Denver area with the distinct possibility that future legislation will make this issue more complex and more expensive.

With the above problems in mind, personnel from the Research Branch and Section 8 maintenance set out to test various combinations of chemicals and sand which might partially alleviate the problems associated with the use of sand. The idea that improved deicing chemicals can reduce the need for road sand is fundamental to this research.

2.0 Background

Typical equipment for distributing salt/sand in Section 8 is a 3½ ton dump truck equipped with a front-mounted plow and a drum sander at the tailgate. The sanders are calibrated each fall to put down approximately 400 pounds per lane mile. This type of equipment allows for fairly uniform distribution of dry materials. Field testing was done with existing CDOT equipment.

2.1 Deicing Chemicals

The SHRP Handbook of Test Methods for Evaluating Chemical Deicers [2], states that the ideal deicing chemical ...

> "has a eutectic temperature (lowest melting point) well below the expected ambient temperature range, dissolves rapidly and exothermically in water and brines, has a low molecular or average ionic weight, and depresses the freezing point of water in high proportions relative to its concentrations

> in water. The deicer selection process, however, is constrained by other factors: actual performance versus theory, cost and availability, storability, handling and application properties, and the severity and significance of environmental impacts, material impacts, and safety in manufacture, handling and use."

The perfect deicing chemical does not exist at this time, however, several of the following chemicals meet at least some of the criteria.

Sodium chloride is the most commonly used deicing chemical. It is generally referred to just as "salt" although most other deicers are also, technically, salts. Its availability and low cost are unmatched by other deicers. Salt's lowest melting (eutectic) temperature is approximately -5° F at a concentration of 23% by weight of anhydrous salt. In practice, the melting ability of sodium chloride is very slow at temperatures below 15° F.

Calcium chloride is typically used as a brine (25-35%). Because the material is hygroscopic (draws moisture from the air) it is difficult to store and handle in the dry form. Calcium chloride has a very low eutectic temperature of approximately -52° F. This material is often used to prewet salt or salt/sand mixtures. Calcium chloride is significantly more corrosive than salt.

Magnesium chloride is also used as a liquid and has a eutectic temperature of approximately -32° F. Magnesium chloride is often used to prewet or is used with spray truck applicators in liquid only deicing. Magnesium chloride is also more corrosive than salt, however, many commercial magnesium chloride products are available with a corrosion inhibitor.

Calcium Magnesium Acetate or CMA is made from dolomitic limestone and acetic acid. The resulting deicer is non-corrosive and has no detrimental effect on vegetation. However, the cost of CMA ($625 per ton) has been the main reason for it not being used more often. CMA has a eutectic temperature that varies according to the ratio of Calcium to Magnesium between -14° and -18° F.

The South Dakota DOT has developed and patented a deicer that is a combination of sodium acetate and sodium formate. This new material promises to combine improved low temperature performance, non-corrosive properties, and low environmental impacts. The material has only been produced in small laboratory batches, however the eutectic temperature of one batch was reported to be -36° F. Samples of this material were made available to CDOT and have been included in most of the tests conducted during this study.

Potassium Acetate is available as a deicer, however it is probably too expensive to be considered as a viable highway deicer as it is even more expensive than CMA. Potassium Acetate has a low eutectic point of -40° F and is noncorrosive.

Other hybrid deicers are available many of which are enhanced salt products. These are typically sodium chloride with 10-20% magnesium chloride or calcium chloride added to improve low temperature performance. These materials are often offered with corrosion inhibitors.

3.0 Field testing

Field tests were conducted to understand how different chemicals would work with existing CDOT owned equipment and to gain experience with practical aspects of other deicing chemicals. A field test site was established at Patrol 26, near the Martin Marietta Plant at South Wadsworth Blvd (State Highway 121). This site was chosen because of relatively high traffic volumes and the close proximity of a maintenance yard to the test site.

Twelve test sections, each 0.1 mile long with a 0.1 mile buffer zone between test sections, were established in the northbound and southbound lanes (six each direction). Because the traffic at this location is highly directional, it was felt that testing should be done in the direction of the most traffic (southbound morning, northbound afternoon) to include the effects of traffic. The test sections were marked with flexible delineators at the beginning and end. Chemicals were mixed with different amounts of aggregate at Patrol 26 and stored in bins which were covered with canvas tarps to prevent leaching of the chemicals.

On Sunday, January 20, 1991, chemical testing was done on SH 121 near Waterton. Snow had been falling beginning Saturday afternoon and continued through part of the night. Temperatures were well below freezing (see attached graphs). Many accidents were reported Saturday evening and several municipalities were on accident alert (motorists needed not call police for minor accidents). Although traffic was light on this day (a Sunday), the comparative results will still be valid.

The first chemical mixture (magnesium chloride and sand) was placed at 5:30 a.m. at an application rate of approximately 200 lbs. per tenth-lane-mile. There were no material handling problems with this mixture.

The second mix (calcium chloride and sand) was applied at 5:50 a.m. at an application of 125 lbs. per tenth-lane-mile. There were application problems with this mixture because of "chunks" in the mix and it appeared that these were hanging up in the sander. The real application rate was most likely lower than that stated above.

The third mix (50% salt:50% sand) was applied at 6:10 a.m. at an application rate of 125 lbs. per tenth-lane-mile. There was a hard crust on the stockpile but it appeared that the material flowed freely once in the sander.

The last of the test mixes (mag. chloride, salt, and sand) was applied at 6:35 a.m. at 125 lbs. per tenth-lane-mile. There were no problems with this mixture.

The standard salt/sand mix was placed at 6:35 a.m. at an application rate of 240 lbs. per tenth-lane-mile.

After all the chemicals had been applied, the test sections were observed and skid measurements were done using the British Portable Skid Tester. Since there was no real melting taking place, the road was very slick.

The test sections were also rated on a 6-point scale during testing. The scale is as follows:

1 = no action
2 = penetration in ice/snow pack
3 = melting/mealy/moisture visible
4 = clearing in wheelpaths
5 = lane clear but wet
6 = lane dry

The ratings taken during testing are shown in the attached graph.

At about 11:15, testing was stopped because the melting action of the sun was causing more melting than any of the chemicals.

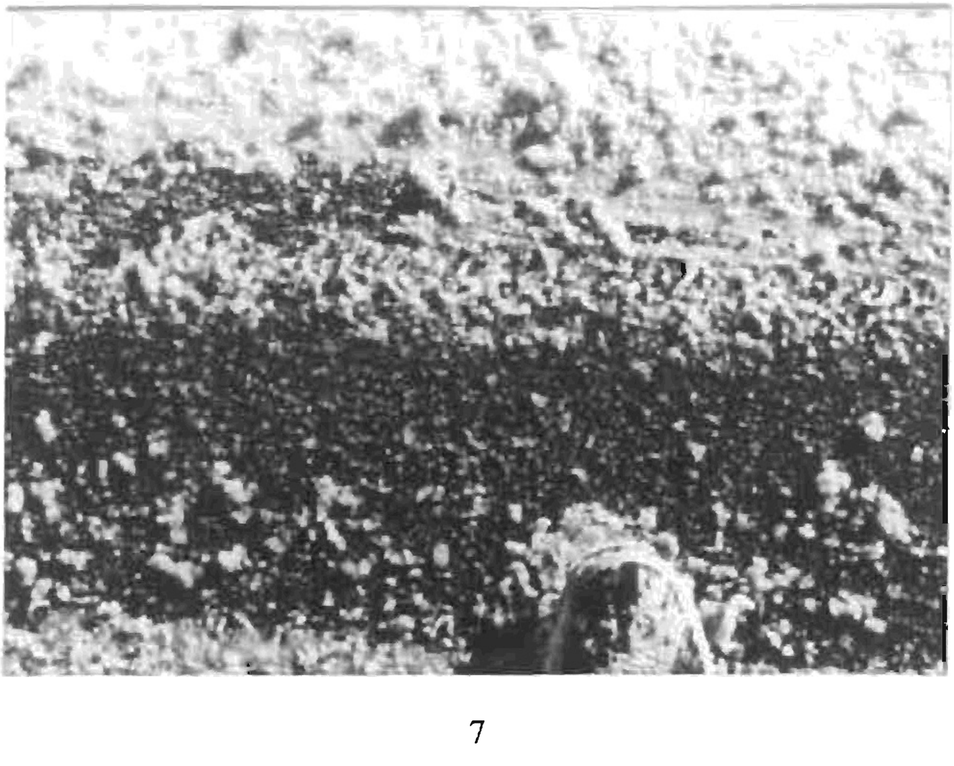
The best mixes, in this test, appeared to be the magnesium chloride sprayed onto the sand (test section 1) and the "hot" salt/sand mix (test section 3).

The calcium chloride was most likely put down at a very low application rate because of the "clumping" problems mentioned above. The standard salt/sand mix was also put down at slightly less than the full application rate.

Photograph 1.
Test Section 1.
Magnesium Chloride + Sand
200 lbs. on Test Section.
Sunday, January 20, 1991
9:30 A.M.

Photograph 2.
Test Section 2.
Calcium Chloride + Sand
125 lbs. on Test Section
Sunday, January 20, 1991
9:30 A.M.

Photograph 3.
Test Section 3.
50% Salt + 50% Sand
125 lbs. on Test Section
Sunday, January 20, 1991
9:30 A.M.



Photograph 4.
Test Section 4.
5% Magnesium Chloride, 5% Salt + Sand
125 lbs. on Test Section
Sunday, January 20, 1991
9:30 A.M.

Photograph 5.
Control Section
240 lbs. on Test Section
Sunday, January 20, 1991
9:30 A.M.

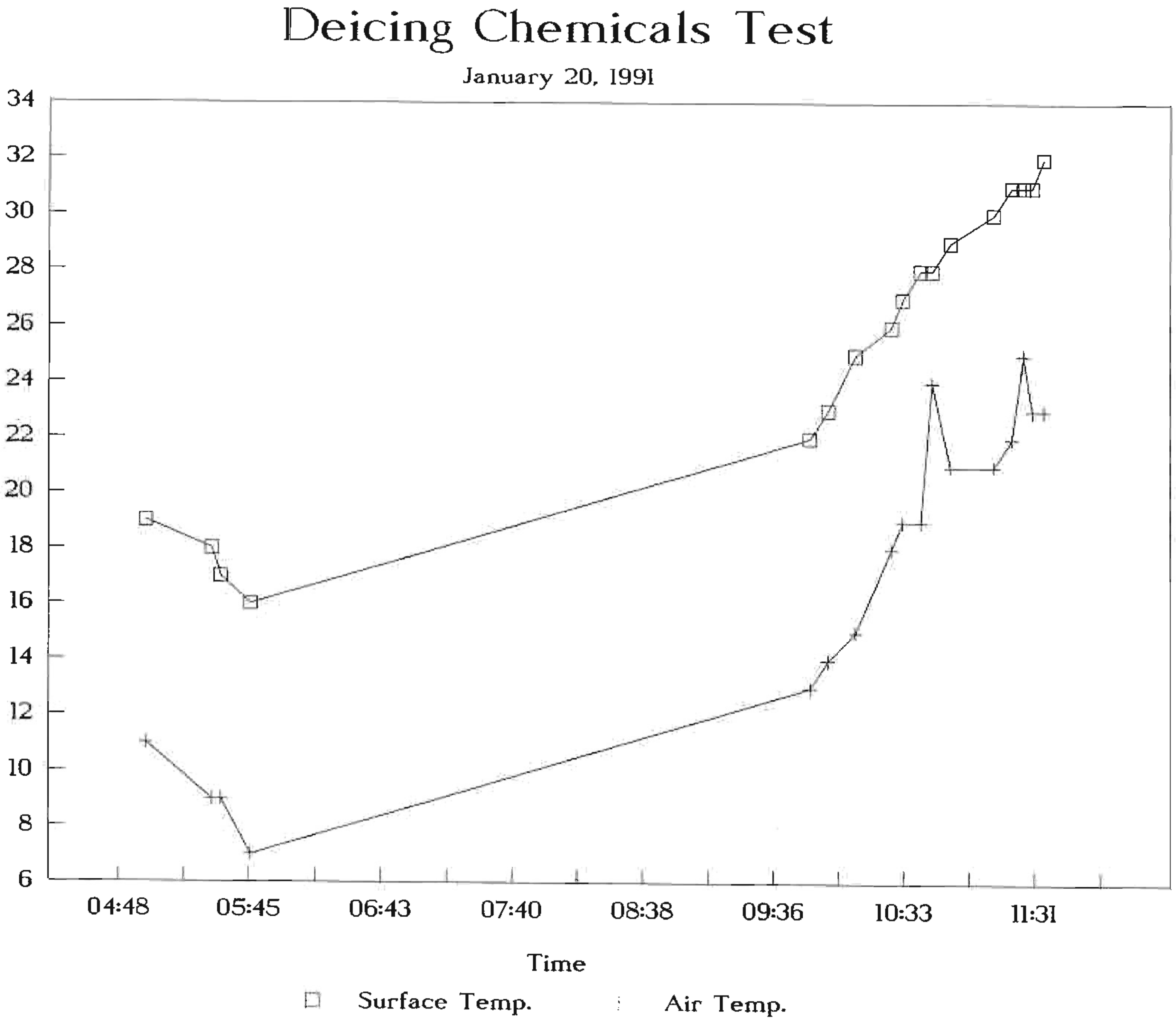


Figure 1. Surface and air temperatures during field testing.

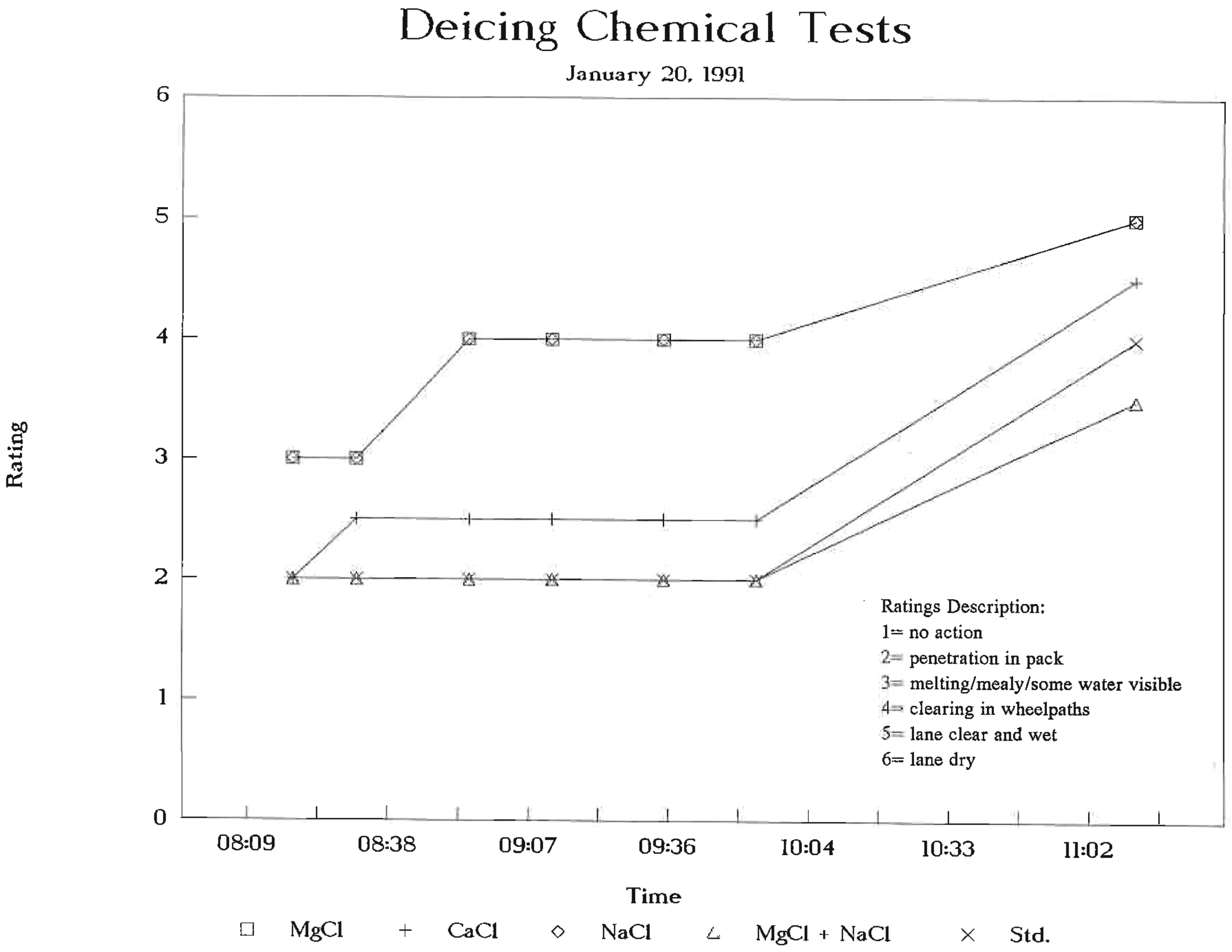


Figure 2. Ratings of test sections during field testing.

