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FINAL REPORT

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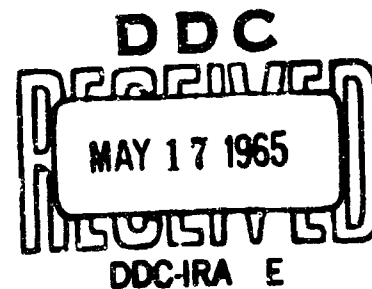
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**CHEMICAL MEANS FOR
PREVENTION OF ACCUMULATION
OF ICE, SNOW, AND SLUSH ON RUNWAYS**

MARCH 1965



This report has been approved for general availability.

PREPARED FOR

FEDERAL AVIATION AGENCY
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

BY

MONSANTO RESEARCH CORPORATION

DAYTON LABORATORY
DAYTON, OHIO 45407

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CHEMICAL MEANS FOR PREVENTION OF ACCUMULATION OF ICE, SNOW, AND SLUSH ON RUNWAYS

March 1965

Prepared by

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This report has been prepared by Monsanto Research Corporation under Contract No. FA-WA-4577 for the Systems Research and Development Service, Federal Aviation Agency, under the technical supervision of Mr. Arthur Hilsenrod, SRDS Project Manager. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA. This report does not constitute a standard, specification or regulation.

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ABSTRACT

The objective of this contract was to develop a mixture capable of melting snow, ice, and slush at temperatures as low as -10°F . This mixture was to be of reasonable cost, be noncorrosive to aircraft and not cause deterioration of runway pavements. Nine primary deicers were tested and many mixtures of them were subjected to primary and secondary screening. These mixtures were then combined with potential corrosion inhibitors and by a simple screening test the kind and amount of inhibitor needed was determined. Minimized corrosion and particularly that of stress corrosion of high strength alloys used in aircraft landing gear was verified by a constant load test procedure. Two surviving candidate mixtures were demonstrated as easily prepared in simple, standard mixing equipment, and their storage characteristics as free flowing granules determined at two temperature extremes. The application rate to produce melting at -10°F was quite nominal (2 oz/ft^2), and the compositions had at most slight spalling effect on concrete. The prime candidate for runway deicing has the following composition: Tripotassium phosphate 75% - formamide 25%. These materials are commercially available, and while their cost exceeds that of calcium chloride, the combination does not cause the extent of corrosion obtained with calcium chloride. While less satisfactory because of stress corrosion characteristics, a second combination proved outstanding for preventive corrosion of steel not under the potentially high stress of landing gear. Quite suitable for road or highway usage was calcium chloride to which was added 1% by weight of Emulsifier STH. This composition retained all its ice-melting qualities with marked corrosion control. Because of the outstanding ice-melting and corrosion-controlled properties of the recommended runway deicer, and its superiority in these qualities to now available composition, it should be field tested.

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INTRODUCTION

One important and as yet uncontrolled seasonal factor in landing and take-off of aircraft is management of ice, snow and slush on runways. A recently issued report (Federal Aviation Agency Contract FA-WA-4685 - see page H-1) estimated the penalties incurred through these winter runway hazards to both airports and airport users. The estimated costs to the airports and airport users included those for removal, while those to the airlines comprised delays, diversions, cancellations and accidents. This survey of eight busy airports showed removal costs totaling \$900,000, estimated to rise to \$3 to \$4.5 million by 1975-76. The total dollar penalties to airlines were estimated to lie between five to six times that suffered by the airports themselves. This survey did not include military airports and an unknown number of civilian airports which must also be serviced to maintain them in ready-condition. In brief, this removal problem is a serious one which will grow in magnitude and for which a satisfactory solution is needed.

Snow, slush and ice removal is not a new problem, and has generally been accomplished by mechanically removing the first two. Mechanical removal of ice is much more difficult. Ice may be removed by heating, followed by draining, brushing, or sweeping the thawed surface. Another means less frequently used by airports is chemical application, causing the iced surface to melt. This latter is frequently a most effective means for liquefying these three offending materials provided that corrosion of equipment, induced by the deicer, is a negligible factor. Heretofore, highway or street usage of salt, calcium chloride, or their combinations has been countenanced, although corrosion of vehicles, equipment, and structures has occurred. Even this usage has come under scrutiny, and the Highway Research Board is sponsoring a contract aimed at reducing such corrosion by suitable inhibition.

Snow and slush can most effectively be removed by mechanical methods when in a dry or semifluid state. When snow becomes packed, or slush solidifies, or sheet ice is formed, a temperature range probably exists at which little thawing occurs. It is here that supplementary methods become necessary.

Where sheet ice is formed, it is possible to make the surface rough enough to maintain effective aircraft-braking by embedding uniformly sized grit in the ice. Application of grit may be made by flamethrower to melt the surface ice,

applying heated grit, or watering the grit with a fine water spray. However, potential difficulty may be encountered from engine ingestion of grit, or in complete removal following thaw. Ice control by sand application is said to be used by the Canadian Air Force.

Were it possible to embed heating coils in the field surface, this would effectively solve the difficulty if run-off facilities were adequate, and high cost relatively unimportant. However, the cost and maintenance of such systems appear to be relatively more costly.

On contract with the U. S. Air Force, Monsanto Research Corporation evaluated a number of runway deicer candidates (Technical Memorandum ASRCE TM-62-10, 6 June 1962), with particular emphasis of deicer effect on corrosion of high strength steel and aluminum alloys used in landing gear. These stress corrosion tests demonstrated the relative effects of a candidate deicer.

Monsanto Research Corporation under contract to the Federal Aviation Agency undertook to develop a mixture of chemicals which by proper application would melt ice or snow to permit run-off before accumulation in restrictive quantities. Our approach was two-pronged: selection of materials which though reasonably effective, had some deficiency such as corrosion to be overcome by proper inhibition, and combination of materials to capitalize upon their hopefully synergistic effects.

A literature search was made and included in the search was a study by the U. S. Naval Engineering Research and Evaluation Laboratory ("Deicing Materials for Military Runways," Project NY 000003-402, Technical Memorandum M-124) that provided a definitive basis for evaluation of potential deicer candidates. Other literature references did not change our technical approach and candidate materials were in general selected on information available on:

- Freezing or slush points of water solutions
- Rate of melting
- Lack of corrosive effect on metals
- Lack of toxicity
- Lack of attack on concrete or asphalt
- Ease of application
- Cost

Commonly available chemical deicers such as salt, calcium chloride, and urea have been used but the first two cause severe corrosion, while the latter is not effective in ice melting at low temperatures. These and other candidate materials were evaluated by a routine designed to minimize technical effort in arriving most expeditiously and economically at successful candidate materials. It was anticipated that commercially available chemicals would be selected which could economically be granulated, packaged, and stored ready for usage. Preparation data and storage stability tests of the remaining few candidate mixtures were also made. Briefly the investigational course followed comprised these main steps:

1. Determination of slush points of single and binary mixtures.
2. Measurement of ice melting rates over a temperature range.
3. Corrosion-inhibiting the effective ice melters and evaluating by a simple immersion test.
4. Stress-corrosion testing those compositions preventing immersion corrosion.
5. Determining effect of inhibited deicer candidates on concrete.

DISCUSSION

Objective

The objective of this program was to develop a noncorrosive deicer mixture effective for liquefying ice at -10°F or below for a reasonable cost and not cause deterioration of runway pavements.

Selection of Deicer Materials

Candidate deicer materials were selected on the basis of:

(1) Freezing or Slush Points of Aqueous Solutions.-- Since most deicers operate by lowering the freezing point of water, it was naturally presumed that they should be water-soluble. Thus, the freezing point of the mixture (ice-water-solute) would be related to the concentration of deicer in solution, and further, the number of ions. Insoluble materials, for example, would be expected to exert no effect other than a slight contribution of stored heat if they have been brought from a heated building.

Although the relative deicing effectiveness of equal weights of materials can be estimated by calculating the freezing point lowering of aqueous solutions, assuming the materials are partly or completely dissociated, it is more reliable to experimentally determine the freezing point (slush point) for a water solution. This gives directly the equilibrium temperature for the system. It does not, however, tell how fast it will be attained.

(2) Rate of Melting.-- Upon dissolving in water, certain materials have an exothermic heat of solution (as for example calcium chloride) while others are endothermic (as urea). It would be desirable if the material would liberate heat in dissolving, as this would assist in the melting operation.

In addition to these effects, if the solid deicer has a high heat content (shown by a specific heat approaching 1.0), it will retain heat from warm storage conditions. This is a potential beneficial effect and aids in melting.

While a material may theoretically melt ice at -25°F , the rate of melting may not be fast enough for practical applications. Hence the rate of melting must be determined or estimated. Rate of melting is strongly dependent on the physical state or the particle size, if a solid, although other factors such as addition of other materials are expected to have an

effect. Even wetting agents and surface active agents should hasten the deicing action. Liquids in general suffer low rates of melting unless agitated with the frozen surface in some manner.

(3) Lack of Corrosive Effects on Metals.- It was recognized that calcium chloride, while one of the most effective deicers, was highly corrosive to metal parts. It was reasonably certain that use of this material would require formulations containing appropriate corrosion inhibitors. These were selected from many types known to industry and effective in small amounts.

(4) Lack of Toxicity.- The materials, either during storage, application, or disposal, were to be no more toxic than calcium chloride.

(5) Lack of Deleterious Effects on Concrete or Asphalt.- It was known that certain salts, such as ammonium nitrate, cause spalling or roughening of concrete surfaces. Since this effect is undesirable, such materials could not be used. Other substances, such as many organic liquids, have undesirable solvent action on asphalt surfaces, and were eliminated.

(6) Ease of Application.- The approach to this problem presumed that conventional highway equipment such as trucks with spreaders would be employed. Thus, solid materials of particle size less than 1/2" in diameter would be used.

(7) Cost.- For large scale application, cost naturally became an important consideration. While it was desirable to work with only the cheapest materials, several of these did not qualify on the basis of one or more of the points given above. With the compilation of the above data for a limited number of materials, the selection of candidates for screening tests as either single-component or mixed formulations were made. To do this, judgment was exercised so that, for example, heat effects received proper emphasis without neglecting cost. In this way, no potentially effective material was eliminated without careful consideration in the early stages of selection. In later stages of selection, cost was a more important criterion. Costs of the raw materials for the selected deicers appear in Table VI, Appendix C. Processing and packaging costs are not included.

After an extensive literature search and consideration of the above characteristics, the following materials were selected as the most promising deicer candidates to be used singly or in combination with any of the other candidate materials:

Calcium Chloride
Sodium Chloride
Acetamide
Ammonium Acetate
Urea

Tripotassium Phosphate
Tetrapotassium Pyrophosphate
Sodium Sulfate
Formamide

Selection of Corrosion Inhibitors

Aqueous corrosion conditions, such as those generated on runways, ramps and taxiways when deicers are used to melt snow, ice or slush, are electrochemical in nature. That is, the corrosion of aircraft components exposed to splashed solutions of deicers is associated with the flow of electric currents. These currents flow between various sites (electrodes) of unequal potentials, through and under the wetted surfaces of the aircraft components. Such potential differences arise from the presence of multi-oriented metal grains, unequal physical stresses, and changes in point-to-point concentration of alloying elements.

While this program concerned development of a noncorrosive ice-melting product, our experience in evaluating the stress-corrosion properties of high strength steels and aluminum alloys indicated that the presence of water (e.g., rain) on runways and exposure to high humidity for extended periods could result in dangerous corrosion to highly stressed aircraft components. Thus, inhibitors developed for use with deicer materials on this project could also be evaluated for usefulness in reducing corrosion damage on a year-round basis. Corrosion resulting from the attack of runway water and humidity on aluminum, as well as on steel aircraft components can result in unpredictable failures.

The principal driving force for the corrosion of metals is the reversible potential developed between the metals and their corrosion products. This is related to the free energy of formation of the corrosion product as shown below*.

$$\Delta F = -23,060 N E_r$$

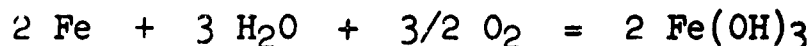
where ΔF is the free energy of formation of the corrosion products, gm.cal.

N is the number of equivalents of electricity that flow through the cell

E_r is the reversible potential, volts

*Hunt, H., Physical Chemistry, p. 523, T. Y. Crowell Co., New York (1947).

For example, when iron corrodes in water in the presence of air (0.21 Atm. O₂), ferric hydroxide is formed according to the following reaction:



The ΔF for this reaction is -80,000 gm.cal./gm. Fe, from which E_r can be calculated:

$$E_r = 80,000/3 \times 23,060 = 1.15 \text{ volts}$$

Obviously, minimizing or eliminating oxygen from the reactive environment would reduce the rusting of iron. An accumulation of Fe(OH)₃ at the anode would accomplish the same task.

In a corrosion circuit at steady state conditions, as in any electrical circuit, the driving force (E_r) must equal the resistive forces. These resistive forces include resistance to the flow of current through the metallic and liquid paths and irreversible electrode polarization effects adjacent to the electrodes. Such irreversible polarization, or back emf effects can be caused by the buildup of gas (e.g., hydrogen) at cathode sites or by the buildup of corrosion products (e.g., iron hydroxide). In other words, the corrosion current is a function of the reversible potential (E_r) for the corrosion reaction, the back emf's at local electrode potential drop due to the electrical resistance of aqueous deicer solution, and the small potential drop due to the flow of current through the low resistance of the metal surface of the aircraft component. The rate of corrosive attack can be modified by controlling the rate of current flow between electrode sites.

Then, by definition, an inhibitor is a substance that reduces the corrosion current. Therefore, an inhibitor should exhibit capabilities for:

1. Reducing the reversible potential (E_r).
2. Increasing the potential of the irreversible polarization or back emf effects.
3. Increasing the resistance to current flow by depositing nonconducting or poorly conducting films over the electrodes.

In its inhibitor research, Monsanto Research Corporation drew on the extensive corrosion technology available in our parent company, Monsanto Company, a major producer of organic and inorganic materials. Specifically, we investigated the use of inhibitors which acted to:

1. Reduce the reversible corrosion potential. Hydrazine and cyclohexylamine, which act to remove oxygen and carbon dioxide from deicer solutions, are examples of the types of materials that were studied.
2. Increase or modify the back emf effects through the use of surfactants that controlled the size of gas bubbles generated at the electrodes.
3. Increase the resistance to current flow through use of films deposited over the electrode surfaces. Materials such as octadecylamine and primary aliphatic amines were investigated as protective film formers.

The foregoing indicates the types of corrosion mechanisms involved and indicates in general the compounds studied.

Available for reference purposes were the extensive Metal Cleaning Bibliographical Abstracts published by the American Society for Testing and Materials*. A complete listing of corrosion inhibitors selected for initial screening is presented in Table II, Appendix A.

It should be emphasized that many of the materials evaluated as corrosion inhibitors were not developed or intended by the manufacturer for the conditions or service to which they were subjected. Any failure or poor performance of an inhibitor was therefore, not necessarily indicative of the utility of this material under less stringent conditions or for other applications.

Screening of Deicer Mixtures

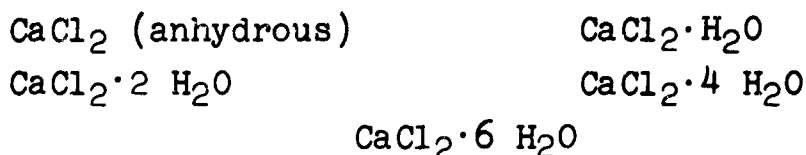
Candidate deicers and mixtures of deicers were screened initially by three simple tests: slush points of saturated aqueous solutions, ice melting ability, and a preliminary corrosion test. Experimentally the tests were quite rapidly and easily performed, and facilitated screening a large number of deicer mixtures including those with added corrosion inhibitors. Detailed descriptions of test methods and equipment are presented in Appendix B.

(1) Slush Points (Freezing Points) of Aqueous Solutions.- Slush points determined for the various deicer mixtures are given in Tables VII and VIII, Appendix C. A slush point of

*ASTM Special Technical Publication 90 et seq. by Jay C. Harris.

-55°F was chosen arbitrarily as a basis for qualifying materials for additional testing. Table I lists twenty deicers and mixtures chosen for melting rate tests at -60°, -30°, and -10°F.

The freezing characteristics of aqueous calcium chloride solutions were quite interesting in that a saturated solution had an indicated slush point of +60°F, while less than saturated solutions had slush points of -60°F. To explain this seemingly inconsistent phenomenon, it was necessary to examine the phase diagram for aqueous calcium chloride solutions. The phase diagram for aqueous calcium chloride solutions is rather complex due to the several hydrates formed, each of which has its own solubility. The various compositions of calcium chloride are:



The behavior of the hexahydrate was of most interest to the deicer program since all of our measurements were made in the region where the hexahydrate is formed. As temperature is increased the solubility of the hexahydrate increases so rapidly that a point is reached at which the water of crystallization of the salt is sufficient for its complete solution. This temperature is 86.6°F and since the composition is the same as that of the solid salt, e.g., one molecule of calcium chloride to six molecules of water, the hydrate will fuse or solidify without change of temperature, and without change of composition, when pressure remains constant, thus giving a false low temperature slush point. When additional molecules of water are present (as in our case) the freezing point of the solution will be lowered. When calcium chloride melts ice or snow it is present at concentrations less than saturation, and melting rather than solidification occurs. In general, the same relationships were also found for sodium sulfate solutions.

(2) Rate of Melting. - Ice melting rates were determined for the selected deicer mixtures at applications ranging from 1/2 - 1/16 pound of deicer per square foot of ice surface. When the mixture permitted, pellets sized to 10-20 mesh were used. Those mixtures that were liquid or very "wet" (slush) were applied in their "as mixed" form.

Table I

MIXTURES SELECTED FOR INITIAL MELTING RATE STUDIES

Composition		Slush Point, °F	Raw Material Cost, ¢/lb.
Calcium Chloride		-60	1.7
Ammonium Acetate		<-84	38.0
Tripotassium Phosphate		<-96	16.5
Tetrapotassium Pyrophosphate		-84	12.6
75% Calcium Chloride	- 25% Acetamide	<-87, <-84	19.5
75% "	- 25% Sodium Chloride	-55	1.6
75% "	- 25% Urea	<-86, <-84	2.5
75% "	- 25% Formamide	<-96	3.9
90% "	- 10% "	-60	2.6
75% Ammonium Acetate	- 25% Acetamide	-77	45.3
75% "	- 25% Sodium Chloride	-86	28.8
75% "	- 25% Urea	<-85, <-94	29.8
25% "	- 75% Tripotassium Phosphate	<-90	21.9
25% "	- 75% Formamide	-77	17.4
25% Sodium Chloride	- 75% "	-69, -66	8.2
75% Tripotassium Phosphate	- 25% "	<-93, <-87	15.0
25% "	- 75% "	-57, -60	12.0
25% Tetrapotassium	- 75% "	-64, -66	11.0
75% "	- 25% "		
75% Sodium Sulfate	- 25% "	<-87, <-93	12.1
		-58, -60	4.7

None of the deicers evaluated proved effective at -60°F, although a few formed a light slush layer at this temperature. The following mixtures had limited melting ability at -30°F. Application was at 1/4 pound per square foot of ice surface.

Mixture	% Ice Melted After 1 Hour @ -30°F
Calcium Chloride	40
75% Calcium Chloride - 25% Acetamide	33
75% " " - 25% Sodium Chloride	17
75% " " - 25% Urea	30
75% " " - 25% Formamide	31
90% " " - 10% "	42
75% Ammonium Acetate - 25% Acetamide	28
75% " " - 25% Urea	20
75% Tetrapotassium pyrophosphate - 25% Formamide	21

When the deicer program was reviewed with Air Force representatives (see Appendix G), it was suggested that a temperature of -10°F would be a more practical target temperature and that 0° to +20°F would perhaps be even more realistic on a broad geographical basis. Emphasis on deicer melting ability was then placed on a -10°F temperature severity.

Mixtures containing calcium chloride were the most effective ice melters as might be expected. However, melts approaching 60% ice melted in one hour were obtained with other formulations.

It was found when application rate (dosage rate) was reduced from 1/4 pound to 1/8 pound per square foot of ice surface that approximately 40% of the deicer melting capability was sacrificed. Optimum dosage of course will depend upon actual usage conditions at a given airport, but at -10°F it appears that dosages of 1/8 to 1/4 pound per square foot would be satisfactory. Reduction to 1/16 pound does not appear feasible at -10°F, although melts of 10% were obtained.

Melting rates and further evaluations of the following mixtures were discontinued because their "as mixed" form froze at all temperatures studied.

75% Formamide	- 25% Ammonium Acetate
75% "	- 25% Sodium Chloride
75% "	- 25% Tripotassium Phosphate
75% "	- 25% Tetrapotassium Pyrophosphate
75% Sodium Sulfate	- 25% Formamide

The most promising remaining deicer mixtures were:

75%	Calcium Chloride	-	25%	Acetamide	
75%	"	"	-	25%	Sodium Chloride
75%	"	"	-	25%	Urea
75%	"	"	-	25%	Formamide
90%	"	"	-	10%	"
75%	Ammonium Acetate	-	-	25%	Acetamide
75%	"	"	-	25%	Urea
75%	Tripotassium Phosphate	-	-	25%	Formamide

Melting rate data are presented in Table IX, Appendix C.

Upon completion of the initial corrosion screening tests, corrosion inhibitors were added to the deicer mixtures with good ice melting capabilities but poor corrosion characteristics, and the melting rate tests repeated. In general, the addition of corrosion inhibitors to deicer mixtures in combination with the amount of hydration incurred during pelletization slightly reduced the melting rates of the selected deicers. Ice melts in the range of 40-60% after one hour at -10°F were obtained and are considered to be satisfactory. Table X presents these melting rate data.

(3) Preliminary Corrosion Test.- A simple corrosion test combining weight-loss with visual examination provided a satisfactory method for screening promising deicer mixtures surviving prior screening tests.

While both high strength aluminum (e.g., 7079 etc.) and steel (e.g., 4340) alloys are used in aircraft components normally exposed to deicer solutions during actual flight operations, we elected to use only AISI 4340 steel specimens for the initial corrosion screening tests. This provided an economical test without sacrificing meaningful data since, in our experience, AISI 4340 specimens develop pitting and other corrosion defects more rapidly and reproducibly than high strength aluminum alloys.

The use of aircraft quality forgings and heat treated transverse-cut specimens provided the reproducible critical grain orientation and sizes representative of those found in actual aircraft components (e.g., landing gear).

Corrosion tests were made with aqueous solutions of the deicer mixtures at various percentages of saturation (10, 50 and saturation).

These initial corrosion tests were very satisfactory for quickly screening deicer mixtures. Mixtures that produced corrosion did so within 48 hours, while deicers causing no

corrosion by then remained essentially corrosion-free for over 200 hours. It was also noted that deicer concentration is inversely proportional to the corrosion rate, i.e., low concentrations give high rates. In all cases where corrosion was visible, the rate exceeded a considered safe rate for steel used in critical applications. These simple corrosion tests indicated that three of the eight deicer mixtures evaluated had excellent corrosion resisting properties. These were:

75% Ammonium Acetate	- 25% Acetamide
75% Ammonium Acetate	- 25% Urea
75% Tripotassium Phosphate	- 25% Formamide

Figure 1 is a photograph showing a typical set of specimens after exposure to test solutions. Note the decrease of corrosion with increasing deicer concentration.

Average corrosion rates for the deicer mixtures are graphically presented in Figure 2. Corrosion rates are tabulated in Table XI, Appendix C. Test repeatability was excellent throughout the evaluation.

Corrosion inhibitors were added to effective deicer mixtures with otherwise excessive corrosion rates and the tests repeated.

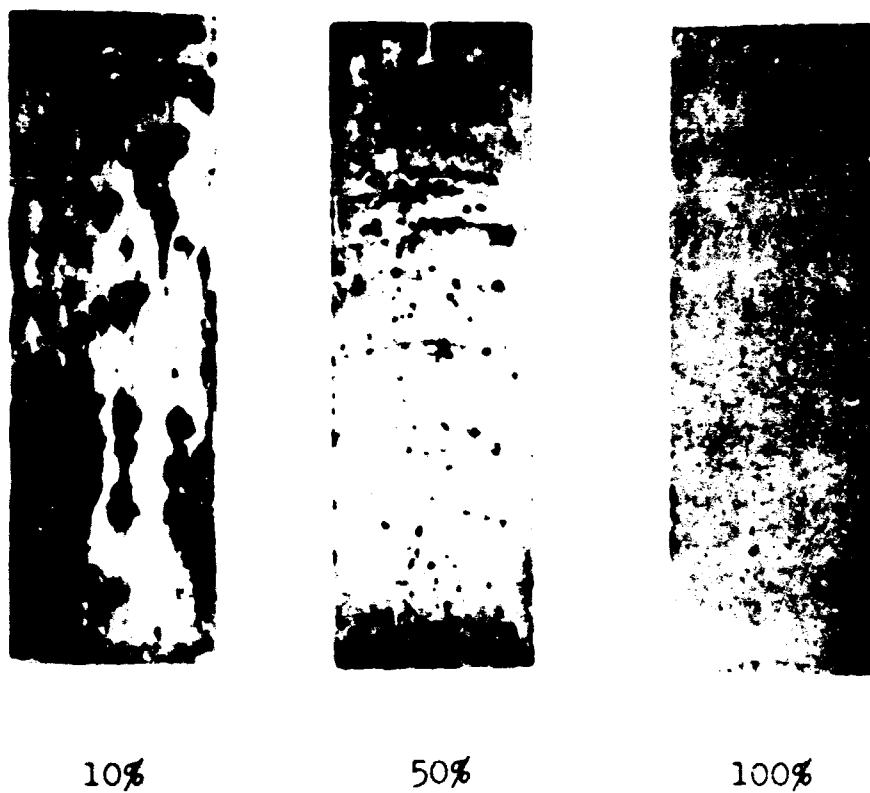
Inhibitors at 0.1 Wt.-% of deicer material were evaluated for effectiveness in the following aqueous solutions:

	<u>% of Saturation</u>
Distilled water + 0.1 Wt.-% inhibitor	
Calcium chloride	10
75% Calcium chloride - 25% Formamide	10
75% Calcium chloride - 25% Urea	10

These mixtures were chosen as representative of deicers that were excessively corrosive but which had excellent melting characteristics. Inhibitors showing promise were then fully evaluated with other promising deicer mixtures.

As inhibitor evaluation work progressed it became apparent that screening with a 10 Wt.-% calcium chloride solution provided data as significant as testing with the other solutions listed above, and testing with those solutions was discontinued.

Corrosion inhibitors were increased to 1.0 Wt.-% and evaluated using aqueous deicer solutions and alternate immersion of AISI 4340 flat steel test specimens. A complete summary of inhibitor data is presented in Tables XII and XIII, Appendix C.