4.0 Laboratory Testing

The Strategic Highway Research Program (SHRP) developed standardized procedures for testing many of the physical characteristics of deicing chemicals. These test procedures became available in early 1993.

Because of the complications of comparing deicers in the field, the melt characteristics (SHRP H-205.1, H-205.2) and ice penetration (H-205.3, H-205.4) test were performed in the summer of 1993 for a variety of commercially-available deicing chemicals. A suitable freezer was found at the Bureau of Reclamation Laboratory in Lakewood for conducting the tests.

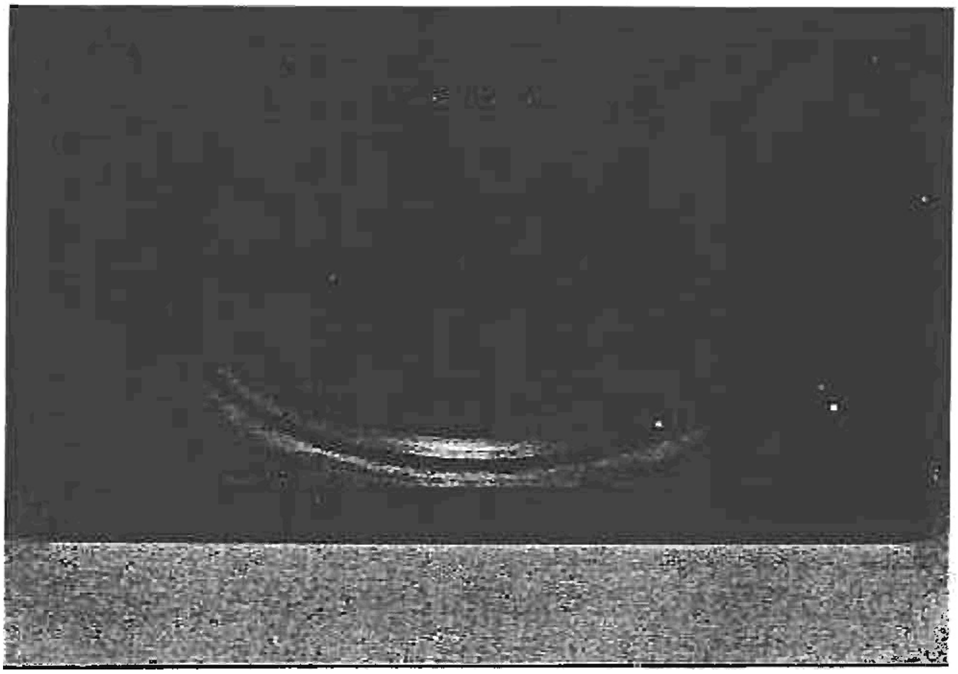
The melt characteristics test is performed in a fabricated plexiglass dish. A small quantity of distilled water is frozen in the dish and the deicer is distributed on the surface of the ice. At selected time intervals, the sample is withdrawn from the freezer and a syringe is used to draw off the available liquid. The amount of liquid generated over time is plotted for comparison with other deicers. This test was run with both liquid and solid chemical deicers at 5, 15, and 25 degrees Fahrenheit.

The ice penetration test requires a small plexiglass block in which vertical 1/8 inch diameter holes have been drilled. The 1-1/2 inch long holes are filled with distilled water and frozen. A small quantity of a dye solution is placed on the top of frozen ice and allowed to refreeze. The deicer is then placed on the column of ice and the distance the chemical penetrates into the ice is recorded at 3, 5, 10, 15, 20, 30, 45, and 60 minutes. The test apparatus remains in the freezer at the prescribed temperature except when measurements are taken. This test was also performed with solid and liquid deicers and at 5, 15, and 25 degrees Fahrenheit.

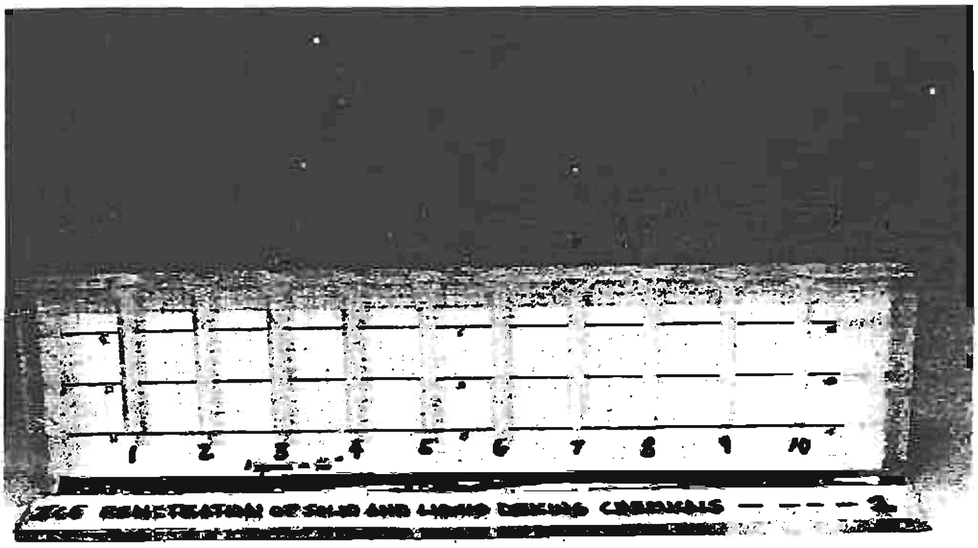
The results of these tests are provided in Appendix A in tabular and graphical form.

Concrete compatibility tests were also performed for many deicers. In fact, the tests were conducted twice because of unexpected results encountered during the first test. This procedure consisted of freeze/thaw tests on saturated cubes which were then tested for compressive strength.

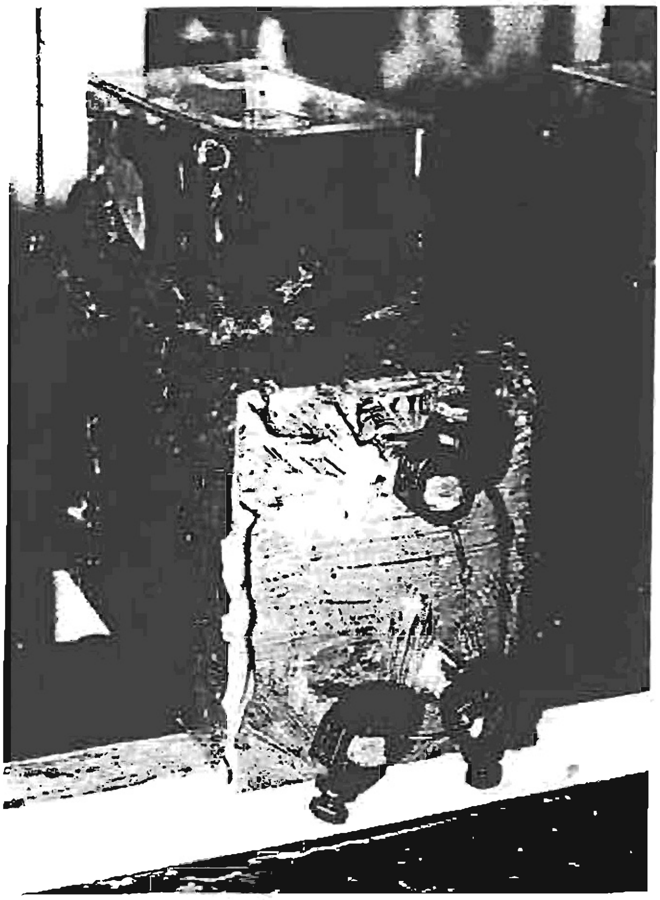
Cubes were cast in 2x2x2 inch molds and allowed to cure for at least 6 months in a moisture room. The cubes were then immersed for 48 hours in solutions containing dilute concentrations of deicing chemicals. Concentrations were determined by the theoretical amount of chemical needed to depress the freezing point of water to 20 degrees Fahrenheit. The solution was drained away and the saturated cubes were placed into a freezer programmed to cycle between 15 and 35 F at six hour intervals. After the cubes had been through 50 freeze/thaw cycles, the cubes were tested for compressive strength. There were four replicates used for each deicer (8 each for CMA and Sodium Chloride). As a control, 4 cubes were soaked in distilled water and subjected to 50 F/T cycles and 4 cubes were neither soaked nor subjected to F/T cycling.



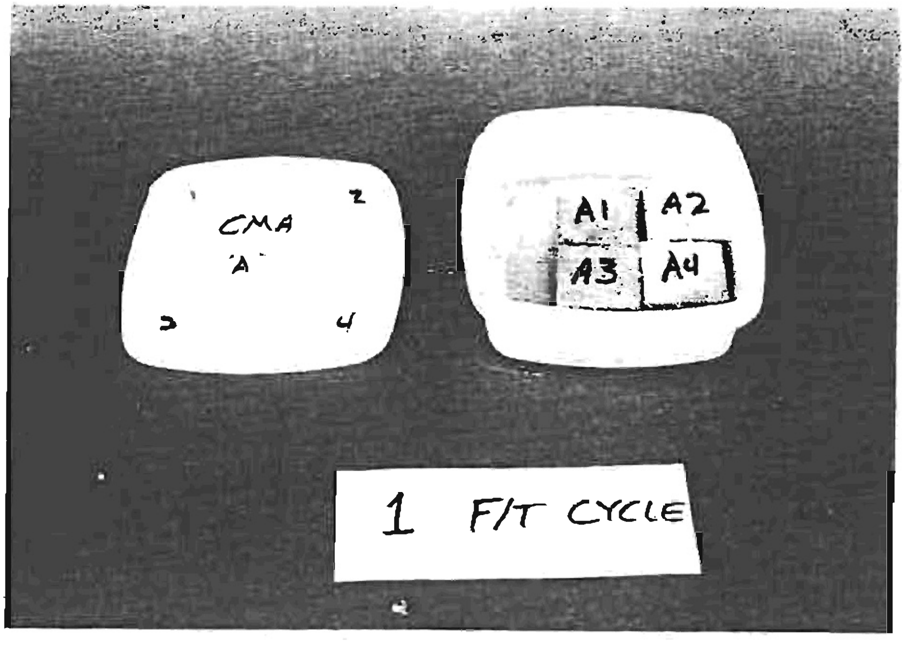
Photograph 6. Test Fixture for Brine Generation Tests



Photograph 7. Device for Measuring Ice Penetration of Deicers.



Photograph 8. Corrosion Macrocell with Plexiglass Reservoir.



Photograph 9. Concrete Cubes for Strength Retention Testing.

Deicing Material	Avg. Strength (lbs)	Std. Deviation	t value	Significance
Control (distilled water)	37,900	1275	NA	NA
Sodium Chloride (8)	35,700	2570	1.60	0.20
Calcium Mag. Acetate (8)	33,150	3955	2.29	0.10
Freezgard	37,725	1790	0.16	> 0.20
Cargill CG-90 Liquid	36,775	2690	0.76	> 0.20
Ice-Stop	38,800	1750	-0.83	> 0.20
Cryotech C-92	36,975	1115	1.09	> 0.20
S. Dakota Deicer	40,275	570	-3.40	0.02
Cargill CG-90 Solid	38,075	1435	-0.18	> 0.20
Calcium Chloride	37,500	970	0.50	> 0.20
Control (no freeze/thaw)	39,600	700	-2.33	0.10

Table 1. Concrete cube strength after 50 freeze/thaw cycles (Second Test).

The initial tests indicated that Calcium Magnesium Acetate (CMA) decreased the strength of concrete by some 20% at a level of significance of 0.10. All other chemicals tested did not significantly decrease the strength of the concrete cubes. This seemed inconsistent with other data so the procedure was repeated after another set of cubes was cast and allowed to cure. The second test used more replicates (8 for CMA and Sodium Chloride) but reached similar conclusions regarding CMA's effect on the compressive strength of concrete. The complete results of this test series can be found in Appendix A.

Corrosion tests were also initiated to gather baseline corrosion data on different deicers and to evaluate the effects of corrosion inhibitors and their ability to protect steel in concrete. Included in the test matrix were Calcium Chloride, Sodium Chloride, Magnesium Chloride (both with and without an inhibitor), and Calcium Magnesium Acetate. Several other cells were fabricated with corrosion inhibitor concrete admixtures.

Corrosion test cells were fabricated according to SHRP H-205.12 and cast on April 30, 1992. After a 28-day cure, the corrosion cells were fitted with precision 100 Ohm resistors between the top and bottom steel bars and reservoirs were fabricated to hold solutions of deicing chemicals on the top of the corrosion cell. Ponding began June 23, 1992 with a four-week cycle for the cells: two weeks with the reservoirs filled with 500 ml solution and two weeks dry. The voltage across the 100 Ohm resistor was measured every two weeks and converted to a corrosion current using Ohm's law. The corrosion currents plotted versus time are shown in Appendix C.

5.0 Summary

The tables below summarize the data gathered and presented in detail in the appendices.

Brine Generation

Deicer Type	Deicer Name	Brine Generation (mL)		
		5° F	15° F	25° F
Liquid	LoTherm	9.3	9.1	17.3
	Cryotech C-92	5.5	8.7	9.3
	Cargill CG-90	4.4	8.2	15.0
	Freezgard	4.9	8.3	15.5
Solid	Calc. Chloride	18.8	18.2	32.8
	Sod. Chloride	5.2	15.7	29.7
	CMA	0.0	0.3	10.3
	S. Dakota	16.3	21.7	36.0
	Cargill CG-90	13.2	15.7	37.5
	Citrus	15.3	24.2	44.5

Table 2. Brine Generation at 60 Minutes.

Ice Penetration

Deicer Type	Deicer Name	Avg. Ice Penetration in tenths of inches		
		5° F	15° F	25° F
Liquid	LoTherm	12.2	8.1	14.5
	Cryotech C-92	9.4	5.8	9.8
	CG-90	9.9	3.5	4.6
	Freezgard	11.8	13.5	14.5
Solid	Calc. Chloride	13.7	14.5	14.5
	Sod. Chloride	10.4	11.6	14.5
	CMA	0.1	0.2	1.1
	S. Dakota	0.9	0.9	3.1
	Cargill CG-90	1.0	1.1	1.7
	Citrus	.5	.9	2.9

Table 3. Ice Penetration at 60 Minutes.

Corrosion of Steel in Concrete

Deicer Name	Average Total Corrosion (Coulombs) at 580 Days
Calcium Chloride	505*
CMA	0
Magnesium Chloride	211
Mag. Chloride w/ Inhibitor	91
Sodium Chloride	487

Table 4. Average Total Corrosion of Four Macrocells.

Ponding Discontinued at 378 Days.

The above described work establishes basic information about alternative deicers with respect to concrete compatibility, corrosion effects on steel in concrete, ice melting and ice penetration capacities, and field handling characteristics. This information, in conjunction with current pricing, should help the maintenance manager to make informed choices regarding the use of alternative chemical deicers.

Current deicing practices are largely dictated by funding levels. Salt is the most cost-effective deicing chemical at about 1/10 th the cost of other deicers. Although other deicers perform better than salt-especially at low temperatures-their increased performance is not proportional to their increased cost. At low temperatures, however, the increased costs of high performance deicers is justified in high traffic areas because of the reduction in accidents and delays. The various test procedures performed during this study, both field and laboratory, have shown that the use of alternate deicing chemicals can improve various aspects of snow and ice control.

The complex interrelationships that exist between environmental, economic, and performance criteria make changes in deicing practice difficult. Costs that are borne indirectly by the motoring public such as automobile corrosion, vehicle paint and windshield damage could be reduced by the use of alternative deicers, however, there would be additional costs which would then be borne by CDOT.

5.1 Pricing

Although pricing is highly dependant upon volume, time of year, shipping costs and other factors, current pricing in the Denver area are given for comparison purposes. The prices are calculated on the basis of a 100% chemical content. This means that a deicing solution that is 25% chemical content will be price-adjusted by a factor of 4 to make the price comparable to chemicals which are approximately 100% active ingredient.