Deicer Saturation in Water Solution

Figure 1. Typical Corrosion Screening Test Specimens.
(4340 Steel)

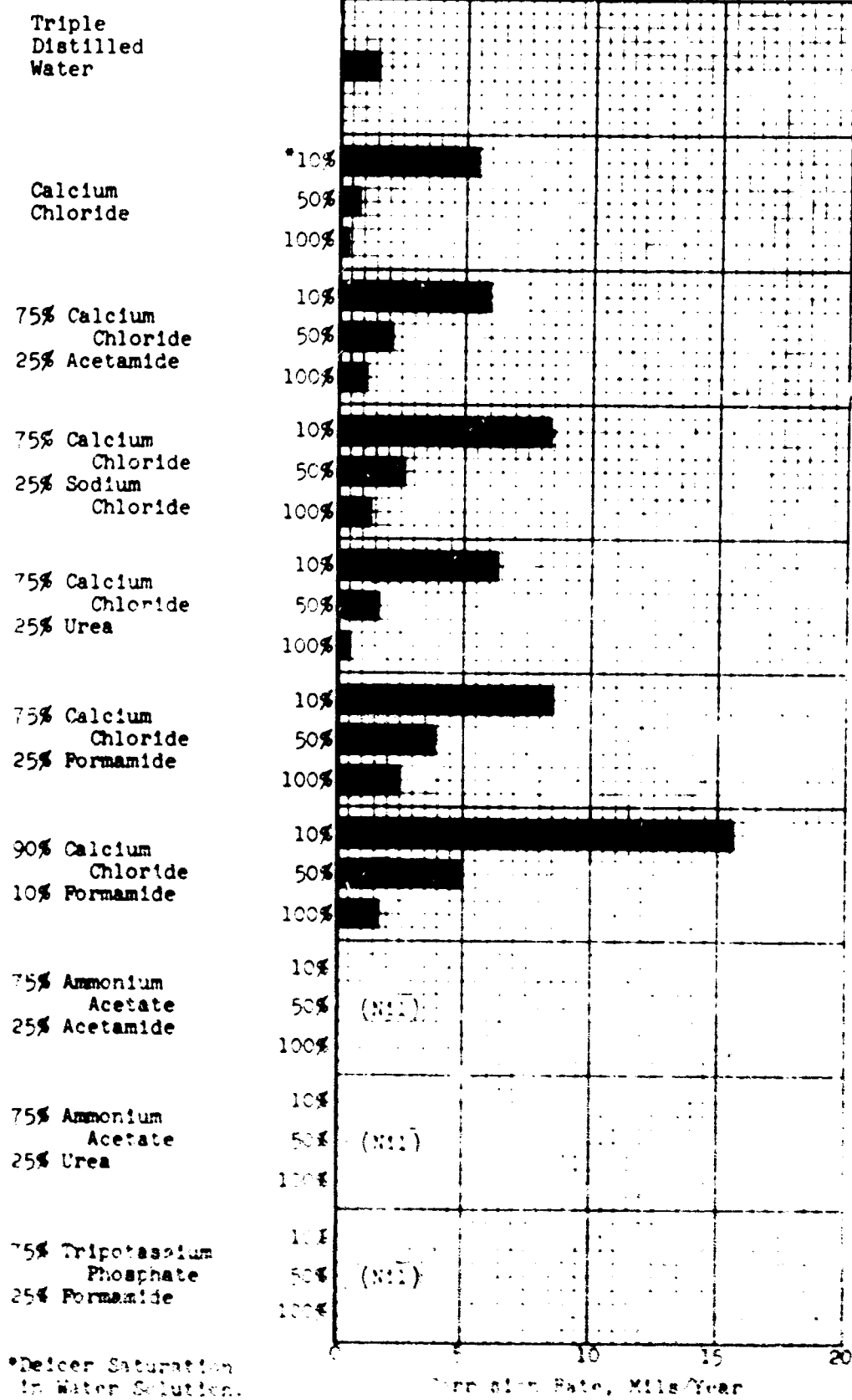


Figure 2. Average Corrosion Rates (4340 Steel)

Eight of the inhibitors were added to pelletized deicer mixtures and evaluated by immersion tests prior to the initiation of stress corrosion tests. The inhibitors were:

Emulsifier STH	Triethylenetetramine
Willimid-513	Ethylenediamine
Victamine-C	Diethylenetriamine
Hercules-Amine D	Textamine-DP

Inhibited deicer mixtures selected for stress corrosion tests were:

<u>Deicer</u>	<u>Inhibitor*</u>
Calcium Chloride	Emulsifier STH Textamine-DP Santolube 203-B Santolube 203-C
75% Calcium Chloride 25% Sodium Chloride	Emulsifier STH Santolube 203-B Santolube 203-C
90% Calcium Chloride 10% Formamide	Emulsifier STH Santolube 203-B Santolube 203-C
75% Calcium Chloride 25% Urea	Emulsifier STH Triethylenetetramine Santolube 203-B Santolube 203-C

*1.0 Wt-% of deicer.

Stress Corrosion

Many aircraft parts are highly stressed and some (landing gear, etc.) are particularly vulnerable to exposure to deicing mixtures applied to runways and the aqueous solutions formed by deicers with melting ice or snow. Before deicing materials can be safely recommended, the effects of stress in combination with exposure to deicer solutions must be determined. Stress corrosion cracking, by definition, is the spontaneous cracking that results from the combined effects of stress and corrosion. Stress corrosion cracking occurs only when surface stresses are in tension.

Structural components such as landing gear are made from alloy steel, heat treated in such a manner as to produce tempered martensite. Unfortunately, such a metallurgical structure is susceptible to hydrogen embrittlement and notch sensitivity as well as stress corrosion cracking. The structure contains residual stresses resulting from both thermal and assembly procedures. Machining and grinding also contribute to residual stresses. Because it is difficult to accurately determine residual stresses nondestructively in test specimens, stress corrosion tests are usually run under direct tension loading. However, for sheet or thin stock material, it is cheaper and easier to use the constant deflection method where the specimen is rigidly held in a fixture at a predetermined deflection.

In November of 1957, the Materials Advisory Board of the National Academy of Sciences requested that the AIA/Aerospace (then Aircraft) Research and Testing Committee (ARTC) establish industry standard methods for the evaluation of stress corrosion susceptibility in three classes of steels. It was suggested that first priority be given to the semi-austenitic, precipitation hardening grades.

In response to this request, the ARTC established Project W-98 to prepare the test procedures. The objective of this project was defined as the preparation of a laboratory method which would be an accelerated test procedure for the evaluation of the stress corrosion susceptibility of the semi-austenitic precipitation hardening steels. The method that was developed was based upon industry's experience with other materials and related laboratory methods. The resulting test procedure was published as Report No. ARTC-21, "Test Procedure for Evaluation of Stress Corrosion in Precipitation Hardening Semi-Austenitic Stainless Steels," dated 15 October 1959.

The testing involved the correlation of ring and strip specimens as well as salt spray, alternate immersion and natural exposure environments. The tests were designed to evaluate the consistency of the tests within individual laboratories and their repeatability between different laboratories. The adequacy of calibration instructions and techniques for both specimen configurations was evaluated.

The results showed that the strip specimen appeared adequate and provided apparently reliable repeatable data. The ring specimen, however, gave inconsistent results and the repeatability of the data was poor.

As ARTC found testing of strip specimens satisfactory for evaluating stress corrosion susceptibility of precipitation hardened semi-austenitic stainless steels, this type of

specimen was selected to supplement the tensile type evaluation of 4340 (martensitic) alloy steel. However, residual stresses vary from specimen to specimen and the constant deflection (bent beam) method is probably less accurate than the direct load method.

A brief summary of advantages and disadvantages of each type of stressing follows:

<u>Direct Load</u>	<u>Bent Beam (Deflection)</u>
Specimen preparation expensive	Specimen preparation less expensive
Expensive test equipment required	Very little test equipment required
Initial stress known - generally increases with time	Initial stress known - generally decreases with time
Number of concurrent tests limited by expensive test stand requirement	Large numbers of tests can be run concurrently
Test periods relatively short and test data generated fairly quickly	Test periods much longer - could run into years in some instances
Excellent control of test conditions	Test conditions not defined as well
General overall corrosion held to minimum during test due to short exposure times	More general overall corrosion due to longer exposure times

For a program limited by time, the direct loaded tensile specimen method offers considerable advantage over the bent beam method because of the much shorter test period required.

A disadvantage of the deflection or bent beam test is that the stressed specimens once loaded, with time can and do relax. This would significantly reduce the stress conditions, with consequent apparently greater resistance to stress corrosion. In contrast, static loading maintains the stresses and consequently is a more severe, indicative, and thus more reliable test method.

In summary, there is no ideal or generally accepted stress corrosion test method at present and the method selected must be based on metal composition, form (roll, cast, forged) and the strength level required for a given service application.

For the requirements of the deicer program, it was found that the direct load (tensile) test gave reliable data, and in a comparatively short time. Data obtained by this test method are presented in Tables XV and XVI, Appendix D. A detailed description of the test procedure appears in Appendix B, section 5.2.1. Both AISI 4340 steel and 7079-T6 aluminum specimens were tested though only deicer mixtures with promising steel corrosion properties were evaluated with aluminum specimens.

Two of the inhibited mixtures (calcium chloride + 1 Wt-% Emulsifier STH and calcium chloride + 1 Wt-% Textamine DP) showed some initial promise based on total stress time (4340 steel) to failure. However, the spread in test results indicated that these mixtures would not be satisfactory for use on aircraft runways without additional corrosion inhibition, with no good inhibitor candidates available. These mixtures were much less corrosive than calcium chloride alone and would probably be acceptable for usage where only ground equipment (not highly stressed) would be exposed to the deicer or for normal highway usage replacing calcium and sodium chlorides.

The following mixtures were also tested and the results for the phosphate mixture were satisfactory without need of further inhibition.

75% Tripotassium Phosphate	- 25% Formamide
75% Ammonium Acetate	- 25% Urea
75% Ammonium Acetate	- 25% Acetamide

Direct loaded aluminum (7079-T6) specimens were exposed to aqueous solutions (10% of saturation) of tripotassium phosphate-formamide and ammonium acetate-urea. Distilled water and an aqueous solution (10% of saturation) of calcium chloride were also included for comparison. No failures occurred with the specimens exposed to distilled water, tripotassium phosphate-formamide and ammonium acetate-urea in over 200 hours. Specimens exposed to calcium chloride failed between 33 to 120 hours.

Stress corrosion tests with the bent beam type specimen (4340 steel) were limited to two environments, distilled water and an aqueous calcium chloride solution (10% by weight). None of the specimens exposed to distilled water for a total cyclic period of 170 hours failed. One specimen out of fifteen failed in the calcium chloride solution after 146 hours of cyclic exposure.

General corrosion was very heavy on all specimens as shown in Figures 3 and 4. This corrosion may have been sufficient to lower or relax the stresses in the specimens to such a point that very long exposure times would be required for complete failure to take place. Since the failure time for the one flat strip was over ten times that of the direct loaded tensile bars under constant load, bent beam testing was discontinued at this point.

Concrete Compatibility

Test procedures are detailed in Appendix B, Section 6.

Fifty freeze-thaw cycles (-10°F to ambient, $75 \pm 3^{\circ}\text{F}$) were completed with light scaling observed for those blocks exposed to 75% tripotassium phosphate-25% formamide and 75% ammonium acetate-25% urea. The blocks exposed to calcium chloride and distilled water were relatively free from scaling.

This scaling effect was primarily loss of the thin concrete layer covering larger aggregate materials near the surface.

Although scaling was not severe, this potential problem area should probably be more thoroughly investigated prior to uncontrolled field use.

Table XVII, Appendix E, presents a summary of the data and Figures 10-12, Appendix E, show the blocks at test completion.

Formulation and Storage Characteristics

(1) Formulation. - Density of a deicer is a recognized factor in the deicer's ability to contact and penetrate the ice surface. Since deicer materials should be readily and highly water-soluble, a dense form is preferred to a light or fluffy form. Depending upon the candidate deicer materials, various standard mixing, compacting, crushing, screening, or other unit processes were employed, with equipment already on site.

In developing an optimum formulation and in selection of prime candidate deicers, the problem of commercial production was kept in mind. With knowledge of the production technology for calcium chloride, urea, and other possible candidate components, the inclusion of additive in a melt, drying, prilling, or other product granulating procedure was considered. To

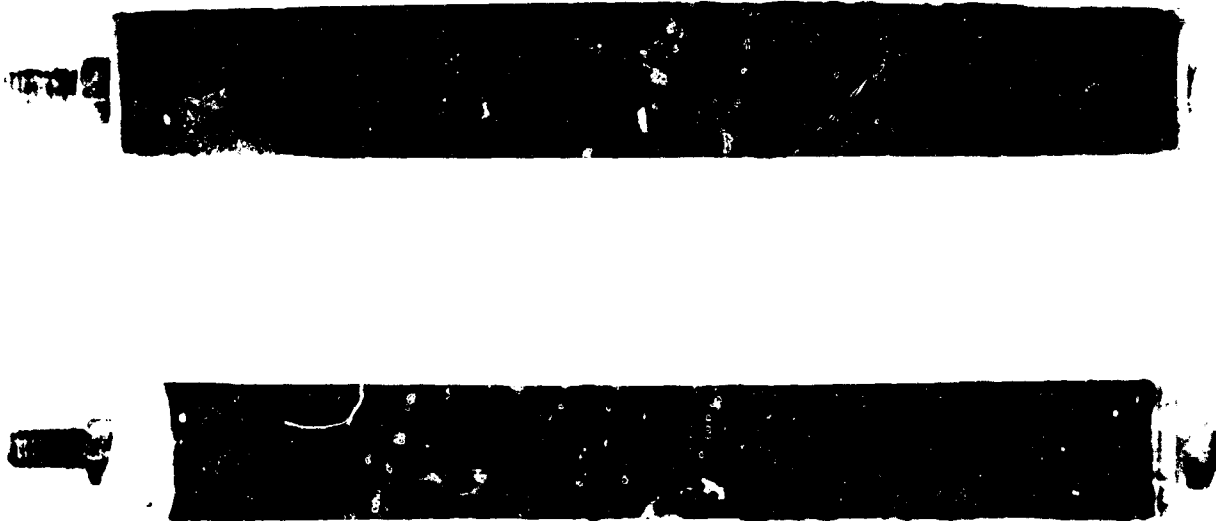


Figure 3. Bent Beam Specimen (Front and Back) Exposed to 10% Calcium Chloride Solution (146 Hours).



Figure 4. Bent Beam Specimen (Front and Back) Exposed to Distilled Water (170 Hours).

be acceptable, in addition to ice melting capacity, water-solubility, storage stability, and other physical properties, the composition had to be capable of being prepared economically, without considerable new plant capital expense, and preferably in an existing process.

Once the prime candidates were developed, it was necessary to prepare sufficient amounts conforming to particle size requirements (4-10 mesh) for use in packaging and accelerated storage tests. Particle sizes of the mixtures were kept as nearly identical as possible to minimize the number of points of contact as small particles intermingled with larger particles can lead to a caking condition. A very small amount of caking inhibitor (drying agent) was used when necessary to produce satisfactory granulation.

Dry deicer candidate mixtures with/without corrosion inhibitors were "pelletized" or granulated by a process similar to that used by the fertilizer industry. This process forms granules from powdered material by moistening the material with water, solvents, or binding solutions with subsequent screening, grinding, or rotary-drying operations, either in the damp condition or in the dry condition or both. With water-soluble mixtures, such as deicer materials, the addition of water alone provided sufficient binding action to form suitably sized granules. Granule size was established by carefully controlling the amount of moisture added to the dry components while mechanically blending the mixtures. This process of adding a moisturizing agent to dry deicer mixtures while mixing them worked well even when only 100 grams of deicer was processed.

Approximately 4-5% by weight of water was required to produce satisfactory granulation. The amount of water added varied slightly, however, from batch to batch because of the hygroscopic nature of the deicers.

Water-soluble corrosion inhibitors were added directly to the water and dispersed in the deicer during granulation. Inhibitors that were not water-soluble were dissolved in a small volume of methanol (mixing solvent) and blended into the dry deicer prior to granulation. Table XIV, Appendix C, summarizes solubility data for each inhibitor when inhibited deicer pellets were dissolved in water for a 10% saturated solution.

Five of the deicer mixtures required the addition of a drying agent before satisfactory granulation could be obtained. The drying agent used was a submicroscopic pyrogenic silica*.

*Cab-O-Sil M-5, manufactured by the Oxides Division of the Cabot Corporation.

This material is reported to be 99.0% pure and to have over 11×10^{15} particles per gram. Drying results were excellent with this material. Table XIX, Appendix F, presents a summary of deicer granulation data, and deicers requiring drying agents are noted. Pellet yields in the 4-10 mesh size range are shown for a 100-gram preparation. Yields should be higher when granulation is performed on a commercial scale.

During the blending of base components (1000-gram batch) for a mixture of 75% tripotassium phosphate and 25% formamide, a strong odor of ammonia was noticed indicating chemical reaction between the two materials. Corrosion and melting tests indicated deicer properties were not affected by this reaction.

(2) Storage Stability.- A multiwall bag* manufactured with an inner ply of free film polyethylene (for moisture resistance) with outer plies of Kraft paper (for low cost strength, handling characteristics, and snag resistance) was selected for the evaluations. Other type bags are available (all plastic, etc.) that probably would be suitable for deicer packaging but were not evaluated.

Pelletized deicer mixtures of 75% tripotassium phosphate-25% formamide and 75% ammonium acetate-25% urea were prepared and packaged in small bags of the type described above. For the purposes of this evaluation the tops of the bags were folded several times and stapled. In practice the tops would be closed by sewing plus heat sealing of the polyethylene inner film. Approximately 2.5 pounds of each deicer were placed in the bags for storage and the bags subjected to a loading approaching 45 pounds/square foot of bag area during storage. This external loading was applied to simulate conditions that might be encountered in warehouse storage.

Storage conditions for the bagged deicers were -10°F , and 100°F at 100% relative humidity. The bags were examined after one week (7 days) storage and the deicers at -10°F were found to be slightly frozen in bags indicating the need for additional drying of the deicers after pelletization before packaging. Samples of the deicers exposed to both storage conditions were removed for melting rate evaluations at -10°F . Table XX, Appendix F, presents these data with original melting rates shown for comparison. Little change in melting efficiency occurred. Melting efficiency after 14 days was comparable with that obtained after 7 days at the test conditions.

*Selected as typical. Supplied by St. Regis Paper Co., Columbus, Ohio.

Samples of the tripotassium phosphate-formamide and ammonium acetate-urea deicers in open containers were placed in a forced air oven maintained at 100°F and allowed to weather for 24 hours. Melting rates at -10°F were determined and as may be seen in Table XX, Appendix F, the melting rate for the tripotassium phosphate-formamide mixture was only slightly retarded while the ammonium acetate-urea mixture lost approximately 30% of its melting efficiency through the exposure.

Deicer Effects on Blue Grass

Aqueous solutions of the 75% tripotassium phosphate-25% formamide and 75% ammonium acetate-25% urea mixtures were prepared at concentrations equivalent to an application of 1/8 pound of deicer/square foot of ice surface when the ice layer is 1/8-inch thick and is assumed to be completely melted. The solutions were applied at one liter/square foot of growing grass. Effects on dormant grass should be obtained during field testing of the deicer. Observations were:

<u>Days After Application</u>	<u>75% Tripotassium Phosphate 25% Formamide</u>	<u>75% Ammonium Acetate 25% Urea</u>
1	Slightly burned	Slightly burned (less than phosphate solution)
2	Tops burned	Tops burned
3	Badly burned	Badly burned
4	No additional change	No additional change
7	Entire treated area completely brown	Entire treated area completely brown

The pH values at various concentrations of the tripotassium phosphate-formamide and ammonium acetate-urea mixtures in aqueous solution were determined. The results are presented in Table XVIII, Appendix E. As may be seen, the mixture of tripotassium phosphate-formamide was strongly alkaline, but below a pH of 12.0, and remained so until the concentration was reduced below 0.01 Wt-%. The ammonium acetate-urea mixture did not change the pH of the water significantly.

Deicer Toxicity

The constituents of the recommended deicer formula exhibit a relatively low degree of potential toxicity. Trisodium phosphate, though rather strongly alkaline in nature, has been used without toxicity complaint in the household for many years as a water softener and cleaner. Tripotassium phosphate used in the deicer composition has essentially identical characteristics. Formamide has a rather ammoniacal odor at high temperatures, but like tripotassium phosphate is relatively nontoxic. Exposure to the skin can be alleviated by ample washing with tap water.

CONCLUSIONS

It is concluded that:

A pelletized runway deicer mixture consisting of 75% tripotassium phosphate-25% formamide was developed which:

1. rapidly melts ice at -10°F and is effective at lower temperatures but at a reduced melting rate,
2. has required application rates that are reasonable ($1/8 - 1/4$ pound deicer/square foot ice surface). Actual required deicer amounts will be dependent upon weather conditions at the time of application,
3. is acceptable stress corrosion-wise with high strength alloys,
4. does not cause excessive deterioration of runway pavements,
5. can be applied with the same equipment as calcium chloride and sand,
6. is nontoxic, and
7. can be manufactured at a moderate price.

Another formulation, ammonium acetate-urea 75-25 mixture, was eliminated from consideration as a runway deicer by stress corrosion and storage stability properties.

Calcium chloride with 1% of an added corrosion inhibitor (Emulsifier JTH) failed to meet the aircraft stress corrosion requirements but otherwise was quite successfully inhibited against steel corrosion, suggesting its application for highway usage.

RECOMMENDATIONS

It is recommended that:

The deicer composition, 75% tripotassium phosphate-25% formamide, be field tested because of its outstanding ice-melting and corrosion-controlled properties.

A more definitive investigation be made of the spalling of concrete surfaces exposed to the deicer mixture.

A P P E N D I X

- APPENDIX A. Corrosion Inhibitors
- APPENDIX B. Test Procedures
- APPENDIX C. Screening of Deicer Mixtures
- APPENDIX D. Stress Corrosion
- APPENDIX E. Effects of Deicers on Concrete
- APPENDIX F. Formulation and Storage Characteristics
- APPENDIX G. Review of Deicer Program with Air Force Representatives
- APPENDIX H. Airport Icing Information
- APPENDIX I. Annotated Bibliography

APPENDIX A

CORROSION INHIBITORS

Table II

CANDIDATE CORROSION INHIBITORSCommercially Available Chemicals

2-Mercaptobenzothiazole	Ethylene dinitrilo
Sodium thiosulfate	Octadecylamine
Sodium nitrite	Triethylenetetramine
Sodium sulfite	Ethylenediamine
Sodium tetraborate (Borax)	Diethylenetriamine
Guanidine nitrate	Guanidine sulfate
Zinc dust	Hydrazine
Sodium aluminate	Melamine

Proprietary Compounds

<u>Description</u>	<u>Trade Name</u>	<u>Manufacturer</u>
Pine resin amine	Hercules Amine D	Hercules Powder Co.
Alkyl ammonium organic phosphate	DuPont RP-2	E. I. DuPont de Nemours
Unconditioned IP-106	-	Monsanto Co.
SAIP 1406	-	Monsanto Co.
Quaternary ammonium compound	Nalquat G-8-13	Nalco Chemical Co.
Quaternary ammonium chloride	Katapone VV-328	General Aniline & Film Corp.
Sodium salt of complex organic phosphate ester	Gafac L0-529	"
Free acid of complex organic phosphate ester	Gafac PE-510	"
Complex resinous fatty amine	Textamine D.P.	Textilana Corp.
Stearamido propyldimethyl- β -hydroxy ethyl ammonium phosphate	Catanac S.P.	American Cyanamid Co.
Fatty imidazoline	Fatchemco 153-0	Universal Chem. Corp.
" "	Fatchemco 153	"
" "	Fatchemco T	"
" "	Fatchemco O	"
Stearyl dimethyl ethyl ammonium bromide	HT-100	Fine Organics, Inc.
Polyoxyethylated alkylamine	Katapol PN-430	General Aniline & Film Corp.

Table II (Cont'd)

Proprietary Compounds

<u>Description</u>	<u>Trade Name</u>	<u>Manufacturer</u>
Sodium salt of N-(alkyl-sulfonyl)- glycine	Emulsifier STH	General Aniline & Film Corp.
Substituted imidazoline	Willimid-412A	Wilson & Co.
Substituted imidazoline	Willimid-313	Wilson & Co.
Substituted amid of alkyl phosphate	Victamine-C	Stauffer Chemical Co.
N-Fatty trimethyl quaternary ammonium chloride	Aliquat-33	General Mills, Inc.
Alkyl benzyl tri- methyl ammonium chloride	Emcol E-12	Witco Chem. Co., Inc.
Fatty amido diamine	Cathol	O. L. King & Co.
N-Fatty propylene diamine	Diam 21-D	General Mills, Inc.
N-Fatty propylene diamine	Diam 26	"
Barium organic sulfonate	Santolube 203B	Monsanto Co.
Barium organic sulfonate	Santolube 203C	"
Organic sulfonate	Santolube 333	"
" "	Santolube 70	"
Organic sulfonate	Lubrizol 344	Lubrizol Corp.
Hindered phenol	Aeronox 9010	American Cyanamid Co.
4,4'-Tetramethyldi- aminodiphenyl- methane	Aeronox MB	"
Amine base	Armohib 28	Armour Industrial Chemical Co.
Petroleum sodium sulfonate	Amoco sulfonate AA, purified	Amoco Chemicals Corp.

NOTE: It should be emphasized that many of the materials evaluated as corrosion inhibitors were not developed or intended by the manufacturer for the conditions or service to which they were subjected. Any failure or poor performance of an inhibitor was therefore not necessarily indicative of the utility of this material under less stringent conditions or for other applications.

APPENDIX B

TEST PROCEDURES

TEST PROCEDURES

1. DEICER CANDIDATES

The following materials were selected as most promising candidates to be used either singly or in combination with any of the other candidate materials. Selection was based upon information gained from an extensive literature search.

Calcium chloride	Tripotassium phosphate
Sodium chloride	Tetrapotassium pyrophosphate
Acetamide	Sodium sulfate
Ammonium acetate	Formamide
Urea	

Binary mixtures of the selected single components were prepared using 100-75-50-25-0 weight percent of each and subjected to a screening plan designed for the early exclusion of candidate mixtures failing to meet deicer and inhibitor requirements.

2. SLUSH POINT OF SATURATED AQUEOUS SOLUTIONS

Saturated aqueous solutions of the candidate materials were prepared by addition of the solute to 100 ml of distilled water until no more would dissolve. The solution was warmed slightly (using hot tap water) and solute was again added until no more would dissolve.

An apparatus to determine multiple slush points was fabricated using a cold bath of dry ice-isopropanol (approximately -110°F), copper-constantan thermocouples and a Brown 12 point recording potentiometer with a selected temperature range of -150° to $+200^{\circ}\text{F}$. Test solutions were poured into 150 ml Pyrex beakers and placed in the cold bath. Figure 5 is a photograph of the slush point apparatus as used for the preliminary screening. The beakers shown in the raised position are in the "melt" cycle of the determination, while those at the lower level are still in the dry ice-isopropanol bath during the "freeze" cycle. Slush points (freezing or melting points) were observed as constant temperature plateaus or in a few instances, when a constant temperature was not obtained, as a marked reduction in the rate of temperature change. This technique proved very satisfactory, generally repeatable within 5°F , and checked manual determination very closely.