Liquid Magnesium Chlorides (30% MgCl Brine)	$ 200 / ton
Calcium Magnesium Acetate	$ 625 / ton
Sodium Chloride	$ 20 / ton
Enhanced Sodium Chlorides (e.g. CG-90 or Quicksalt)	$ 200 / ton
South Dakota Deicer (estimate)	$ 300 / ton
Calcium Chloride	$ 240 / ton

6.0 Implementation

The following recommendations apply to large metropolitan areas where high traffic volumes necessitate achieving bare pavements as quickly as possible. Air pollution is another factor driving these recommendations. Another factor is that wholesale replacement of winter maintenance equipment is not possible given funding constraints. Because of this, changes will have to be phased in over perhaps 5 to 10 years.

It is recommended that reductions in the amount of sand applied to highways can best be accomplished by incremental reductions in the sand content of the deicing mixture. In conjunction with this, equipment should be installed to apply liquid low temperature deicing chemicals to the dry mixture at the back of the truck. Reducing or eliminating the sand in the chemical mixture means that distribution equipment must be capable of uniformly applying smaller amounts of chemical. This also means that distribution must be tied to ground speed of the truck.

For environmental and political reasons it is imperative that the amount of salt applied to the road should not exceed current levels. As an example, if currently a truck is applying 400 lbs. per lane mile of a mixture of 80% sand and 20% salt, then it only needs to apply 80 lbs. of a 100% salt mixture to achieve the same deicing. This also means that a truck can cover five times the number of lane miles before returning to the patrol to reload. In order to make salt more effective, "prewetting" has been found to be a valuable procedure [3,4,5,6]. By providing the initial moisture salt needs to begin melting, prewetting speeds up the reaction and allows the salt to embed in the snow/ice pack. This means that the melting action is accelerated and the chemical is less likely to end up on the shoulder of the road. Prewetting the salt also reduces the total amount of chemical applied to the roadway [7]. Having the option of prewetting, available at the material "spinner", increases the versatility of the deicing operation. In cold weather, additional material can be applied to increase the low temperature performance of the deicer. During warmer storms, or when sufficient moisture is present on the pavement, the prewetting may not be necessary.

The use of 100% liquid deicers is not recommended for several reasons. From a practical view, since most liquid deicers are 65 to 75% water, the material handling and application is not as efficient as using solid deicers. In cold temperatures, when a snow or ice pack is on the pavement, or during precipitation, the danger of refreeze is high. The refreeze phenomenon can be seen in the graphs of brine generation for liquid deicers in Appendix A. In nearly every graph, the melt volume peaks at about 30 minutes and decreases as the chemical becomes diluted and begins to freeze, reducing the brine volume. Liquid application also requires specialized equipment which the State does not currently own and which is not as versatile as a dump truck for year-round maintenance work.

In conjunction with the above recommendations, public education campaigns need to be initiated to inform motorists that the same amounts of salt are being used and the reasons for reducing the use of sand.

References

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[3] Swedish Road and Traffic Research Institute, Methods and Materials for Snow and Ice Control on Roads and Runways: MINSALT Project, TRB Record 1387, 1993.

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[5] Midwest Research Institute, Current Status of U.S. Anti-Icing Technology Development, TRB Record 1387, 1993.

[6] Swiss Federal Highways Office, Snow Removal and Ice Control Technology on Swiss Highways, TRB Record 1387, 1993.

[7] Finish National Road Administration, Goals and Methods of Winter Maintenance in Finland, TRB Record 1387, 1993.

Appendix A

Ice Melt Characteristics
and
Ice Penetration Tests

—BRINE GENERATION FOR LIQUIDS—

5 deg. F

BRINE GENERATED AT SAMPLE TIME

DEICER	10	20	30	45	60
LoTherm	6.7	8.1	9.4	8.5	9.3
Cryotech C-92	7.9	8.5	8.3	6.3	5.5
CG-90	7.3	5.5	5.6	5.1	4.4
Freezegard	7.9	7.2	6.5	4.9	4.9

15 deg. F

BRINE GENERATED AT SAMPLE TIME

DEICER	10	20	30	45	60
LoTherm	8.4	10.4	10.8	9.2	9.1
Cryotech C-92	10.8	11.8	11.9	9	8.7
CG-90	8.9	9.2	9.7	8.2	8.2
Freezegard	9.1	10.3	10.3	8.7	8.3

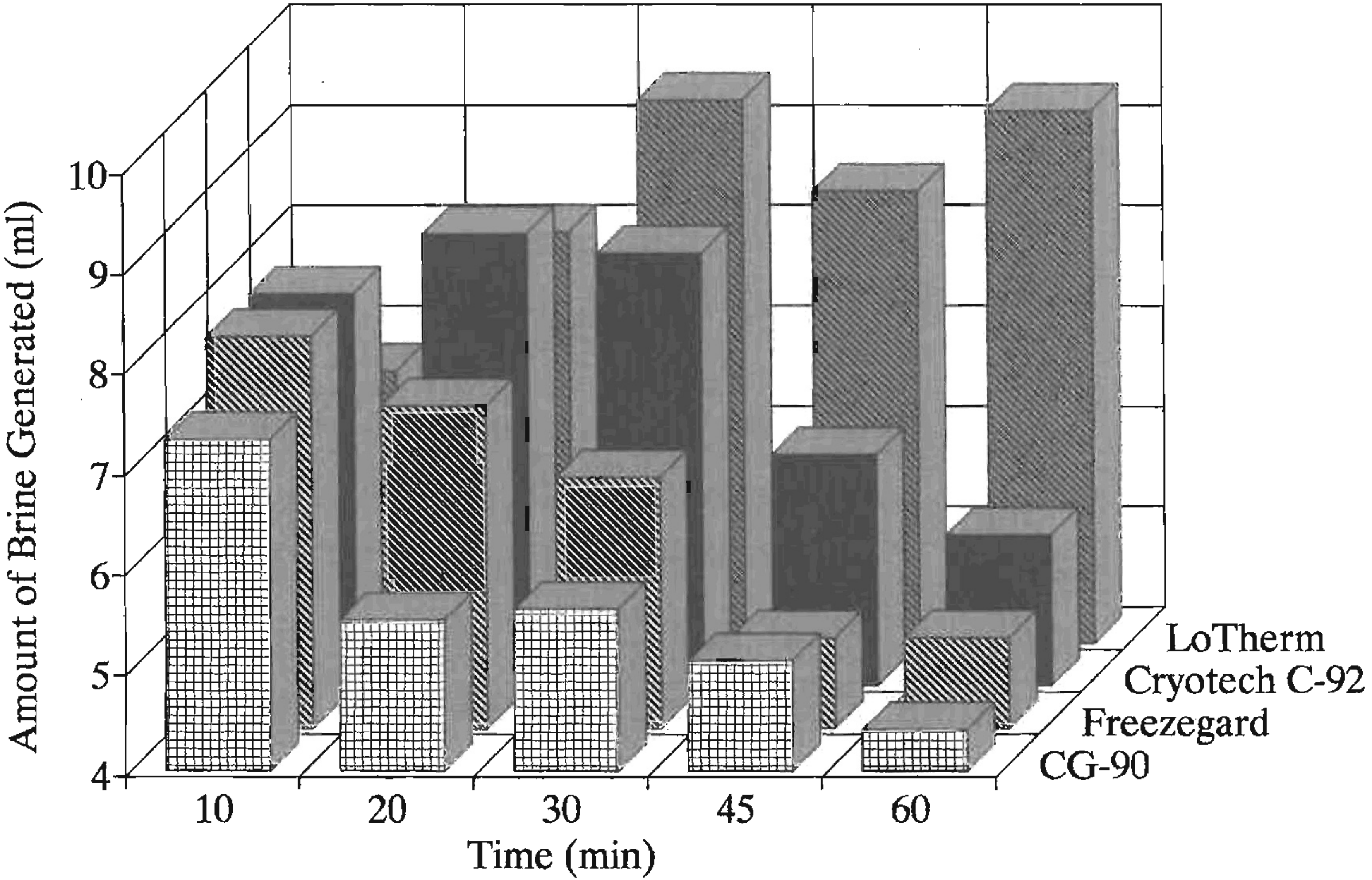
25 deg. F

BRINE GENERATED AT SAMPLE TIME

DEICER	10	20	30	45	60
LoTherm	15.4	18.5	19.8	18	17.3
Cryotech C-92	15	19.3	21.3	22.5	19.3
CG-90	13.4	16.2	17.6	16.9	15
Freezegard	15.5	17.7	19.1	16.3	15.5

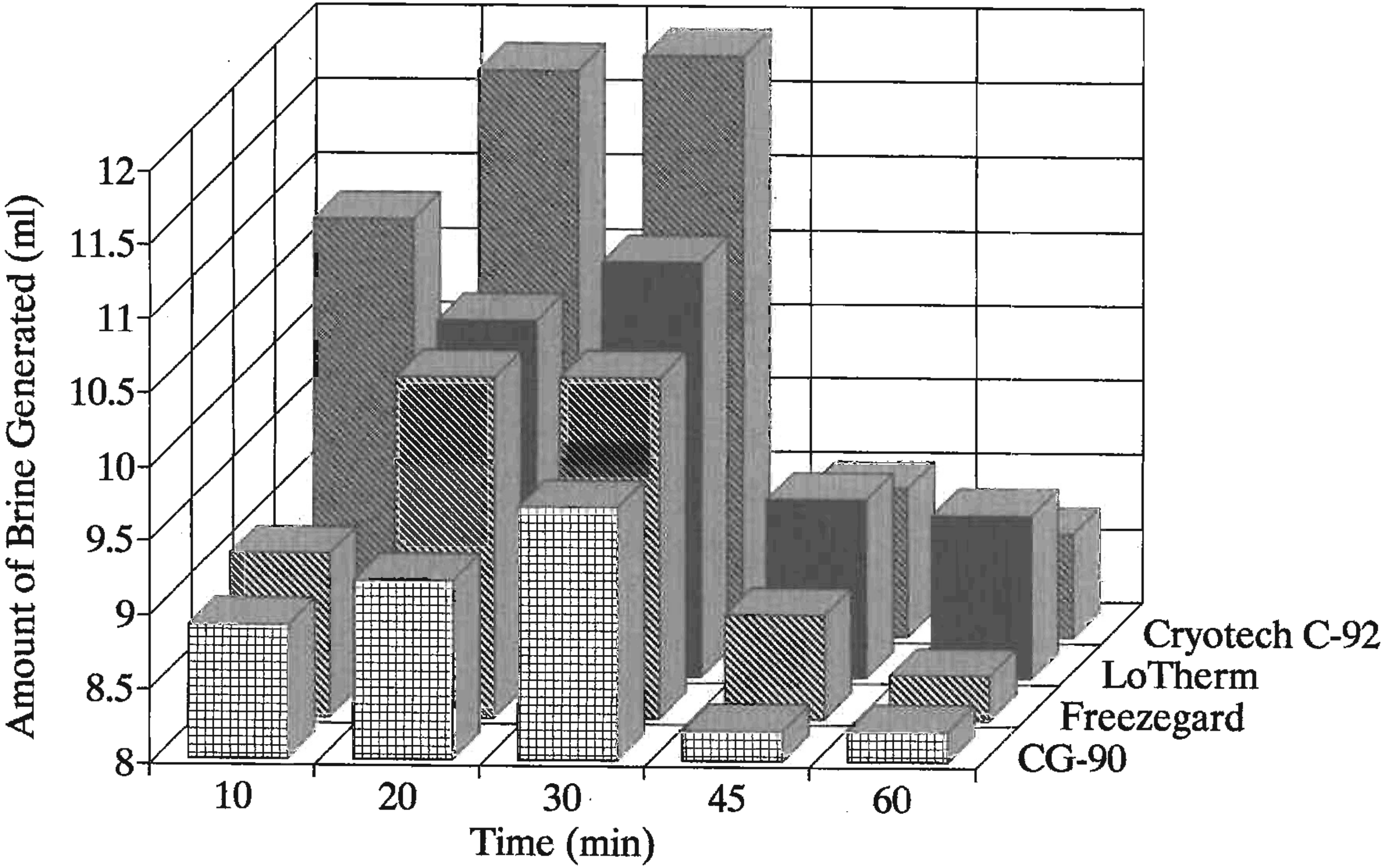
BRINE GENERATION OF LIQUIDS

Amount of Brine Generated @ 5 deg. F



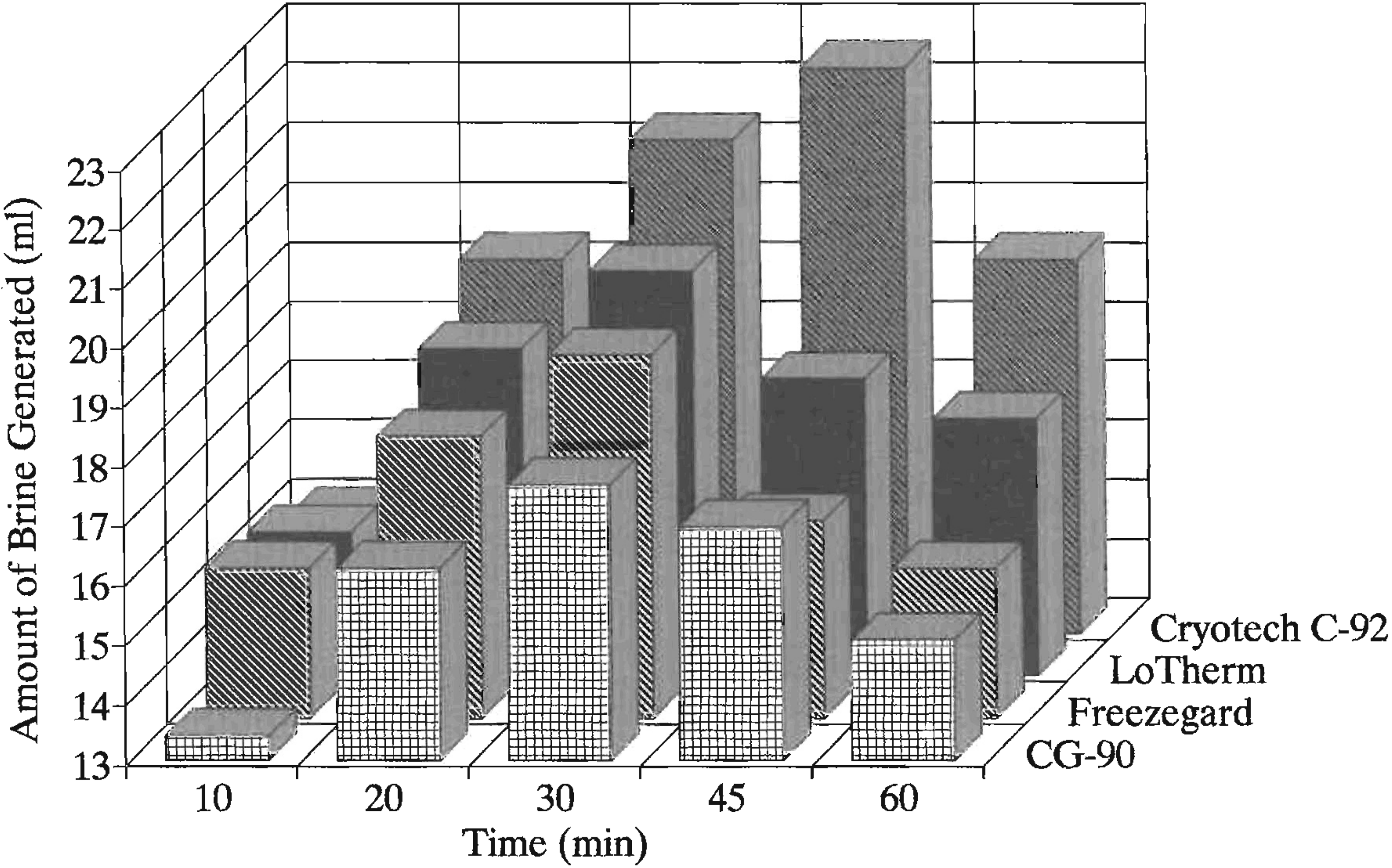
BRINE GENERATION OF LIQUIDS

Amount of Brine Generated @ 15 deg. F



BRINE GENERATION OF LIQUIDS

Amount of Brine Generated @ 25 deg. F



—BRINE GENERATION FOR SOLIDS

5 deg. F BRINE GENERATED AT SAMPLE TIME

DEICER	10	20	30	45	60
CaCl	4.3	10.8	13.2	17.2	18.8
S. Dakota	3.6	9.0	10.3	13.0	16.3
CG-90	1.8	3.7	6.2	10.6	13.2
Ice-B-Gone	0.0	0.0	0.0	0.0	0.0
NaCl	1	1.5	2.6	3.8	5.2
Citris	7.7	11	13.8	16.4	15.3

15 deg. F BRINE GENERATED AT SAMPLE TIME

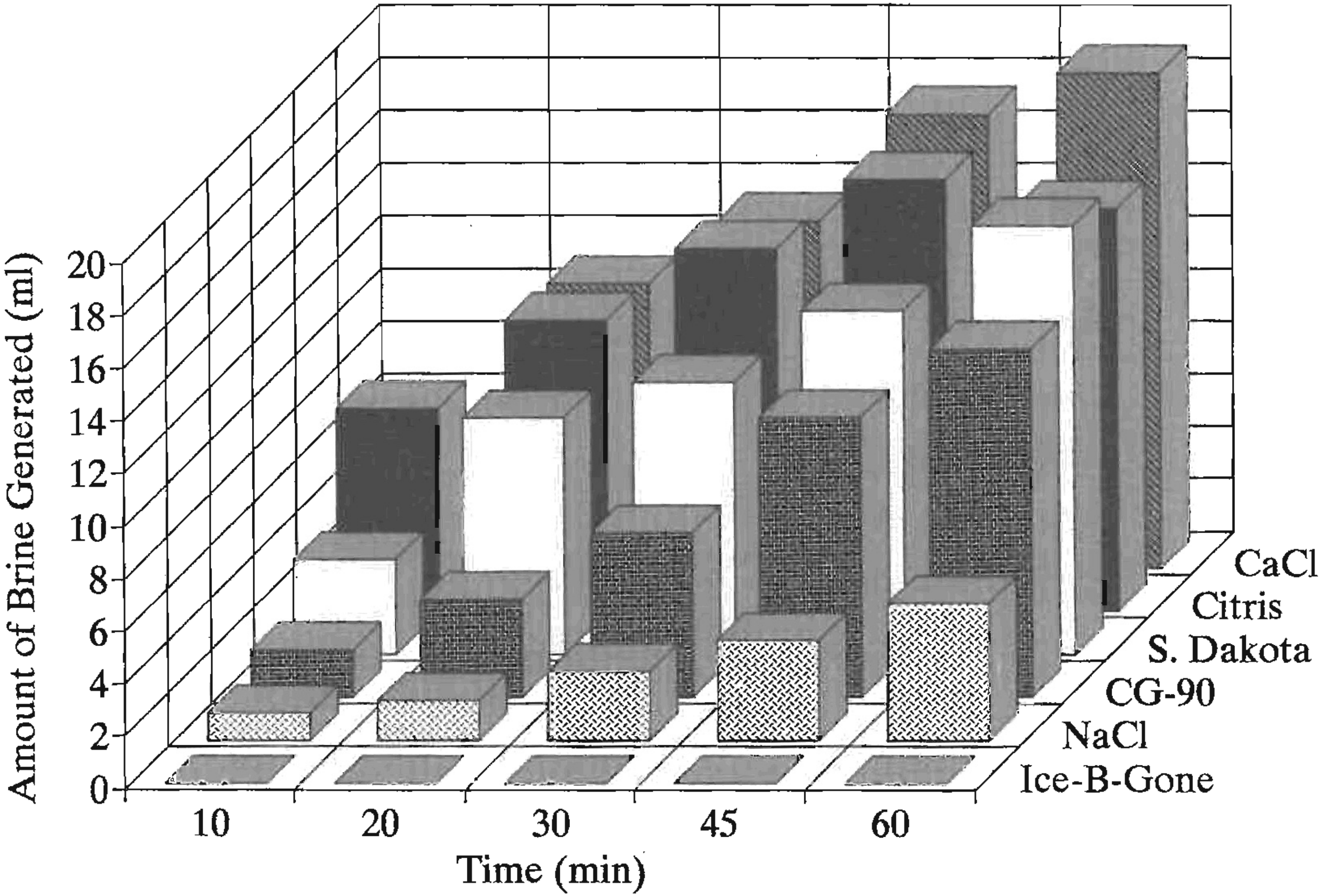
DEICER	10	20	30	45	60
CaCl	4.8	7.5	12.8	15.7	18.2
S. Dakota	6.2	10.3	15.7	18.7	21.7
CG-90	3.2	5.7	9.7	12.8	15.7
Ice-B-Gone	0.0	0.0	0.0	0.0	0.3
NaCl	3.1	6	9.3	12.7	15.7
Citris	9.7	14.5	16.5	19.5	24.2

25 deg. F BRINE GENERATED AT SAMPLE TIME

DEICER	10	20	30	45	60
CaCl	10.0	21.0	25.5	29.5	32.8
S. Dakota	13.5	21.2	26.3	31.0	36.0
CG-90	8.7	17.3	25.3	31.7	37.5
Ice-B-Gone	1.8	3.7	5.5	8.3	10.3
NaCl	8.7	15.3	21.3	26.2	29.7
Citris	3.7	11	20.6	30.1	44.5

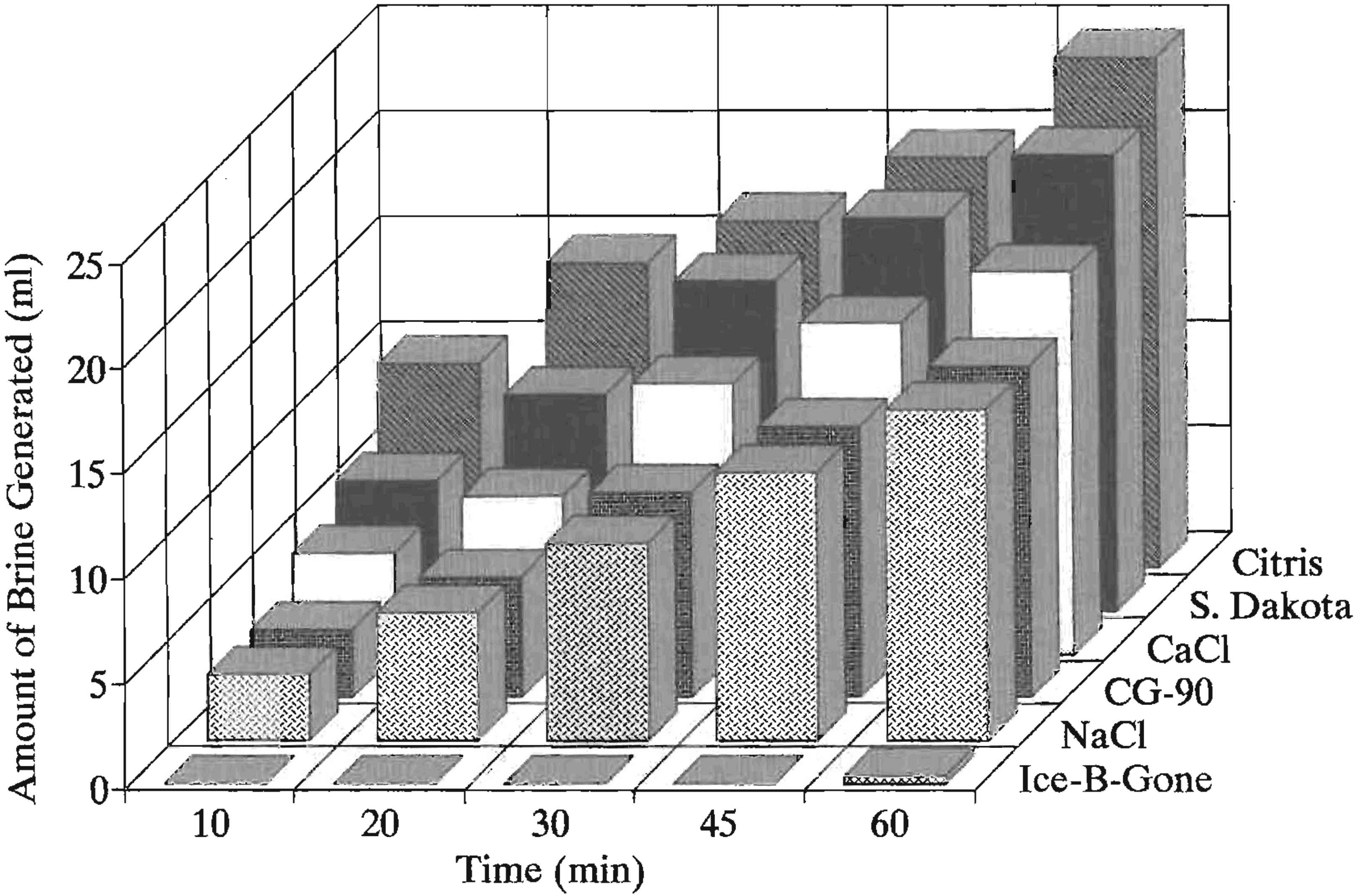
BRINE GENERATION OF SOLIDS

Amount of Brine Generated @ 5 deg. F



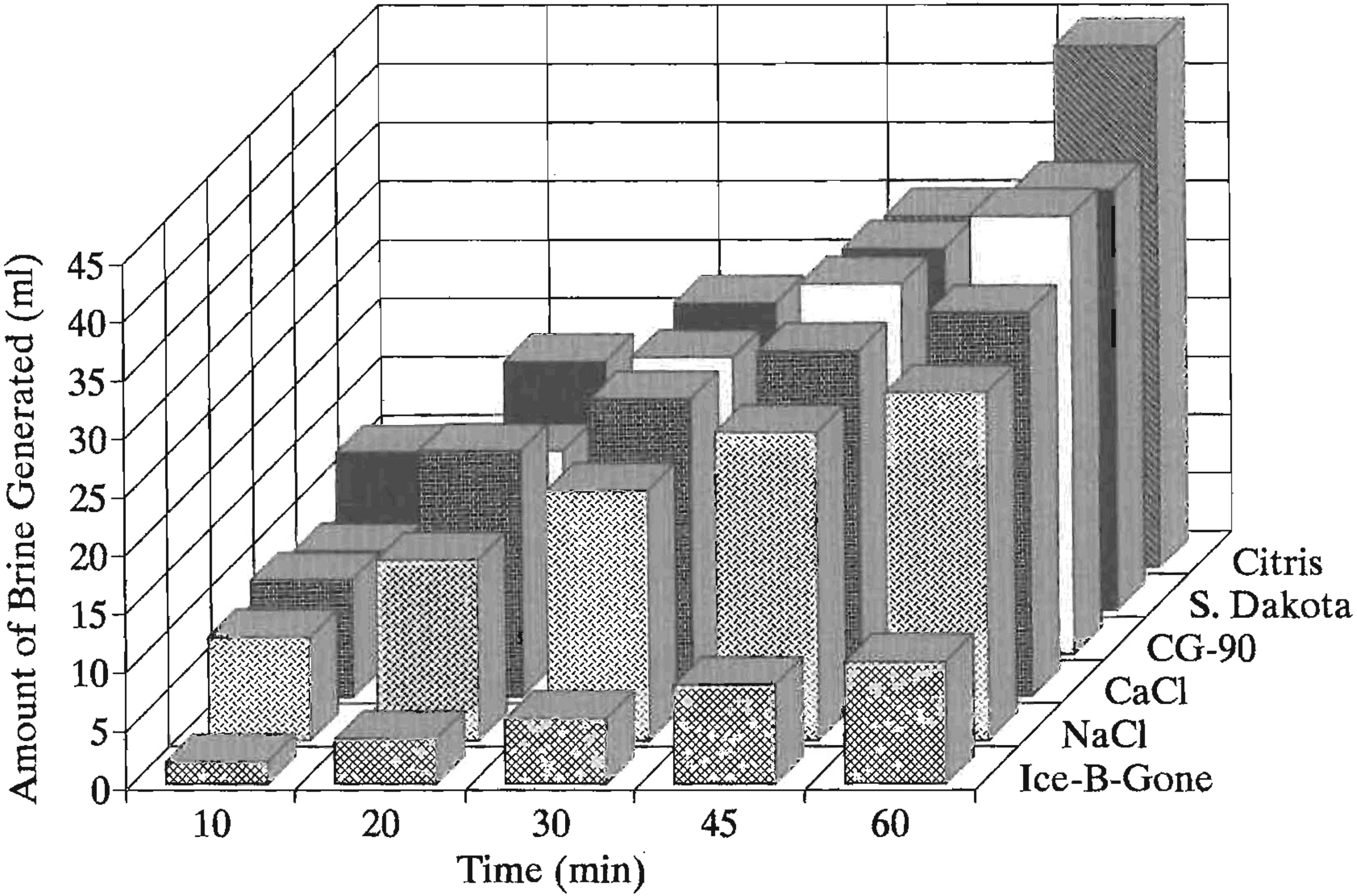
BRINE GENERATION OF SOLIDS

Amount of Brine Generated @ 15 deg. F



BRINE GENERATION OF SOLIDS

Amount of Brine Generated @ 25 deg. F



—ICE PENETRATION FOR LIQUIDS—

5 deg. F

TIME (Minutes) **LIQUID DEICER**	**5**	**10**	**15**	**20**	**30**	**45**	**60**
LoTherm	0.54	0.96	1.34	2.86	8.54	11.4	12.2
Cryotech C-92	0.84	1.22	1.76	2.82	7.22	9.02	9.38
CG-90	0.88	1.2	1.72	2.44	7.7	9.22	9.94
Freezegard	0.7	1.12	1.72	2.38	9.92	11.04	11.84

15 deg. F

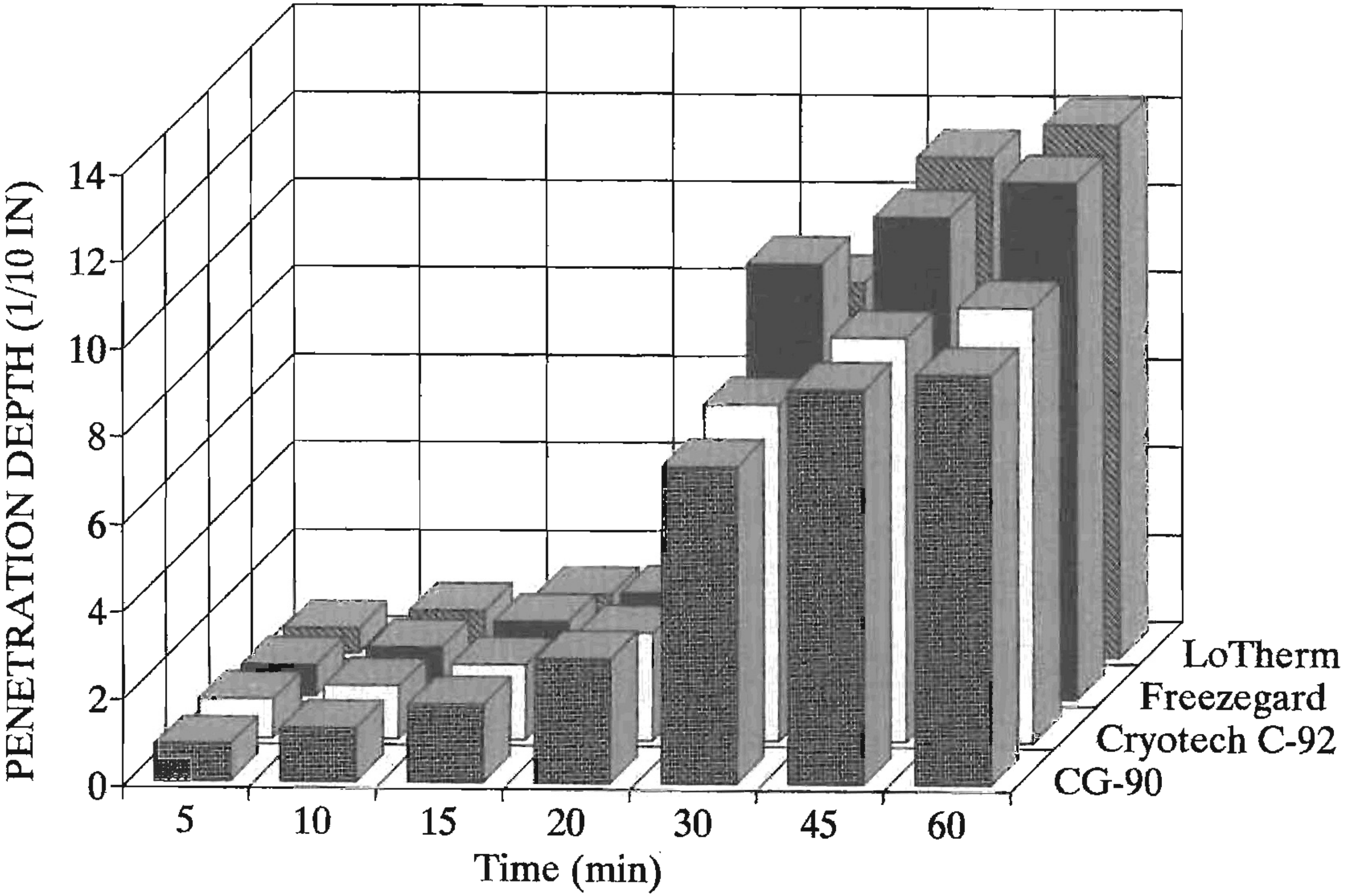
TIME (Minutes) **LIQUID DEICER**	**5**	**10**	**15**	**20**	**30**	**45**	**60**
LoTherm	0.82	1.04	1.4	3.04	6.76	7.86	8.14
Cryotech C-92	0.98	1.4	2.3	3.24	4.82	5.64	5.84
CG-90	0.84	1.06	1.46	2.14	2.96	3.36	3.5
Freezegard	0.88	1.4	2.66	4.68	12.62	13.4	13.5