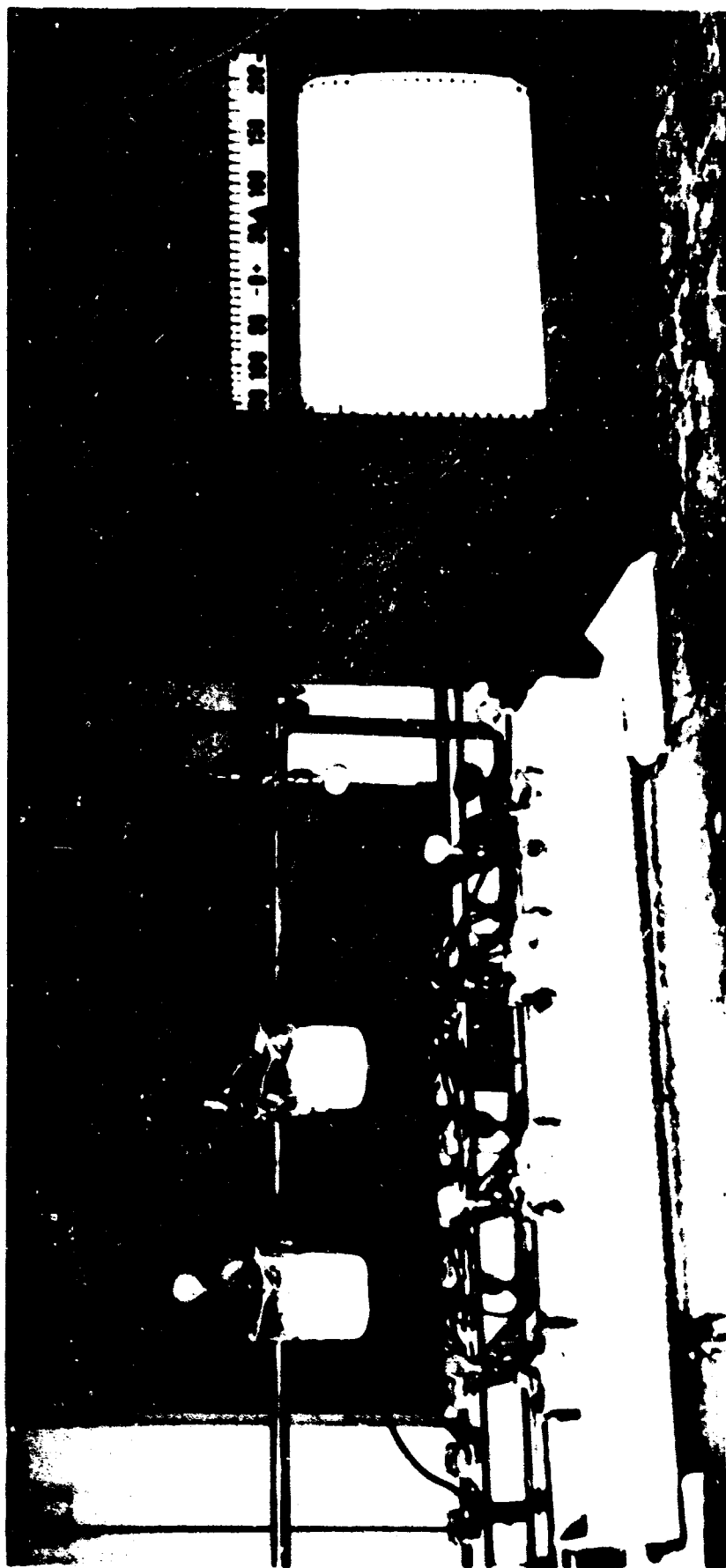


Figure 5. Slush Point Apparatus.

3. DEICER GRANULATION

Because particles of adequate size and of high density can penetrate ice layers more effectively than fine, light powders, many of the deicer mixtures were prepared in granular form.

For initial screening by melting rate, pellets of one-inch diameter and approximately 1/8-inch thickness were made using a hydraulic press, under pressures ranging from 6000 to 12,000 psi. The higher pressures produced pellets giving a smaller amount of fines when crushed and sieved than the pellets formed at the lower pressures. For the purposes of these small scale studies, the pellets were crushed by hand and sieved to obtain particles ranging from 10 to 20 mesh in size. This particle size was used for all melting rate studies except tests with naturally liquid mixtures, solid suspended in liquid, or extremely wet mixtures which were tested in the "as mixed" form.

Deicer mixtures with the most promising ice melting rates were then granulated by a process similar to that used by the fertilizer industry. This process forms granules from powdered material by moistening the material with water, solvents, or binding solutions while under rotation as in a ribbon blender, with subsequent screening, grinding, or rotary-drying operations, either in the damp condition or in the dry condition or both. With water-soluble mixtures, such as deicer materials, the addition of water alone may provide sufficient binding action to form suitable sized granules. Granule size was established by carefully controlling the amount of moisture added to the dry components while mechanically blending the mixtures. The process of adding a moisturizing agent to dry deicer mixtures while mixing them worked well even when only 100 grams of deicer was processed.

Approximately 4-5% by weight of water was required to produce a satisfactory granulation. The amount of water added varied slightly, however, from batch to batch because of the hygroscopic nature of the deicers.

Water-soluble corrosion inhibitors were added directly to water and dispersed in the deicer during granulation. Inhibitors that were not water-soluble were dissolved in a small volume of methanol (mixing solvent) and blended into the dry deicer prior to granulation.

4. MELTING RATE TESTS

Ice planchets were prepared by freezing 10 mls of distilled water at test temperature in a 56 mm x 11 mm Petri dish. The sized (10-20 mesh) deicer mixtures were precooled to test temperature and sprinkled as evenly as possible in the prescribed quantity over the ice surface. Four planchets were prepared for each deicer mixture and dosage. After 15 minutes, one planchet was examined for each mixture and all liquid (at test temperature) was decanted into a graduated cylinder. The recovered water was allowed to warm to room temperature and the volume recorded. The remaining planchets were examined and the water decanted in a similar manner after 30, 45 and 60 minutes.

The mixtures used in the "as mixed" form (liquids or slushes) were not cooled to test temperature before application since they froze into a solid mass at the test temperatures.

Deicer melting rates were established at -60° , -30° , and -10°F using application dosages ranging from $1/2$ to $1/16$ pound deicer/square foot of ice surface area.

5. CORROSION TESTS

5.1 Corrosion Screening Test.- A simple corrosion test in which weight-loss was combined with visual examination provided a satisfactory method for screening promising deicer mixtures.

While both high strength aluminum (e.g., 7079 etc.) and steel (e.g., 4340) alloys are used in aircraft components normally exposed to deicer solutions during actual flight operations, we elected to use only AISI 4340 steel specimens for the initial corrosion screening tests. This provided an economical test without sacrificing meaningful data since in our experience, AISI 4340 specimens develop pitting and other corrosion defects more rapidly and reproducibly than high strength aluminum alloys.

Flat specimens, $1/8"$ x $1"$ x $3"$, were cut from the short transverse direction of a hand forged aircraft quality billet of AISI 4340 alloy. All sides of each specimen were ground to a smooth 16 RMS reproducible finish after being heated to an ultimate strength of 200,000 to 280,000 psi. All edges of each specimen were honed to a nominal $1/64"$ radius.

The use of aircraft quality forgings and heat treated transverse-cut specimens provided reproducible critical grain orientation and sizes representative of those found in actual aircraft components (e.g., landing gear).

The specimens were accurately measured to determine surface area (nominally 1" x 3" x 1/8"), chemically cleaned, and weighed to the nearest 0.1 mg. The specimens were then exposed to continuous alternate immersion (10 minutes in solution, 20 minutes air dry at room temperature) in aqueous test solutions of 10, 50, and 100% deicer saturation. Triple distilled water was used as a control.

After exposure times varying from 40 to over 200 hours, the specimens were cleaned of all corrosion products and reweighed to determine weight loss. Corrosion rates were calculated as mils/year using the equation*:

$$\text{mils/year} = \frac{554 W}{DAT}$$

where: W = weight loss in milligrams
D = density of corrosion specimens, gms/cc
A = area of specimen, square inches
T = time of test in hours

These initial corrosion tests were very satisfactory for screening deicer mixtures quickly. Mixtures that produced corrosion did so within 48 hours, while deicers causing no corrosion remained essentially corrosion-free for over 200 hours. It was also noted that deicer concentration is inversely proportional to the corrosion rate, e.g., low concentrations give high rates.

5.2 Stress Corrosion. - Previous testing on another project indicated that specimens cut in the short transverse direction have too large a spread in mechanical properties to give meaningful stress corrosion test data. Therefore, long transverse test specimens were selected for evaluating candidate deicer materials. Both direct loading (static tensile) and bent beam (constant deflection) specimens were machined and heat treated to an ultimate strength of 260,000 to 280,000 psi which is typical of aircraft landing gear components. They were ground to a final specimen size with a 16 RMS finish.

*Fontana, M. G., Corrosion: A Compilation, 1957, p. 4,
The Press of Hollenback, Columbus, Ohio.

5.2.1 Direct Loaded Tensile Specimens.- The direct loading specimen design used for our tests was that of a miniature ASTM (E8-57T) test bar specimen and is shown in Figure 6.

Figure 7 shows the bank of specially built high load capacity test stands used for these tests. Each stand was equipped with a reservoir arrangement to permit cyclic immersion of the stressed test specimens with an aqueous deicer solution. All deicer mixtures were arbitrarily prepared to a 10% by weight solution in deionized water. The cyclic exposure time was 10 minutes immersion followed by 20 minutes drying time. Each specimen was loaded to the required stress level before any exposure to the deicer solution. Timing mechanisms were started at the beginning of the first immersion cycle.

Mechanical properties of the test specimens were determined by tensile tests and average ultimate and yield strengths were calculated. The individual load for each test stand was calculated based on 80% of the average yield strength (0.2% offset).

The heat treating procedure was:

- a. Heat treated at 1550°F for 1 hour in inert atmosphere.
- b. Quenched in agitated oil at 130°F.
- c. Cold treated at -110°F for 3 hours.
- d. Tempered in air at 400°F for 4 hours.

Aluminum (7079) specimen material was purchased in the T6 condition and required no additional heat treat.

5.2.2 Bent Beam (Constant Deflection) Specimens.- Specimen blanks were cut from the same forging used for the fabrication of the tensile type specimens.

After rough grinding the blanks were heat treated to Rockwell C 50-51 hardness.

The heat treating procedure was:

- a. Preheated at 1200°F in neutral salt for 5 minutes.
- b. Hardened at 1525°F in neutral salt for 5 minutes.
- c. Quenched in agitated oil at 130°F.
- d. Tempered at 400°F for 2 hours.
- e. Air cooled to room temperature.
- f. Cold treated at -110°F for 4 hours.
- g. Warmed to room temperature.
- h. Tempered in salt at 400°F for 2 hours.

Table III

TYPICAL TENSILE TESTS
FOR YIELD POINT DETERMINATIONS

AISI 4340 Steel

<u>Yield, psi</u>	<u>Ultimate, psi</u>
228,600	273,300
228,000	271,300
227,500	271,700
229,800	274,000
231,800	274,600
228,500	275,200
229,200	273,500
Average 229,057	273,371

Specimen Load = 80% of Yield = $0.80 \times 229,100 = 183,300$ psi.

7079-T6 Aluminum

<u>Yield, psi</u>	<u>Ultimate, psi</u>
64,970	75,240
62,790	72,590
61,920	70,820
62,200	72,180
Average 62,970	72,710

Specimen Load = 80% of Yield = $0.80 \times 62,970 = 50,376$ psi.



Figure 6. Miniature ASTM (E8-57T) Test Bar.

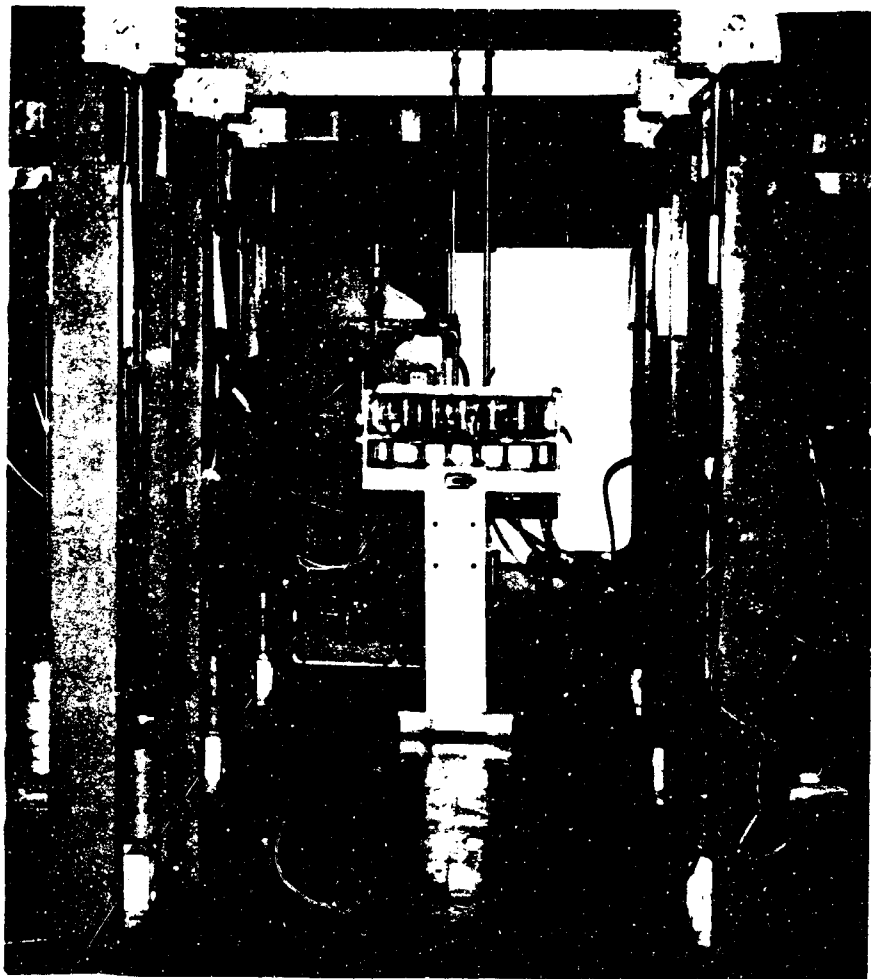


Figure 7. Bank of Stress Corrosion Test Stands.

A jig fixture (Figure 3) was built to align the specimens during loading. Mechanical properties for the test specimens were determined by tensile tests and the average ultimate and yield strengths calculated. Tests were made to establish the relationship of deflection vs. tensile fiber stress by means of strain gages and a dial indicator.

Exposure of the specimens to the deicer media during stress corrosion tests were on a cyclic basis with 10 minutes immersion followed by 20 minutes of draining and drying.

Groups of five flat specimens were run at the same stress levels and corrosion cycles as the tensile bars to provide a direct comparison of test data.

Table IV

MECHANICAL PROPERTIES OF DEFLECTION SPECIMENS

<u>Yield Strength</u> <u>(psi)</u>	<u>Ultimate Strength</u> <u>(psi)</u>
<u>Group I</u>	
205,800	305,100
218,100	279,200
203,400	297,100
208,200	297,100
196,200	301,100
<u>Group II</u>	
216,500	276,900
210,000	279,400
197,800	258,000
*	279,300
*	268,400
Average 207,000	284,200

Group I held with flat grips.

Group II held with steel pin grip.

*Extensometer slipped.

Table V

STRAIN GAGE AND DEFLECTION CALCULATIONS

1. Outer fiber tensile strength

80% of average yield strength (.2% offset)

$$.80 \times 207,000 = 166,000 \text{ psi}$$

2. Modulus of elasticity

Handbook value = 29,000,000 psi

(calculated from stress-strain curve) = 31,000,000 psi

Value used in this work = 30,000,000 psi

3. Strain gage reading calculation

$$\epsilon = \frac{\text{Stress (psi)}}{\text{Strain } (\mu\text{in./in.)}}$$

$$30 \times 10^6 = \frac{16.6 \times 10^4}{\text{Strain}}$$

$$\text{Strain} = 5533 \times 10^{-6} \text{ in./in.}$$

4. Deflections

Deflections were measured by determining the specimen height before and after loading to a strain gage reading of 5530 $\mu\text{in./in.}$

<u>Strain Gage</u>	<u>Deflection</u>
5530 $\mu\text{in./in.}$	1.265
"	1.262
"	1.298
"	1.305
"	<u>1.305</u>
Average	1.287

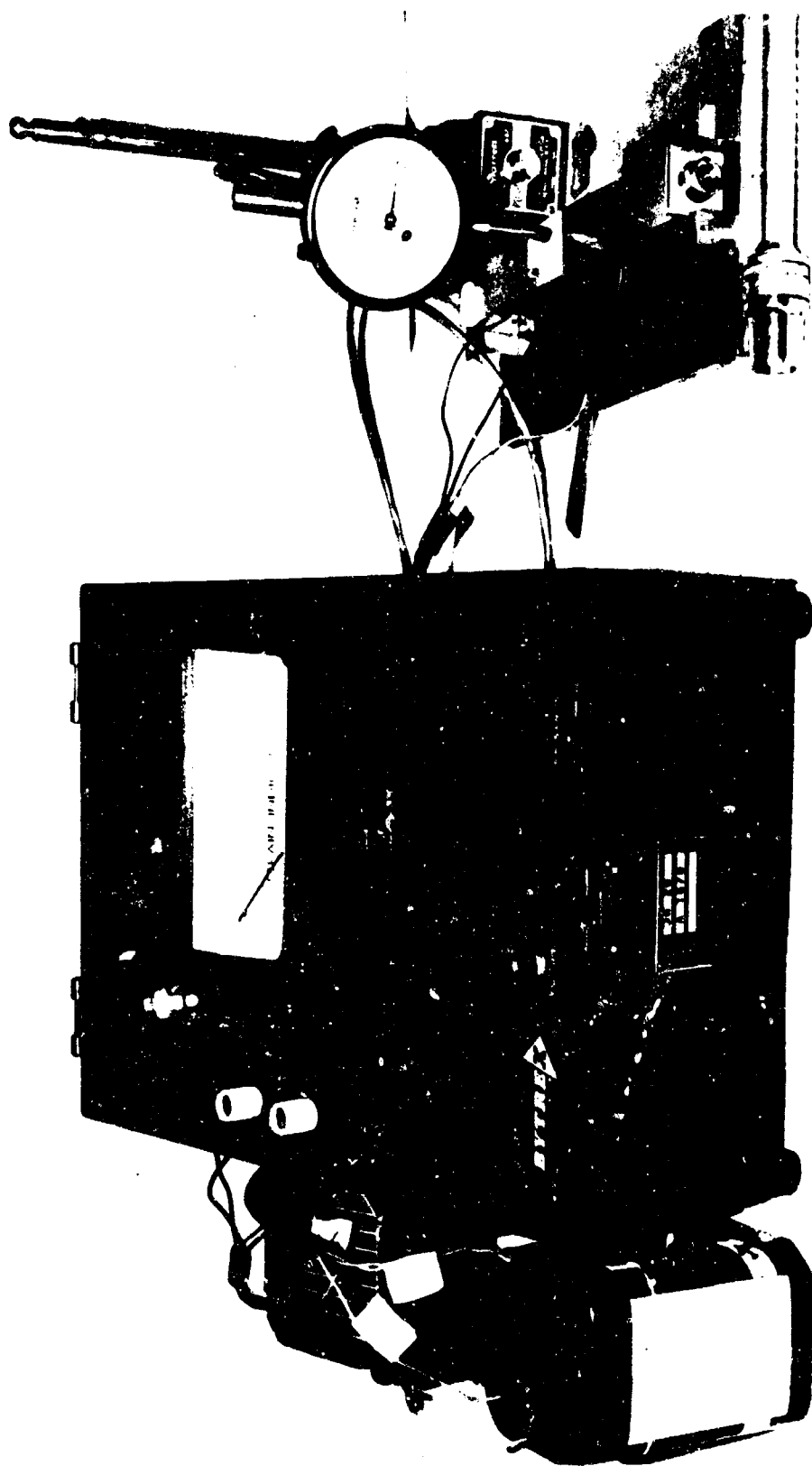


Figure 8. Stress-Deflection Calibration Apparatus.

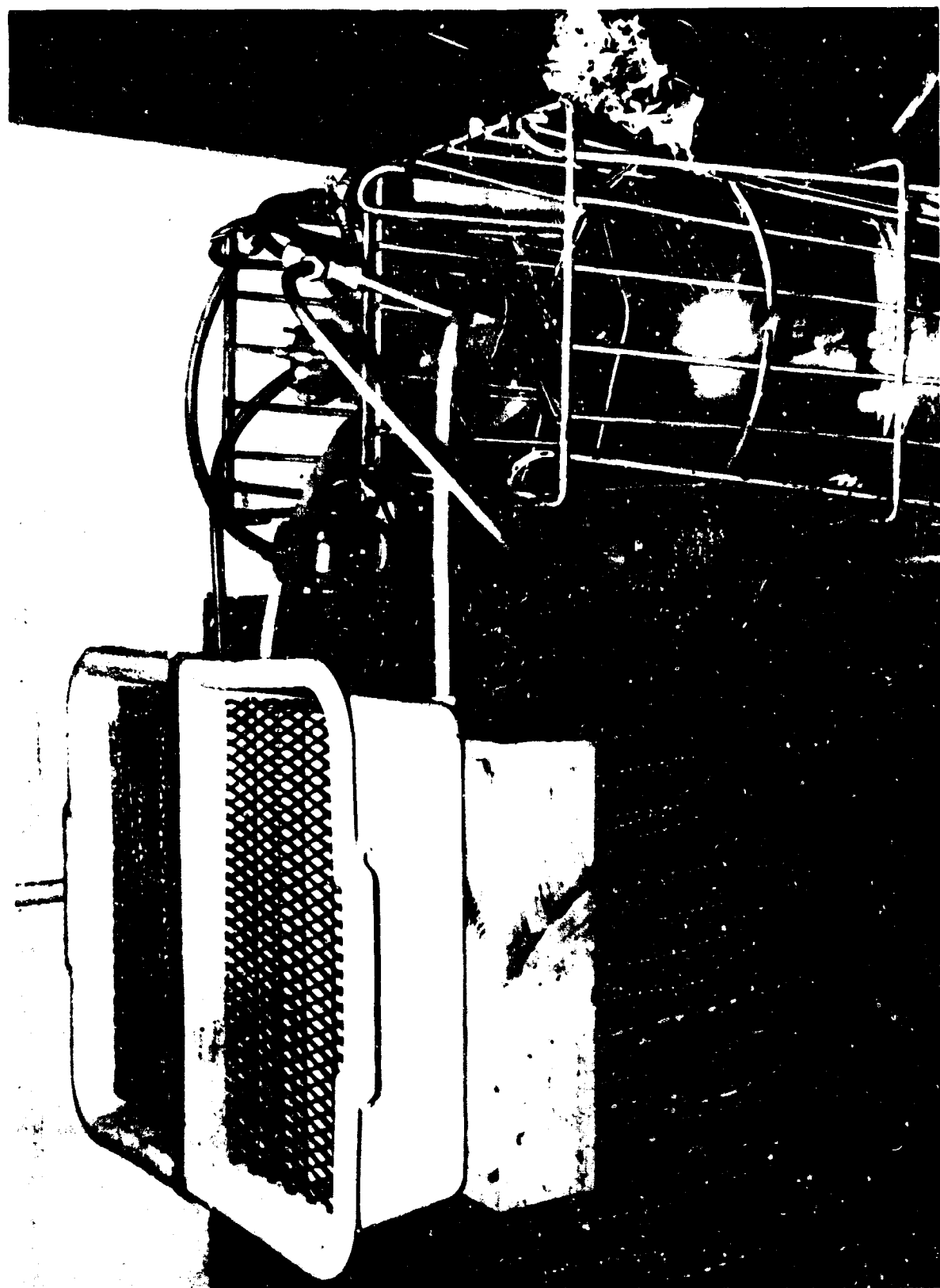


Figure 9. Bent Beam Alternate Immersion System.

6. . CONCRETE COMPATIBILITY

Specimens were prepared from a commercial concrete mix (e.g., Sakrete*, gravel mix) using 6" x 6" x 1-1/2" forms. The bottoms of the forms were lined with a double layer of aluminum foil to provide relative water tightness. The concrete mix/water ratio was that prescribed by the manufacturer. The wet concrete was poured into the forms until they were half full and puddled to remove air bubbles and to insure filling of the corners and edges. Filling of the forms was completed and the specimens were smoothed on the top surface. After approximately one hour, each specimen was given a light broom finish**, brushing in both directions with a stiff whisk broom.

The specimens were kept damp for three days after an initial cure of one day at ambient conditions. After the damp cure period, the specimens were stored at ambient conditions until used.

The test consisted of:

(a) A fixed volume (74 mls) of water was poured onto the specimen and frozen at -10°F in a laboratory cold box. A water depth of 1/8 inch (liquid state) on the specimen surface was obtained by using a rubber retaining dam cut from an old inner tube slipped around the specimen in such a manner to form a reservoir approximately 1/4-inch deep.

(b) Frozen specimens were removed from the freezer and pelletized deicer applied at 1/8 pound/square foot of surface area.

(c) After thawing at ambient laboratory temperature (approximately 75°F), the specimens were washed and the reservoirs refilled with fresh water.

(d) The freeze-thaw cycle was repeated (two cycles/24 hours).

(e) Thaw times and amount of scaling were observed for each cycle.

(f) Two specimens were tested for each deicer mixture evaluated.

*Sakrete, Inc., Cincinnati, Ohio.

**Highway Research Board, Bulletin 323, Effects of Deicing Chemicals on Structures - A Symposium. National Academy of Sciences - National Research Council. Publication 1002.

APPENDIX C

SCREENING OF DEICER MIXTURES

(Slush Point, Melting Rate, Corrosion Screening Test)

Table VI

COST OF BASIC DEICER COMPONENTS

<u>Component</u>	<u>¢/lb</u>
Calcium Chloride ⁽¹⁾	1.7
Acetamide ⁽²⁾	69
Ammonium Acetate ⁽¹⁾	38
Sodium Chloride ⁽²⁾	1.1
Urea ⁽¹⁾	5
Tripotassium Phosphate ⁽²⁾	16.5
Tetrapotassium Pyrophosphate ⁽¹⁾	12.6
Sodium Sulfate ⁽¹⁾	2.7
Formamide ⁽¹⁾	10.5

⁽¹⁾ C & E News, 29 April 1963.