25 deg. F

TIME (Minutes) **LIQUID DEICER**	**5**	**10**	**15**	**20**	**30**	**45**	**60**
LoTherm	0.58	1.4	2.98	7.54	10.44	14.06	14.5
Cryotech C-92	0.94	1.38	2.24	2.84	6.84	9.4	9.76
CG-90	0.84	1.3	1.62	2.38	3.48	4.26	4.58
Freezegard	0.86	1.8	2.84	7.6	12.02	14.5	14.5

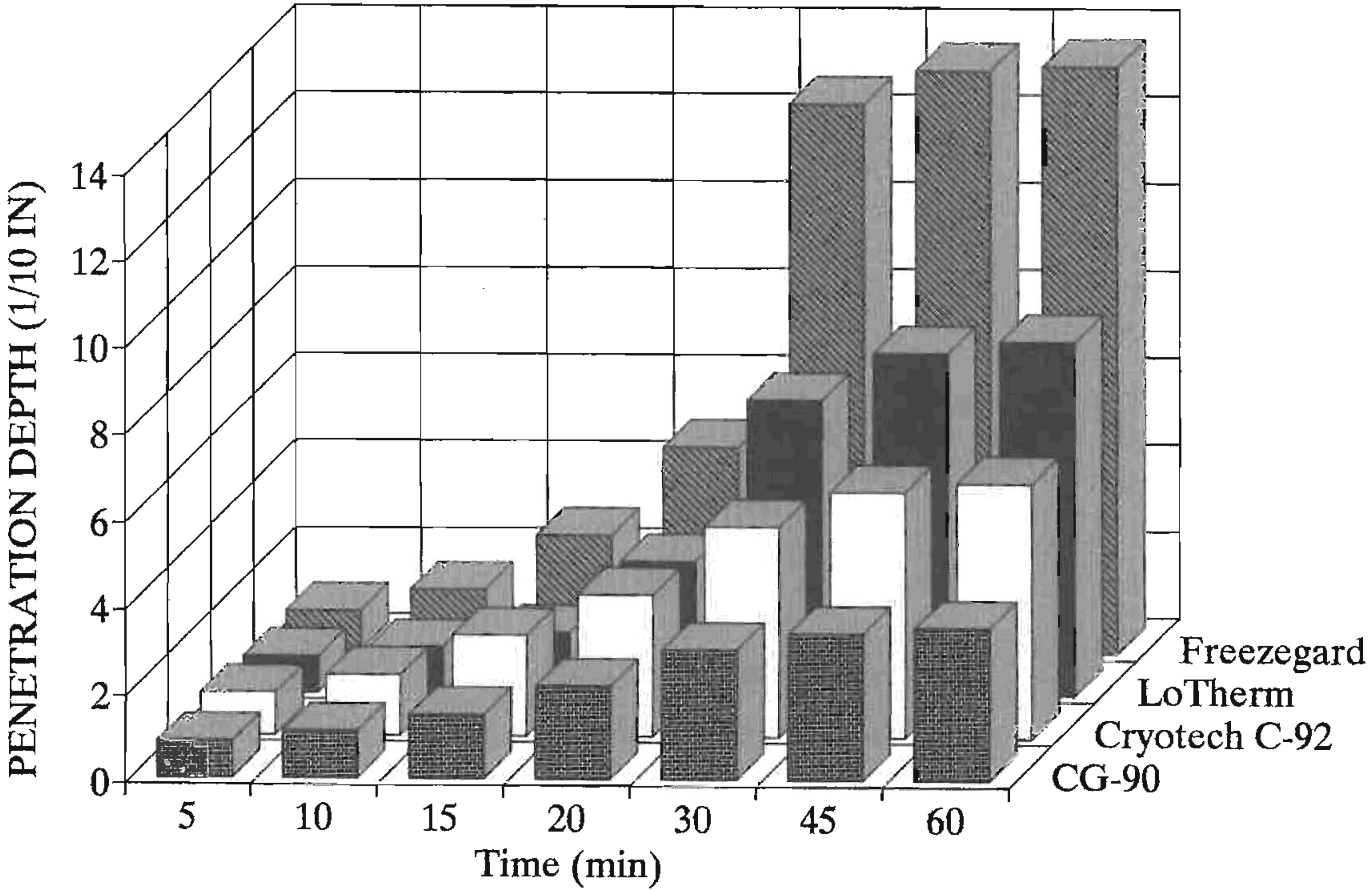
ICE PENETRATION OF LIQUIDS

PENETRATION DEPTH @ 5 DEG. F



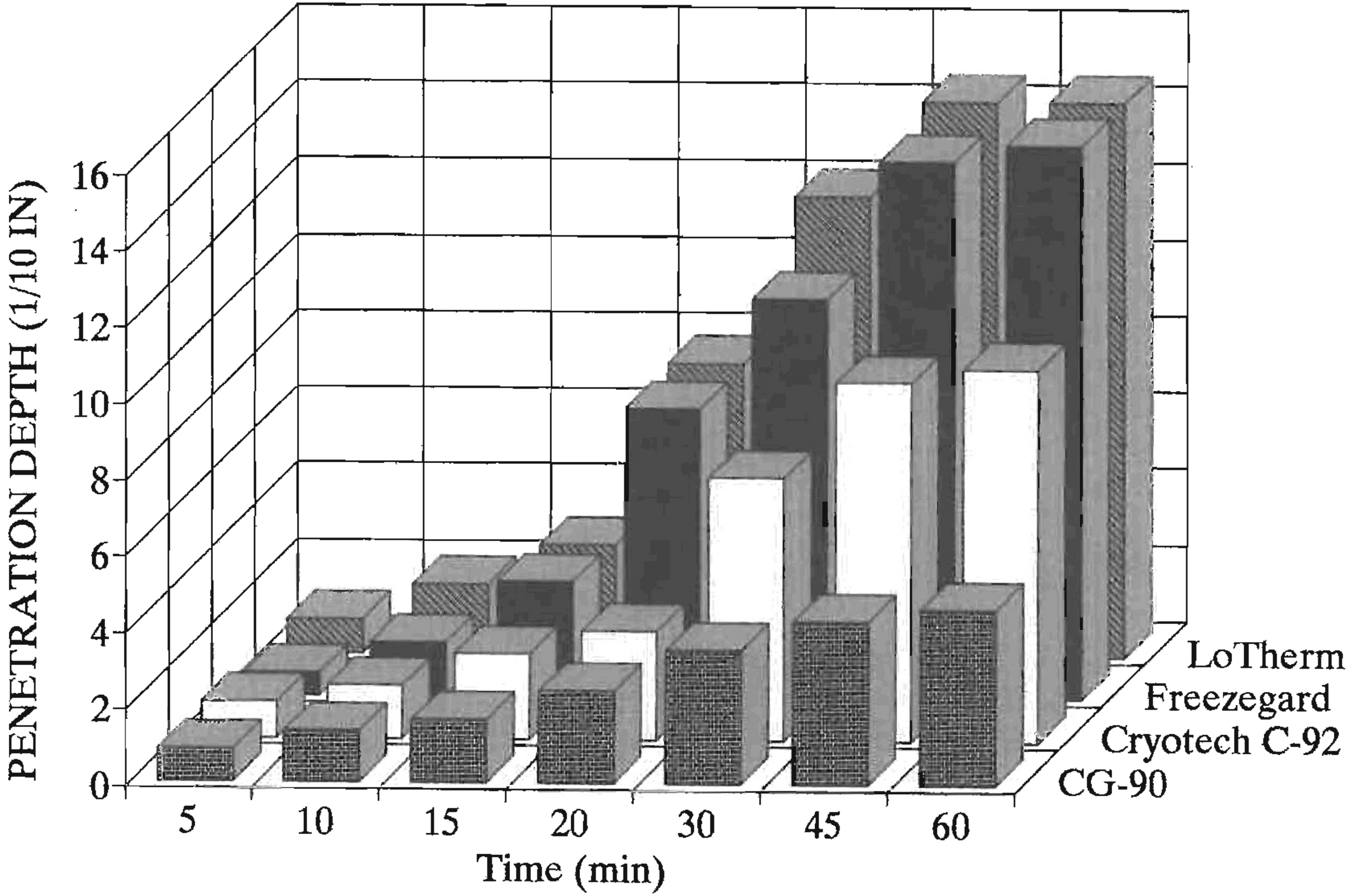
ICE PENETRATION OF LIQUIDS

PENETRATION DEPTH @ 15 DEG. F



ICE PENETRATION OF LIQUIDS

PENETRATION DEPTH @ 25 DEG. F



—ICE PENETRATION FOR SOLIDS—

5 deg. F

PENETRATION (1/10TH INCH)

TIME (Minutes)	3	5	10	15	20	30	45	60
SOLID DEICER								
CaCl	2.2	2.3	4.9	5.8	6.7	10.16	13.74	13.74
NaCl	1.0	2.1	3.4	5.2	6.3	9.74	10.22	10.38
CMA (Peladow)	0.1	0.3	0.9	1.2	1.4	2.18	3.4	4.62
South Dakota	0.9	1.1	2.2	2.8	3.6	4.28	4.94	5.52
CG-90	1	1.1	2.44	3.04	4.84	13.48	13.5	13.6
Citris	0.5	0.8	1.6	2.02	2.24	2.58	2.66	2.7

15 deg. F

PENETRATION (1/10TH INCH)

TIME (Minutes)	3	5	10	15	20	30	45	60
SOLID DEICER								
CaCl	2.9	8.1	14.5	14.5	14.5	14.5	14.5	14.5
NaCl	2.0	2.4	4.6	7.7	9.6	10.96	11.5	11.6
CMA (Peladow)	0.2	0.6	1.2	1.9	3.8	8.86	10.7	12.18
South Dakota	0.9	1.7	3.2	7.4	12.1	12.78	14.5	14.5
CG-90	1.08	1.33	8.05	9.38	14.5	14.5	14.5	14.5
Citris	0.9	1.86	3.94	5.56	7.44	13.38	13.56	13.56

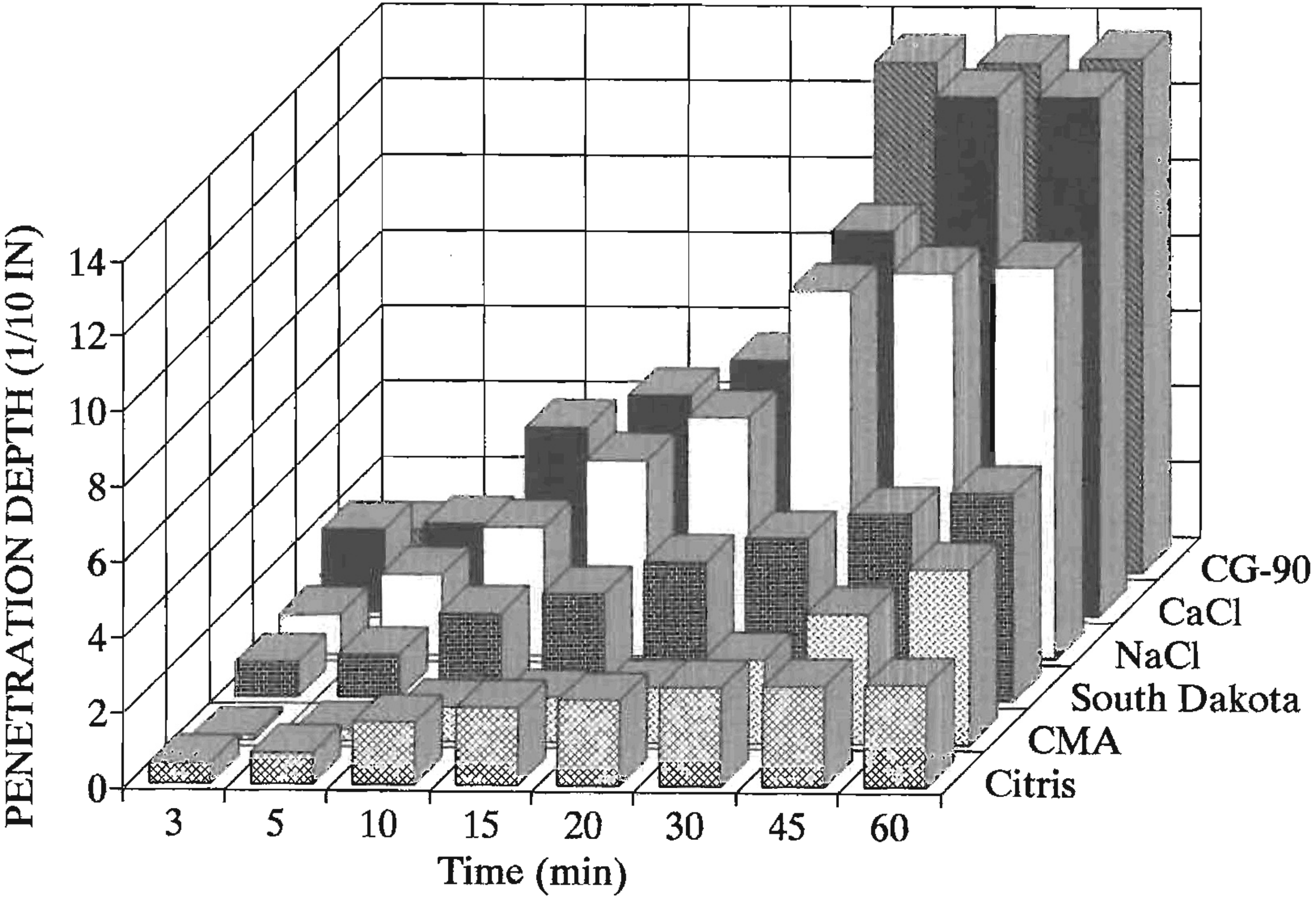
25 deg. F

PENETRATION (1/10TH INCH)

TIME (Minutes)	3	5	10	15	20	30	45	60
SOLID DEICER								
CaCl	2.3	4.0	5.6	8.5	14.5	14.5	14.5	14.5
NaCl	2.4	3.5	11.7	12.8	13.9	14.5	14.5	14.5
CMA (Peladow)	1.1	1.4	4.8	14.5	14.5	14.5	14.5	14.5
South Dakota	3.1	4.1	5.7	14.5	14.5	14.5	14.5	14.5
CG-90	1.68	3.06	4.92	10.94	13.7	14.5	14.5	14.5
Citris	2.9	3.3	4.2	5.3	7	8.6	10.3	11.6