⁽²⁾ Quoted Prices

Table VII

SLUSH POINTS OF SATURATED AQUEOUS BINARY DEICER MIXTURES

		Composition				
Wt. % Calcium Chloride		100	75	50	25	0
Wt. % Other Constituent		0	25	50	75	100
Calcium Chloride						
Slush Point, °F	+60 ^(b)					
Gms/100 mls water ^(a)	111					
Cost, \$/lb	1.7					
Acetamide						
Slush Point, °F	+60	<-87, <-84	-50, -46	-38, -42	-22, -24	
Gms/100 mls water	111	95.5	89.5	99.5	97.5	
Cost, \$/lb	1.7	19.5	35.4	52.2	69	
Ammonium Acetate						
Slush Point, °F	+60	-11, -16	-11, -11	-28, -28	<-84	
Gms/100 mls water	111	58.7	51	60	148	
Cost, \$/lb	1.7	10.8	19.9	28.9	38	
Sodium Chloride						
Slush Point, °F	+60	-55, -55	-21, -19	-8, -12	-5, -7	
Gms/100 mls water	111	55.7	44.6	36.1	35.7	
Cost, \$/lb	1.7	1.6	1.4	1.3	1.1	
Urea						
Slush Point, °F	+60	<-86, <-84	-54	-13, -12	+11, +12	
Gms/100 mls water	111	115	126	131	119.3	
Cost, \$/lb	1.7	2.5	3.4	4.2	5.0	
Tripotassium Phosphate						
Slush Point, °F	+60	-	-	-	<-96 ^(d)	
Gms/100 mls water	111	-	Did not dissolve	-	90	
Cost, \$/lb	1.7	-	-	-	16.5	
Tetrapotassium Pyrophosphate						
Slush Point, °F	+60	-	-	-	-84	
Gms/100 mls water	111	-	Did not dissolve	-	117.5	
Cost, \$/lb	1.7	-	-	-	12.6	
Sodium Sulfate						
Slush Point, °F	+60	-	-	-	+31, +31	
Gms/100 mls water	111	-	Did not dissolve	-	48.8	
Cost, \$/lb	1.7	-	-	-	2.7	
Formamide						
Slush Point, °F	+60	<-96	-54, -52	<-92 ^(e)	+30, +29	
Gms/100 mls water	111	136.5	263.5	300 ^(e)	No water	
Cost, \$/lb	1.7	3.9	6.1	8.3	10.5	
Wt. % Acetamide		100	75	50	25	0
Wt. % Other Constituent		0	25	50	75	100
Calcium Chloride						
Slush Point, °F	-22, -24	-38, -42	-50, -46	<-87, <-84	+60 ^(b)	
Gms/100 mls water	97.5	99.5	89.5	95.5	111	
Cost, \$/lb	69	52.2	35.4	18.5	1.7	
Acetamide						
Slush Point, °F	-22, -24					
Gms/100 mls water	97.5					
Cost, \$/lb	69					
Ammonium Acetate						
Slush Point, °F	-22, -24	-81	-83	-77	<-84	
Gms/100 mls water	97.5	120	140	150	148	
Cost, \$/lb	69	61.3	53.5	45.8	38	
Sodium Chloride						
Slush Point, °F	-22, -24	-41, -45	-38	-19, -17	-5, -7	
Gms/100 mls water	97.5	80	60.4	44.6	35.7	
Cost, \$/lb	69	52.0	35.1	18.1	1.1	
Urea						
Slush Point, °F	-22, -24	-37	-37	-37	+11, +12	
Gms/100 mls water	97.5	165	175	167	119.3	
Cost, \$/lb	69	53.0	37.0	21.0	5.0	
Tripotassium Phosphate						
Slush Point, °F	-22, -24	-26, -25	-19, -16	-30, -25	<-96	
Gms/100 mls water	97.5	72.7	60	65	90	
Cost, \$/lb	69	55.9	42.8	29.6	16.5	
Tetrapotassium Pyrophosphate						
Slush Point, °F	-22, -24	-27	-23	-27	-84	
Gms/100 mls water	97.5	75.5	80.6	72.9	117.5	
Cost, \$/lb	69	54.9	40.8	26.7	12.6	
Sodium Sulfate						
Slush Point, °F	-22, -24	-27, -24	+12, +12	+20, +18	+31, +31	
Gms/100 mls water	97.5	56	45.3	44.2	48.8	
Cost, \$/lb	69	52.4	35.9	19.3	2.7	
Formamide						
Slush Point, °F	-22, -24	-	- Not tested -	-	-	
Gms/100 mls water	97.5	-	-	-	-	
Cost, \$/lb	69	-	-	-	-	

Footnotes listed on page C-6.

Table VII (Cont'd)

		Composition				
Wt. % Ammonium Acetate	100	75	50	25	0	
Wt. % Other Constituent	0	25	50	75	100	
Calcium Chloride						
Slush Point, °F	<-84	-26, -28	-11, -11	-11, -16	+60(b)	
Oms/100 mls water	148	60	51	56.7	111	
Cost, \$/lb	38	28.9	19.9	10.8	1.7	
Acetamide						
Slush Point, °F	<-84	-77	-83	-81	-22, -24	
Oms/100 ml water	148	150	140	120	97.5	
Cost, \$/lb	38	45.8	53.5	61.3	69	
Ammonium Acetate						
Slush Point, °F	<-84					
Oms/100 mls water	148					
Cost, \$/lb	38					
Sodium Chloride						
Slush Point, °F	<-84	-86	-46, -40	-24, -24	-5, -7	
Oms/100 mls water	148	97	62.9	43.2	35.7	
Cost, \$/lb	38	28.8	19.6	10.3	1.1	
Urea						
Slush Point, °F	<-84	<-85, <-94	-59	-20, -16	+11, +12	
Oms/100 mls water	148	256	255.2	115	119.3	
Cost, \$/lb	38	29.8	21.5	13.3	5.0	
Tripotassium Phosphate						
Slush Point, °F	<-84	-26, -22	-22, -30	<-90	<-96	
Oms/100 mls water	148	56.2	59.5	137.2	90	
Cost, \$/lb	38	32.6	27.3	21.9	16.5	
Tetrapotassium Pyrophosphate						
Slush Point, °F	<-84	-13, -10	-30, -25	-46	-84	
Oms/100 mls water	148	45.7	64	100	117.5	
Cost, \$/lb	38	31.7	25.3	19.0	12.7	
Sodium Sulfate						
Slush Point, °F	<-84	+8, +10	+50, +51	+50, +50	+31, +31	
Oms/100 mls water	148	65	57.5	55.1	48.8	
Cost, \$/lb	38	29.2	20.4	11.5	2.7	
Formamide						
Slush Point, °F	<-84	<-92	<-83	-77, -78	+30, +29	
Oms/100 mls water	148	243.5	300(a)	300(a)	No water	
Cost, \$/lb	38	31.1	24.3	17.4	10.5	
Wt. % Sodium Chloride						
		100	75	50	25	
		0	25	50	75	
		100				
Calcium Chloride						
Slush Point, °F	-5, -7	-8, -12	-21, -19	-55, -55	+60(b)	
Oms/100 mls water	35.7	36.1	44.6	55.7	111	
Cost, \$/lb	1.1	1.3	1.4	1.6	1.7	
Acetamide						
Slush Point, °F	-5, -7	-19, -17	-38	-41, -45	-22, -24	
Oms/100 mls water	35.7	44.6	60.4	80	97.5	
Cost, \$/lb	1.1	18.1	35.1	52.0	69	
Ammonium Acetate						
Slush Point, °F	-5, -7	-24, -24	-46, -40	-86	<-84	
Oms/100 mls water	35.7	43.2	62.9	97	148	
Cost, \$/lb	1.1	10.3	19.6	28.8	38	
Sodium Chloride						
Slush Point, °F	-5, -7					
Oms/100 mls water	35.7					
Cost, \$/lb	1.1					
Urea						
Slush Point, °F	-5, -7	-14	-12	-12	+11, +12	
Oms/100 mls water	35.7	46	69.5	140.5	119.3	
Cost, \$/lb	1.1	2.1	3.1	4.0	5.0	
Tripotassium Phosphate						
Slush Point, °F	-5, -7	-10	-11	-2, 0	<-96	
Oms/100 mls water	35.7	47.6	41.7	55	90	
Cost, \$/lb	1.1	5.0	8.8	12.7	16.5	
Tetrapotassium Pyrophosphate						
Slush Point, °F	-5, -7	-10	-11, -12	-6	-84	
Oms/100 mls water	35.7	15	22	55	117.5	
Cost, \$/lb	1.1	4.0	6.9	9.7	12.6	
Sodium Sulfate						
Slush Point, °F	-5, -7	-6	-7	-7	+31, +31	
Oms/100 mls water	35.7	37.8	38	42.5	48.8	
Cost, \$/lb	1.1	1.5	1.9	2.3	2.7	
Formamide						
Slush Point, °F	-5, -7	-27	-32, -30	-69, -66	+30, +29	
Oms/100 mls water	35.7	44.3	69.5	157	No water	
Cost, \$/lb	1.1	3.5	5.7	8.2	10.5	

Footnotes listed on page C-6.

Table VII (Cont'd)

		Composition				
Wt. % Urea	100	75	50	25	0	
Wt. % Other Constituent	0	25	50	75	100	
Calcium Chloride						
Slush Point, °F	+11, +12	-13, -12	-54	<-86, <-84	+ (t)	
Oms/100 mls water	119.3	131	126	115	111	
Cost, \$/lb	5.0	4.7	3.4	2.5	1.7	
Acetamide						
Slush Point, °F	+11, +12	-37	-37	-37	-22, -24	
Oms/100 mls water	119.3	167	175	165	97.5	
Cost, \$/lb	5.0	21.0	37.0	53.0	69	
Ammonium Acetate						
Slush Point, °F	+11, +12	-20, -16	-59	<-85	<-84	
Oms/100 mls water	119.3	115	255.2	256	148	
Cost, \$/lb	5.0	13.3	21.5	29.8	38	
Sodium Chloride						
Slush Point, °F	+11, +12	-12	-12	-14	-5, -7	
Oms/100 mls water	119.3	140.5	69.5	46	35.7	
Cost, \$/lb	5.0	4.0	3.1	2.1	1.1	
Urea						
Slush Point, °F	+11, +12					
Oms/100 mls water	119.3					
Cost, \$/lb	5.0					
Tripotassium Phosphate						
Slush Point, °F	+11, +12	0, -1	-3, -4	-38	-36	
Oms/100 mls water	119.3	110	100	75.5	97	
Cost, \$/lb	5.0	7.9	10.8	13.6	16.5	
Tetrapotassium P ₂ rophosphate						
Slush Point, °F	+11, +12	+3, +2	-10, -10	-26, -28	-34	
Oms/100 mls water	119.3	113	116.5	109.3	117.5	
Cost, \$/lb	5.0	6.9	8.8	10.7	12.6	
Sodium Sulfate						
Slush Point, °F	+11, +12	+9	+9	+8	+31, +31	
Oms/100 mls water	119.3	110	99.1	54.5	48.8	
Cost, \$/lb	5.0	4.4	3.9	3.3	2.7	
Formamide						
Slush Point, °F	+11, +12	-	- Not tested -	-	-	
Oms/100 mls water	119.3					
Cost, \$/lb	5.0					
Wt. % Tripotassium Phosphate	100	75	50	25	0	
Wt. % Other Constituent	0	25	50	75	100	
Calcium Chloride						
Slush Point, °F	<-96	-	-	-	+60 (t)	
Oms/100 mls water	90		Did not dissolve		111	
Cost, \$/lb	16.5				1.7	
Acetamide						
Slush Point, °F	<-96	-30, -25	-19, -16	-26, -25	-22, -24	
Oms/100 mls water	90	65	60	72.7	97.5	
Cost, \$/lb	16.5	21.0	37.0	53.0	69	
Ammonium Acetate						
Slush Point, °F	<-96	<-90	-22, -30	-26, -22	<-84	
Oms/100 mls water	90	137.2	59.5	56.2	148	
Cost, \$/lb	16.5	21.9	27.3	32.6	38	
Sodium Chloride						
Slush Point, °F	<-96	-2, 0	-11	-10	-5, -7	
Oms/100 mls water	90	55	41.7	47.6	35.7	
Cost, \$/lb	16.5	12.7	8.8	5.0	1.1	
Urea						
Slush Point, °F	<-96	-38	-3, -4	0, -1	+11, +1	
Oms/100 mls water	90	75.5	100	115	119.3	
Cost, \$/lb	16.5	13.6	10.8	7.9	5.0	
Tripotassium Phosphate						
Slush Point, °F	<-96					
Oms/100 mls water	90					
Cost, \$/lb	16.5					
Tetrapotassium Pyrophosphate						
Slush Point, °F	<-96	-----Not Tested-----			-84	
Oms/100 mls water	90				117.5	
Cost, \$/lb	16.5				12.6	
Sodium Sulfate						
Slush Point, °F	<-96	+12, +10	+22, +20	+20	+31, +31	
Oms/100 mls water	90	26.8	28.8	37	48.8	
Cost, \$/lb	16.5	13.1	9.6	6.2	2.7	
Formamide						
Slush Point, °F	<-96	<-33, <-87	<-88, <-91	-57, -60	+30, +29	
Oms/100 mls water	90	122	151	252	No water	
Cost, \$/lb	16.5	15.0	13.5	12.0	17.5	

Footnotes listed on page 5-6.