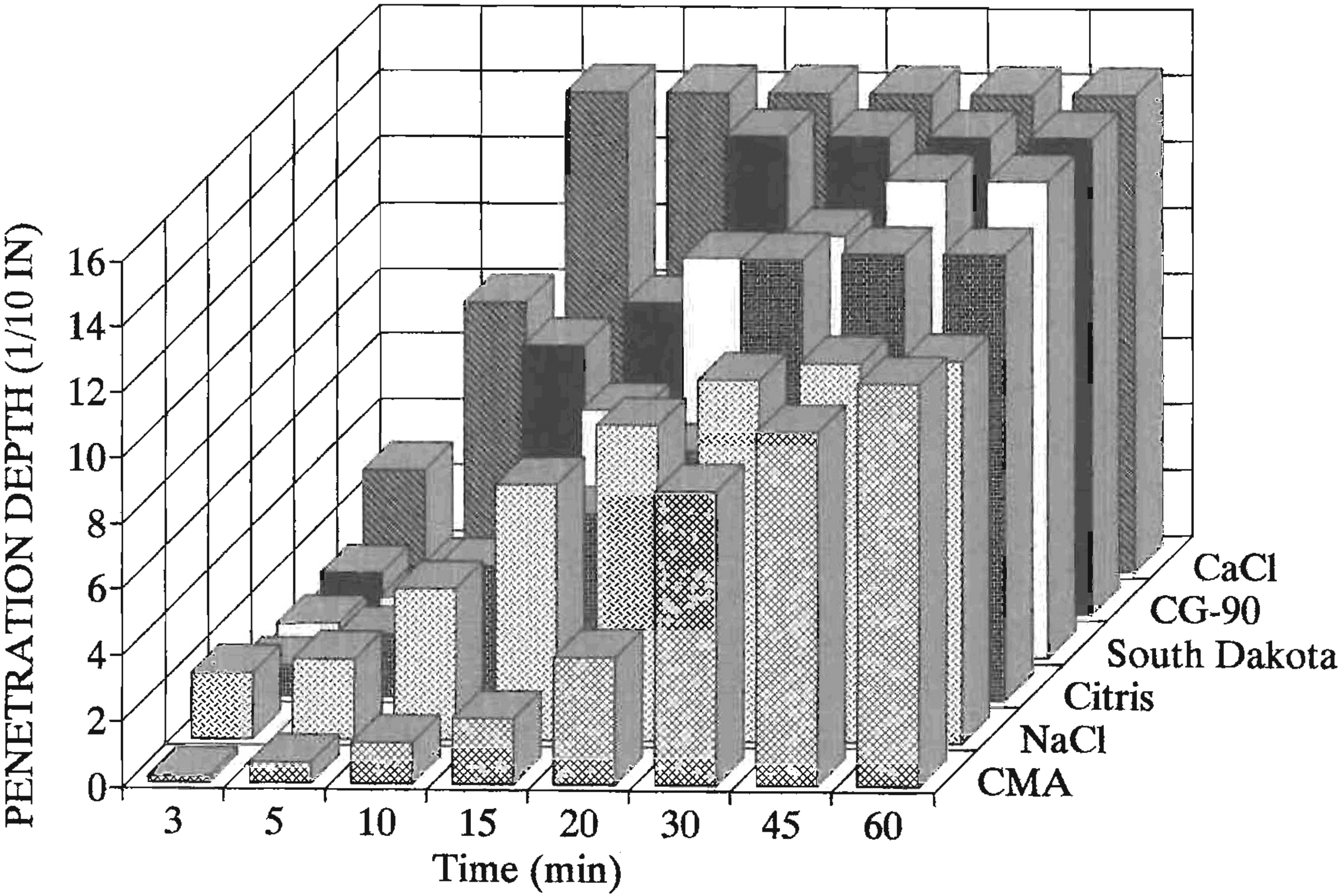
ICE PENETRATION OF SOLIDS

PENETRATION DEPTH @ 5 DEG. F



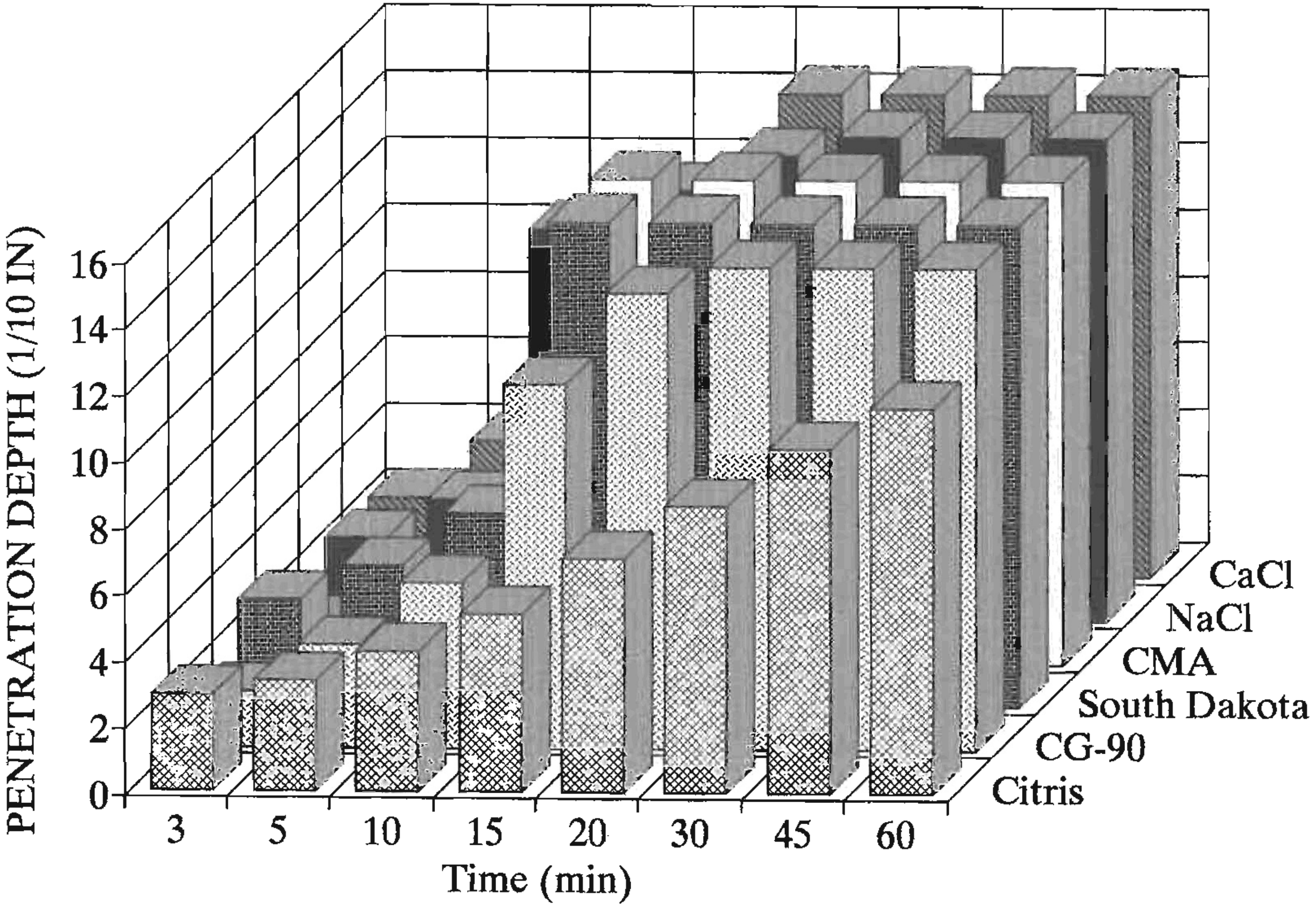
ICE PENETRATION OF SOLIDS

PENETRATION DEPTH @ 15 DEG.F



ICE PENETRATION OF SOLIDS

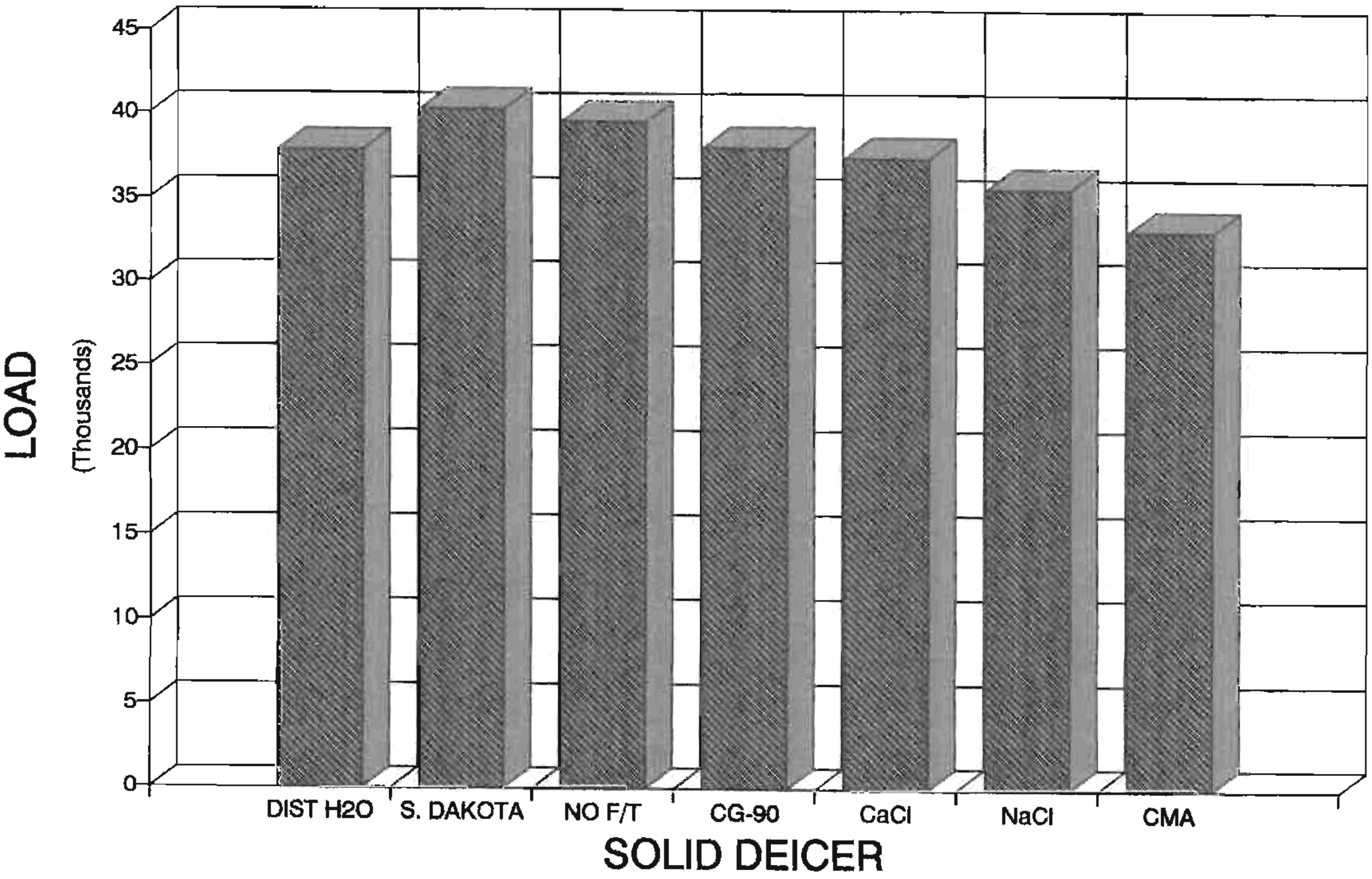
PENETRATION DEPTH @ 25 DEG. F



Appendix B

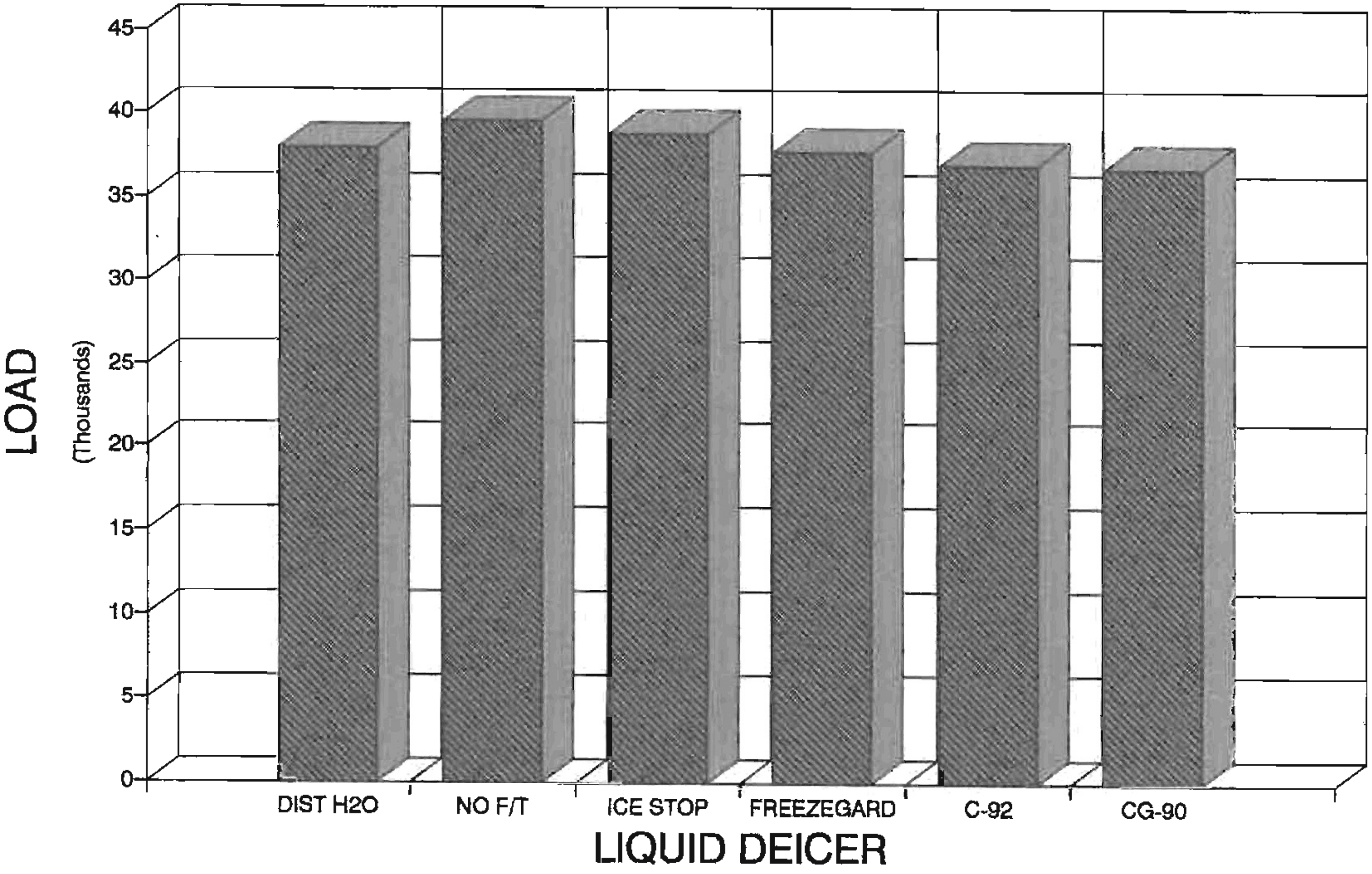
Compatibility of Deicers and Concrete Cubes Subjected to Freeze/Thaw Cycling

MEAN COMPRESSIVE STRENGTH
AFTER 50 FREEZE/THAW CYCLES



MEAN COMPRESSIVE STRENGTH

AFTER 50 FREEZE/THAW CYCLES

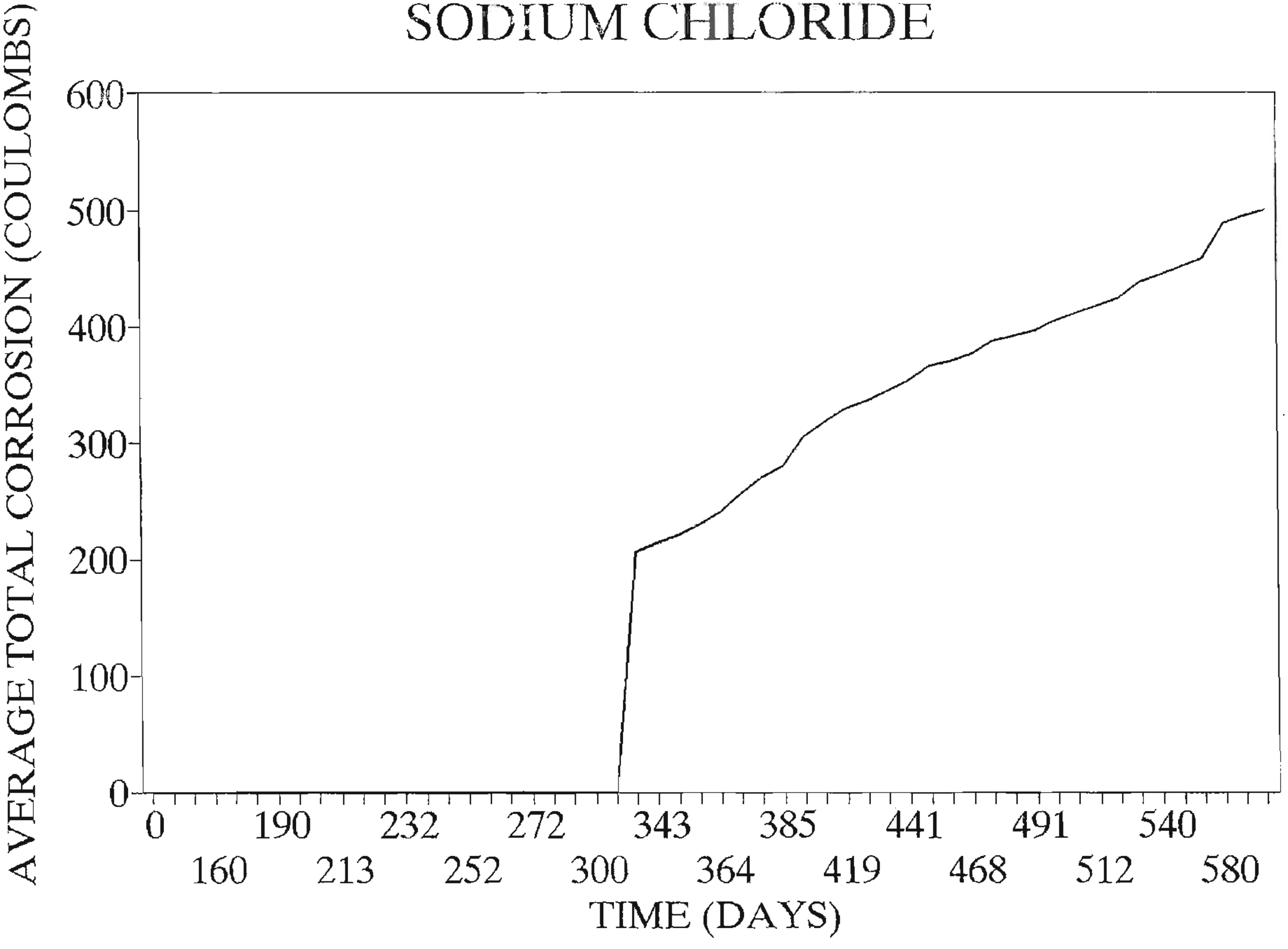


Appendix C

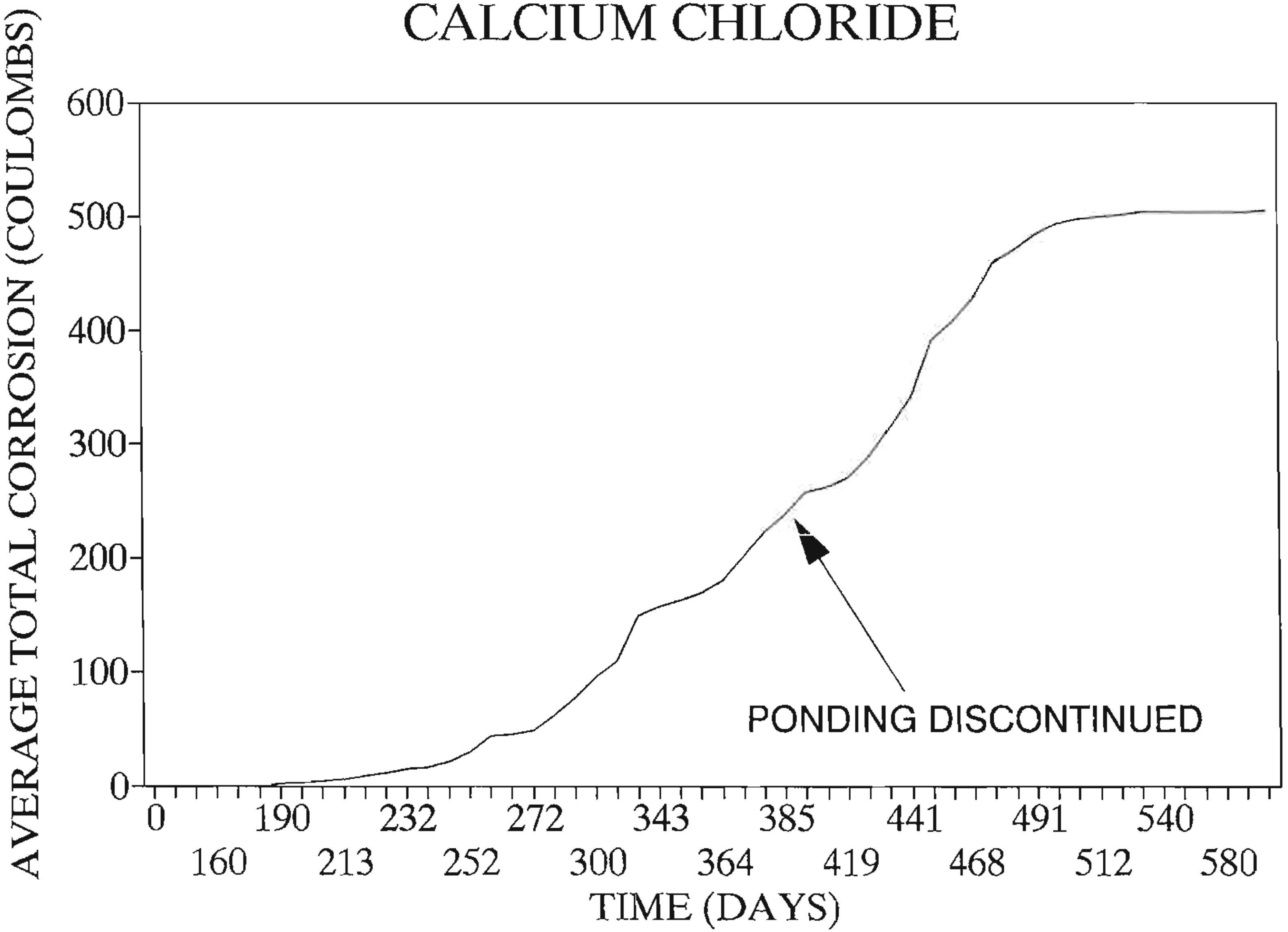
Corrosion Properties
of
Chemical Deicers

CHEMICAL DE-ICER

SODIUM CHLORIDE

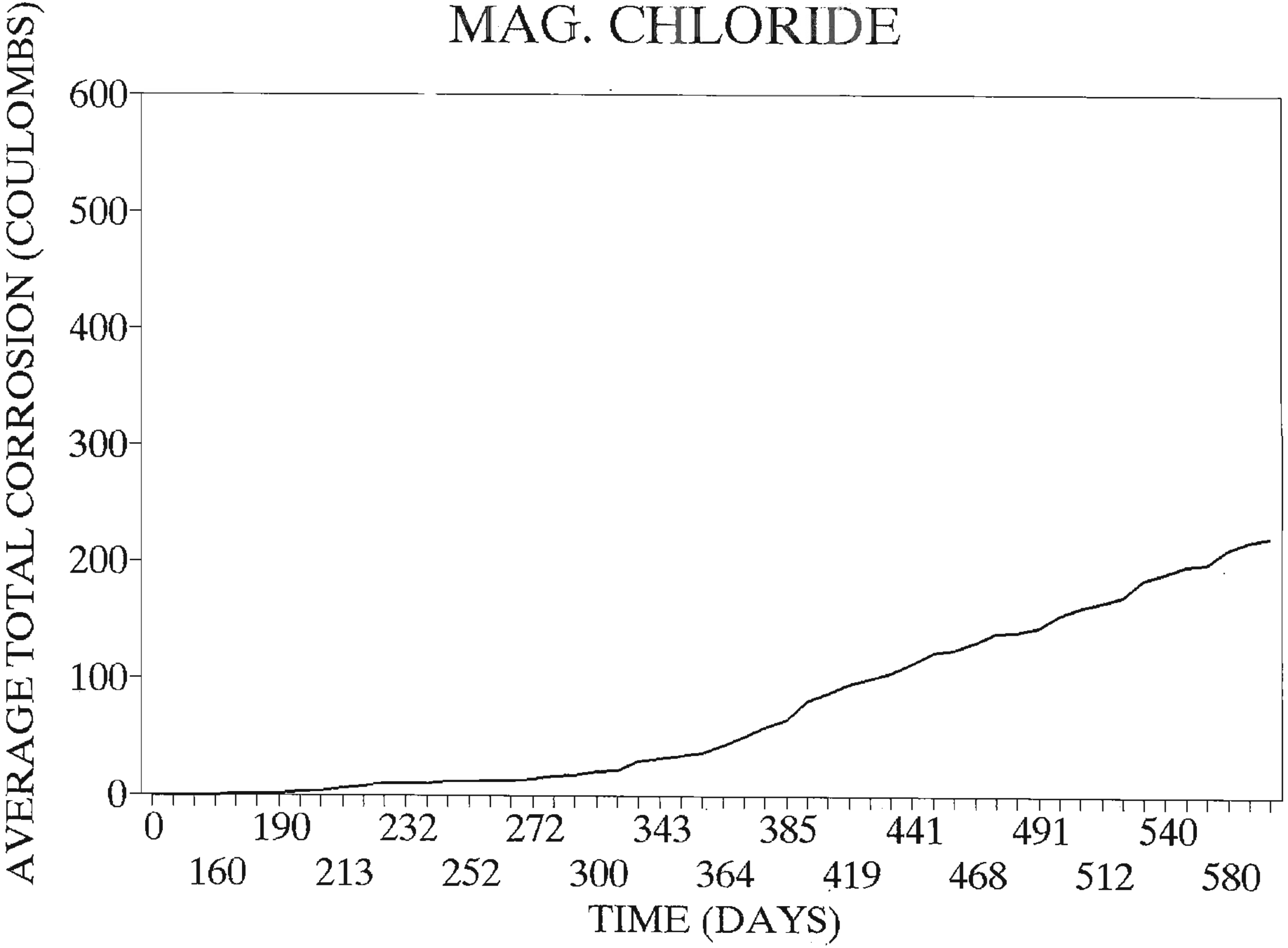


CHEMICAL DE-ICER
CALCIUM CHLORIDE



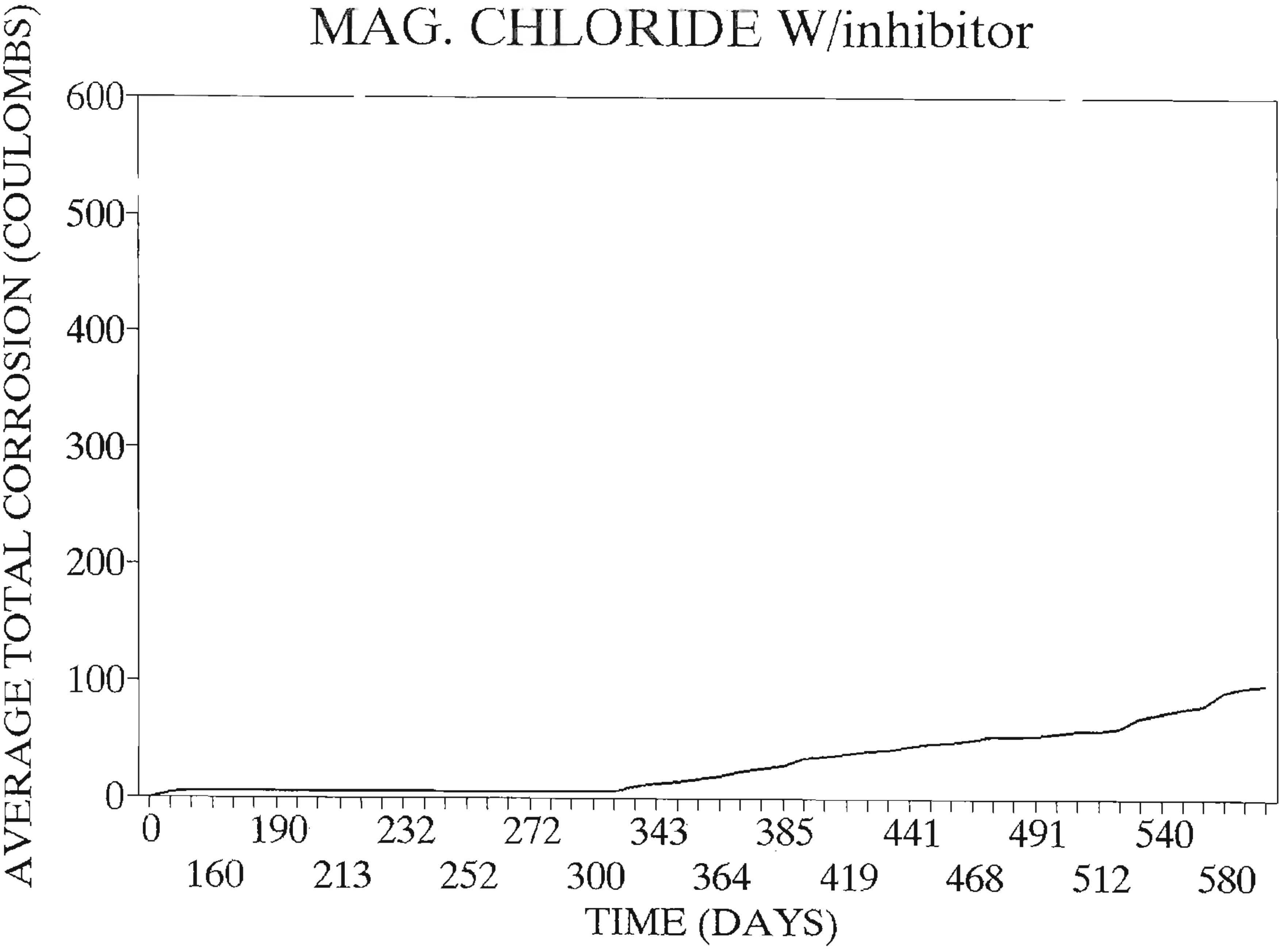
CHEMICAL DE-ICER

MAG. CHLORIDE



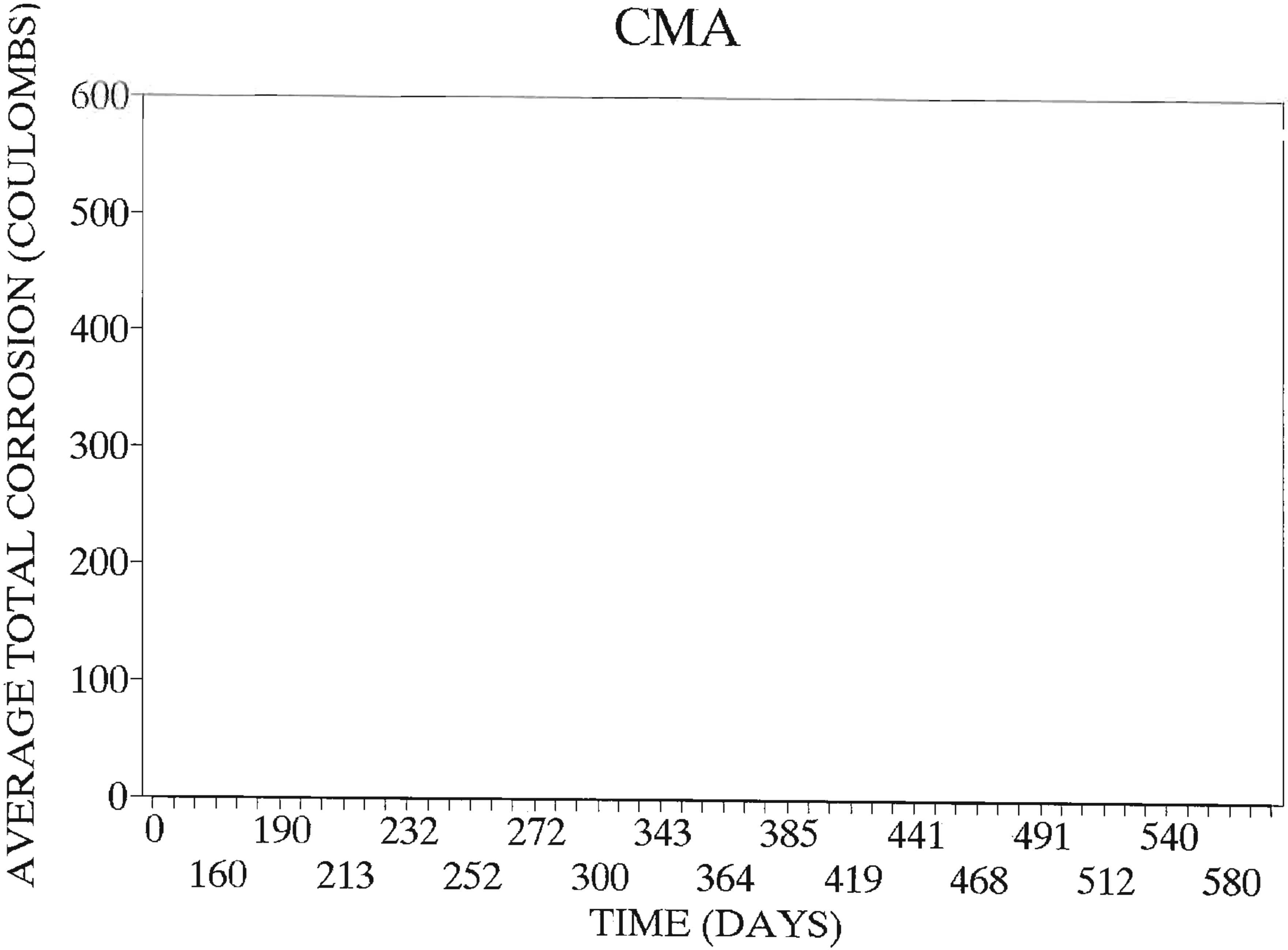
CHEMICAL DE-ICER

MAG. CHLORIDE W/inhibitor



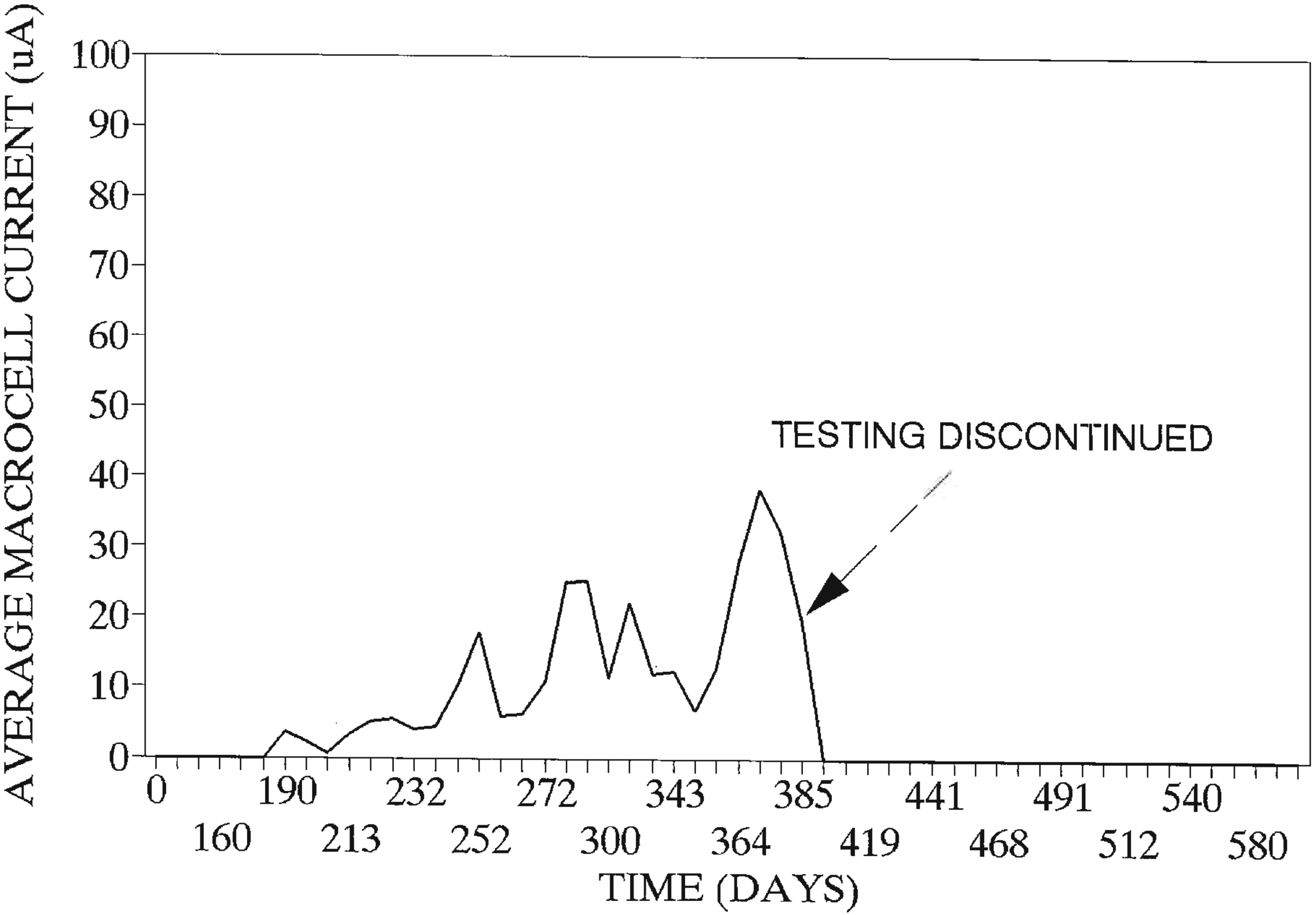
CHEMICAL DE-ICER

CMA



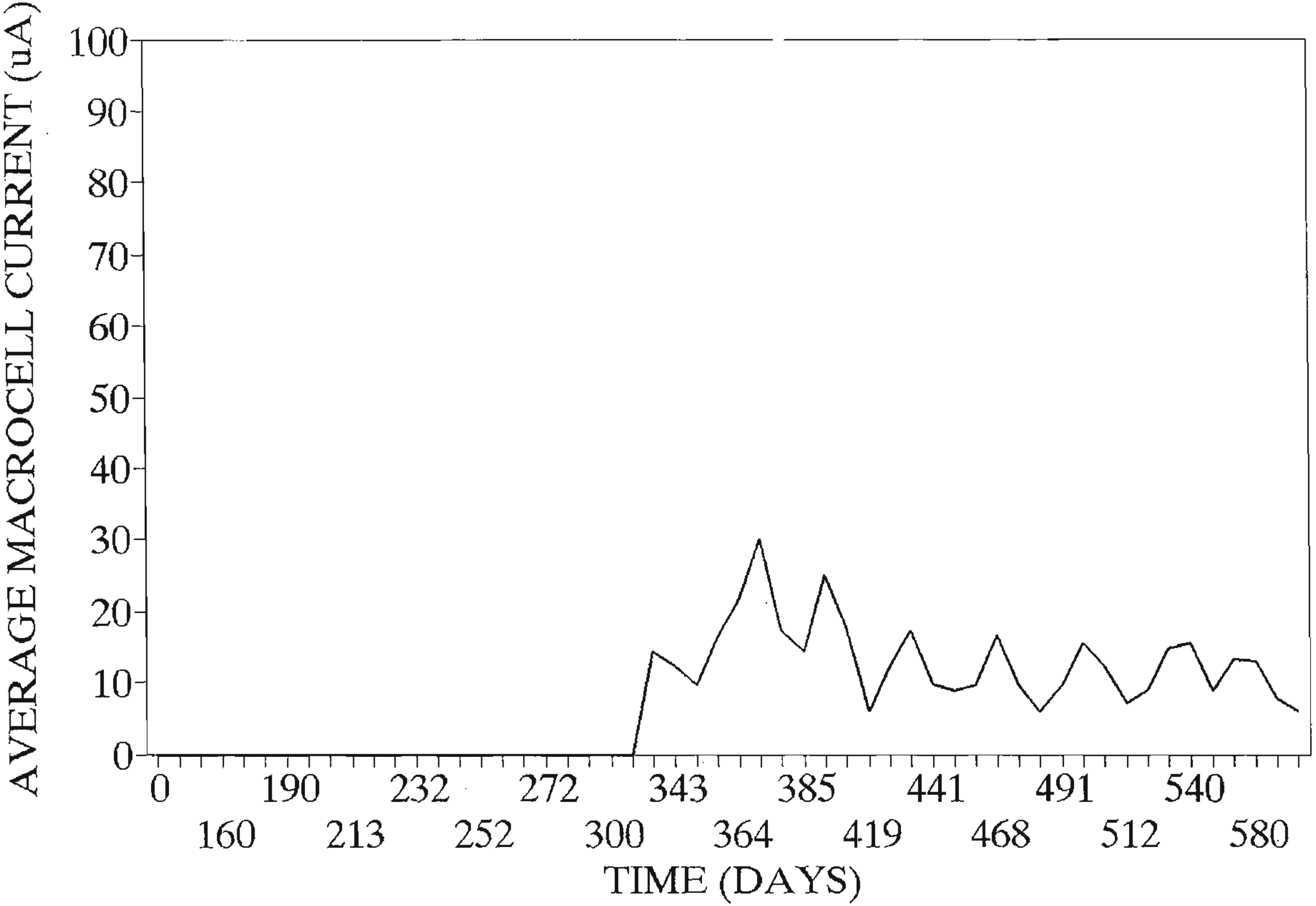
CHEMICAL DE-ICER

CALCIUM CHLORIDE



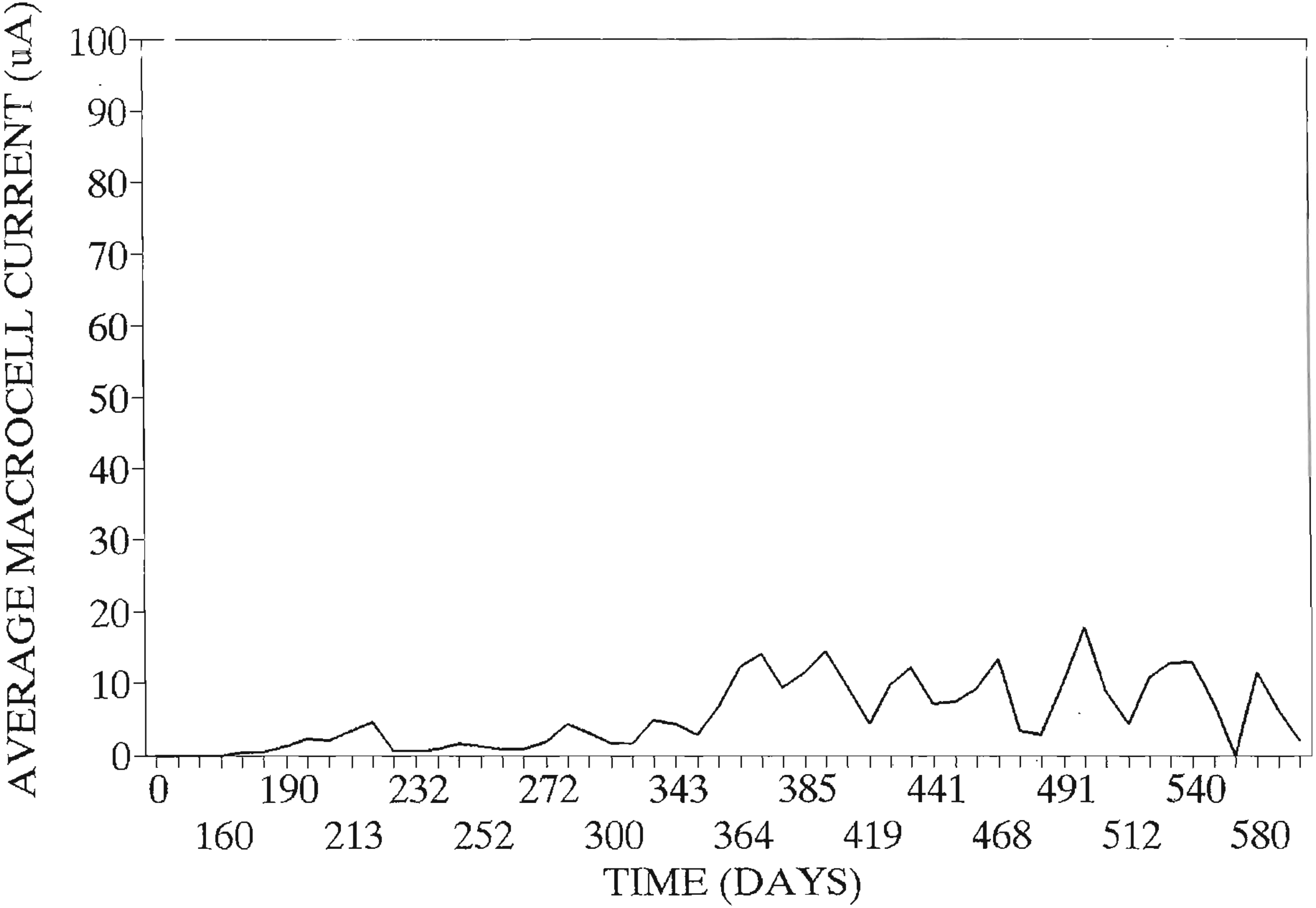
CHEMICAL DE-ICER

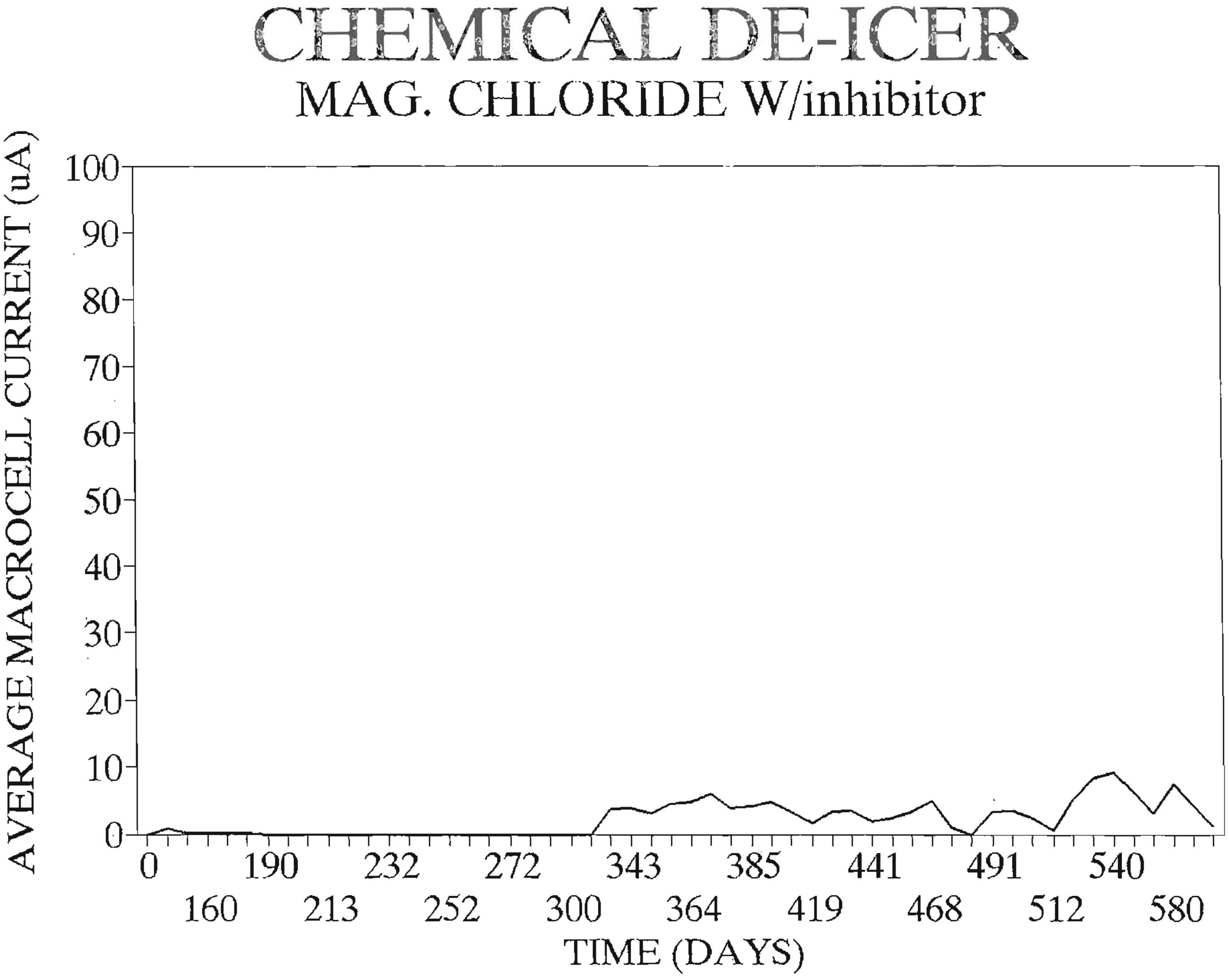
SODIUM CHLORIDE



CHEMICAL DE-ICER

MAG. CHLORIDE




CHEMICAL DE-ICER
MAG. CHLORIDE W/inhibitor
AVERAGE MACROCELL CURRENT (uA)
100
90
80
70
60
50
40
30
20
10
0
0
160
190
213
232
252
272
300
343
364
385
419
441
468
491
512
540
580
TIME (DAYS)

CHEMICAL DE-ICER

CMA