Table VII (Cont'd)

		Composition				
Wt. % Tetrapotassium Pyrophosphate	100	75	50	25	0	
Wt. % Other Constituent	0	25	50	75	100	
Calcium Chloride						
Slush Point, °F	-84	-	-	-	+60(b)	
Oms/100 mls water ^(a)	117.5	Did not dissolve			111	
Cost, \$/lb	12.6				1.7	
Acetamide						
Slush Point, °F	-84	-27	-23	-27	-22, -24	
Oms/100 mls water	117.5	72.9	80.6	75.5	97.5	
Cost, \$/lb	12.6	26.7	40.8	54.9	69	
Ammonium Acetate						
Slush Point, °F	-84	-46	-30, -25	-13, -10	<-84	
Oms/100 mls water	117.5	100	64	45.7	148	
Cost, \$/lb	12.6	19.0	25.3	31.7	38	
Sodium Chloride						
Slush Point, °F	-84	-6	-11, -12	-10	-5, -7	
Oms/100 mls water	117.5	55	22	15	35.7	
Cost, \$/lb	12.6	9.7	6.9	4.0	1.1	
Urea						
Slush Point, °F	-84	-26, -28	-10, -10	+3, +2	+11, +12	
Oms/100 mls water	117.5	109.3	116.5	113	119.3	
Cost, \$/lb	12.6	10.7	8.8	6.9	5.0	
Tripotassium Phosphate						
Slush Point, °F	-84	----- Not tested -----			<-96	
Oms/100 mls water	117.5				90	
Cost, \$/lb	12.6				16.5	
Tetrapotassium Pyrophosphate						
Slush Point, °F	-84					
Oms/100 mls water	117.5					
Cost, \$/lb	12.6					
Sodium Sulfate						
Slush Point, °F	-84	+18	+24	+24	+31, +31	
Oms/100 mls water	117.5	33.2	37.9	27	48.8	
Cost, \$/lb	12.6	10.1	7.7	5.2	3.7	
Formamide						
Slush Point, °F	-84	-87, <-93	<-85, <-93	-64, -66	+30, +29	
Oms/100 mls water	117.5	149	180	270.5	No water	
Cost, \$/lb	12.6	12.1	11.6	11.0	10.5	
Wt. % Sodium Sulfate	100	75	50	25	0	
Wt. % Other Constituent	0	25	50	75	100	
Calcium Chloride						
Slush Point, °F	+31, +31	-	-	-	+60(b)	
Oms/100 mls water	48.8	Did not dissolve			111	
Cost, \$/lb	2.7				1.7	
Acetamide						
Slush Point, °F	+31, +31	+20, +18	+12, +12	-27, -24	-22, -24	
Oms/100 mls water	48.8	44.2	45.3	56	97.5	
Cost, \$/lb	2.7	19.3	35.9	52.4	69	
Ammonium Acetate						
Slush Point, °F	+31, +31	+50, +50	+50, +51	+8, +10	<-84	
Oms/100 mls water	48.8	55.1	57.5	65	148	
Cost, \$/lb	2.7	11.5	20.4	29.2	38	
Sodium Chloride						
Slush Point, °F	+31, +31	-7	-7	-6	-5, -7	
Oms/100 mls water	48.8	42.5	38	37.8	35.7	
Cost, \$/lb	2.7	2.3	1.9	1.5	1.1	
Urea						
Slush Point, °F	+31, +31	+8	+9	+9	+11, +12	
Oms/100 mls water	48.8	54.5	69.1	110	119.3	
Cost, \$/lb	2.7	3.3	3.9	4.4	4.0	
Tripotassium Phosphate						
Slush Point, °F	+31, +31	+40	+22, +20	+12, +10	<-96	
Oms/100 mls water	48.8	37	28.8	28.8	90	
Cost, \$/lb	2.7	6.2	9.6	13.1	16.5	
Tetrapotassium Pyrophosphate						
Slush Point, °F	+31, +31	+24	+24	+18	-84	
Oms/100 mls water	48.8	27	37.9	33.2	117.5	
Cost, \$/lb	2.7	5.2	7.7	10.1	12.6	
Sodium Sulfate						
Slush Point, °F	+31, +31					
Oms/100 mls water	48.8					
Cost, \$/lb	2.7					
Formamide						
Slush Point, °F	+31, +31	-58, -60	-57, -57	-58, -60	+30, +29	
Oms/100 mls water	48.8	49.1	54.5	56.5	No water	
Cost, \$/lb	2.7	8.7	6.6	8.6	10.5	

Footnotes listed on page C-6.

Table VII (Contd.)

Wt. % Permanganate					
Wt. % Other constituent					
Calcium Chloride					
Slush Point, °F	+3, +4	-1, -2	-3, -4	-5, -6	+1, +2
Ans/100 ml water (a)	1.0	1.0	1.0	1.0	1.0
Cost, \$/lb	1.0	1.0	1.0	1.0	1.0
Acetamide					
Slush Point, °F	+3, +4	-1, -2	-3, -4	-5, -6	+1, +2
Ans/100 ml water	1.0	1.0	1.0	1.0	1.0
Cost, \$/lb	1.0	1.0	1.0	1.0	1.0
Ammonium Acetate					
Slush Point, °F	+3, +4	-1, -2	-3, -4	-5, -6	+1, +2
Ans/100 ml water	1.0	1.0	1.0	1.0	1.0
Cost, \$/lb	1.0	1.0	1.0	1.0	1.0
Sodium Chloride					
Slush Point, °F	+3, +4	-1, -2	-3, -4	-5, -6	+1, +2
Ans/100 ml water	1.0	1.0	1.0	1.0	1.0
Cost, \$/lb	1.0	1.0	1.0	1.0	1.0
Urea					
Slush Point, °F	+3, +4	-1, -2	-3, -4	-5, -6	+1, +2
Ans/100 ml water	1.0	1.0	1.0	1.0	1.0
Cost, \$/lb	1.0	1.0	1.0	1.0	1.0
Tripotassium Phosphate					
Slush Point, °F	+3, +4	-1, -2	-3, -4	-5, -6	+1, +2
Ans/100 ml water	1.0	1.0	1.0	1.0	1.0
Cost, \$/lb	1.0	1.0	1.0	1.0	1.0
Tetrapotassium Pyrophosphate					
Slush Point, °F	+3, +4	-1, -2	-3, -4	-5, -6	+1, +2
Ans/100 ml water	1.0	1.0	1.0	1.0	1.0
Cost, \$/lb	1.0	1.0	1.0	1.0	1.0
Sodium Sulfate					
Slush Point, °F	+3, +4	-1, -2	-3, -4	-5, -6	+1, +2
Ans/100 ml water	1.0	1.0	1.0	1.0	1.0
Cost, \$/lb	1.0	1.0	1.0	1.0	1.0
Permanganate					
Slush Point, °F	+3, +4	-1, -2	-3, -4	-5, -6	+1, +2
Ans/100 ml water	1.0	1.0	1.0	1.0	1.0
Cost, \$/lb	1.0	1.0	1.0	1.0	1.0

Footnotes

- (a) Amount mixture required to saturate 100 ml of distilled water.
 (b) Drops to -2 (°F) - 1 gms and 100 ml of water.
 (c) Not saturated.
 (d) Appears clear to this temperature.
 (e) Liquid Permanganate - no water.

Table VIII

SLUSH POINTS OF SUPPLEMENTARY DEICER MIXTURES

<u>Composition</u>		<u>Slush Point, °F</u>	<u>Gms/100 mls Water*</u>	<u>Cost, ¢/lb</u>
60% Calcium Chloride	- 40% Acetamide	-66	100	28.6
50% "	- 40% Urea	<-80	150	3.0
40% "	- 10% Formamide	-60	120	2.6
90% Sodium Chloride	- 10% Ammonium Acetate	-16, -12	38.5	4.8
60% "	- 40% "	-32, -25	54	15.9
60% "	- 40% Acetamide	-31, -27	50.5	28.3
90% "	- 10% Formamide	-27	39.8	2.0
90% Acetamide	- 10% Ammonium Acetate	-31, -30	150	65.9
90% Triphenylmethyl Phosphate	- 10% Formamide	-72	112	15.0

*Amount mixture required to saturate 100 mls distilled water.

Table IX

DEICER MELTING RATES

Composition	Form Applied	Dosage Rate lb/ft ²	Deicer Temp., °F	Ice Temp., °F	% Ice Melted After Minutes					Description of Ice Remaining After 60 Minutes
					15	30	45	60		
Calcium Chloride	Pelletized	0.25	-60	-60	0	0	0	0	0	Very light slush layer on top of ice
	"	0.25	-30	-30	28	33	38	42	42	25% slush
	"	0.25	-10	-10	40	56	72	76	76	No slush observed
	"	0.125	-10	-10	49	51	80	64	64	No slush observed
	"	0.0625	-10	-10	7	10	13	18	18	No slush observed
75% Calcium Chloride 25% Acetamide	"	0.03	-10	-10	0	0	0	0	0	No slush observed
	Pelletized	0.50	R.T.*	-60	0	0	0	0	0	No melting
	"	0.25	-60	-60	0	0	0	0	0	No melting
	"	0.25	-30	-30	10	22	29	33	33	No slush observed
	"	0.25	-10	-10	29	33	39	41	41	No slush observed
75% Calcium Chloride 25% Sodium Chloride	"	0.125	-10	-10	21	28	35	39	39	No slush observed
	"	0.0625	-10	-10	2	4	3	3	3	No slush observed
	Pelletized	0.50	R.T.	-60	0	0	0	0	0	No melting
	"	0.25	-30	-30	0	0	5	17	17	No slush observed
	"	0.25	-10	-10	34	51	72	88	88	No slush observed
75% Calcium Chloride 25% Urea	"	0.125	-10	-10	24	34	33	40	40	No slush observed
	"	0.0625	-10	-10	6	9	12	11	11	No slush observed
	Pelletized	0.50	R.T.	-60	0	0	0	0	0	No melting
	"	0.25	-30	-30	7	16	22	30	30	No slush observed
	"	0.25	-10	-10	29	47	47	51	51	No slush observed
75% Calcium Chloride 25% Formamide	"	0.125	-10	-10	32	34	-	37	37	No slush observed
	"	0.0625	-10	-10	6	7	8	8	8	No slush observed
	Pelletized	0.50	R.T.	-60	0	0	0	0	0	Very light slush layer formed
	"	0.25	-60	-60	0	0	0	0	0	No melting
	"	0.25	-30	-30	9	16	27	31	31	No slush observed
90% Calcium Chloride 10% Formamide	"	0.25	-10	-10	29	44	45	74	74	No slush observed
	"	0.125	-10	-10	21	34	31	46	46	No slush observed
	"	0.0625	-10	-10	2	4	4	4	4	No slush observed
	Pelletized	0.25	-60	-60	0	0	0	0	0	Very light slush layer formed
	"	0.25	-30	-30	34	42	42	42	42	Pellets melted through ice in several places after 30, 45, and 60 min.
75% Ammonium Acetate 25% Acetamide	"	0.25	-10	-10	46	55	62	69	69	No slush observed
	"	0.125	-10	-10	36	53	49	40	40	No slush observed
	"	0.0625	-10	-10	3	5	7	8	8	No slush observed
	Pelletized	0.50	R.T.	-60	0	0	0	0	0	Light slush layer formed
	"	0.25	-30	-30	0	14	20	28	28	No slush observed
75% Ammonium Acetate 25% Sodium Chloride	"	0.25	-10	-10	26	42	42	56	56	No slush observed
	"	0.0625	-10	-10	8	14	15	18	18	No slush observed
	Pelletized	0.50	R.T.	-60	0	0	0	0	0	Light slush layer formed
	"	0.25	-30	-30	0	0	0	0	0	No melting
	"	0.25	-10	-10	9	28	45	51	51	No slush observed
	"	0.0625	-10	-10	5	7	11	16	16	No slush observed

*R.T. - Room Temperature

Table IX (Cont'd)

Composition	Form Applied	Dosage Rate lb/ft ²	Deicer Temp., °F	Ice Temp., °F	% Ice Melted After Minutes			Description of Ice Remaining After 60 Minutes
					15	30	45	
75% Ammonium Acetate 25% Urea	Pelletized	0.50	R.T.*	-60	0	0	0	No melting
	"	0.25	-30	-30	0	3	17	No slush observed
	"	0.25	-10	-10	29	45	54	No slush observed
	"	0.0625	-10	-10	7	5	10	No slush observed
75% Tripotassium Phosphate 25% Ammonium Acetate	Pelletized	0.50	R.T.	-60	0	0	0	No melting
	"	0.25	-30	-30	0	0	0	No melting
	"	0.25	-10	-10	6	19	33	No slush observed
	"	0.0625	-10	-10	5	5	7	No slush observed
75% Tripotassium Phosphate 25% Formamide	Pelletized	0.25	-30	-30	0	2	6	No slush observed
	"	0.25	-10	-10	30	53	58	No slush observed
	"	0.0625	-10	-10	8	10	13	No slush observed
75% Formamide 25% Ammonium Acetate	"As Mixed"	0.50	R.T.	-60	0	0	0	No melting
75% Formamide 25% Sodium Chloride	"As Mixed"	0.50	R.T.	-60	0	0	0	No melting
75% Formamide 25% Tripotassium Phosphate	"As Mixed"	0.50	R.T.	-60	0	0	0	No melting
	"	0.25	-30	-30	32	28	15	Initial melting result of heat content of deicer when applied.
75% Formamide 25% Tetrapotassium Pyrophosphate	"As Mixed"	0.50	R.T.	-60	0	0	0	No melting
	"	0.25	-30	-30	30	27	28	Initial melting result of heat content of deicer when applied.
75% Tetrapotassium Pyrophosphate 25% Formamide	Pelletized	0.25	-30	-30	7	11	16	No slush observed
	"	0.25	-10	-10	13	28	27	No slush observed
	"	0.0625	-10	-10	5	6	5	No slush observed
75% Sodium Sulfate 25% Formamide	"As Mixed"	0.50	R.T.	-60	0	0	0	No melting
	"	0.25	-30	-30	0	0	0	No melting
Ammonium Acetate	Pelletized	0.25	-60	-60	0	0	6	Ice slushy after 15 minutes
	"	0.25	-30	-30	25	35	49	No slush observed
	"	0.25	-10	-10	32	45	50	No slush observed
	"	0.0625	-10	-10	5	7	12	No slush observed
Tripotassium Phosphate	Pelletized	0.25	-10	-10	27	29	40	No slush observed
	"	0.0625	-10	-10	0	0	0	No slush observed
Tetrapotassium Pyrophosphate	Pelletized	0.25	-10	-10	18	23	33	No slush observed
	"	0.0625	-10	-10	0	0	0	No slush observed

*R.T. - Room Temperature

Table X

MELTING RATES OF CORROSION INHIBITED DEICERS

Deicer	Inhibitor ^a	Form Applied ^b	Dosage Rate lb/ft ²	Temp., °F Deicer	% Ice Melted After (Minutes)			
					15	30	45	60
Calcium Chloride	-	pelletized	0.25	-10	40	55	75	68
	Emulsifier STH	"	"	"	17	32	40	42
	Textamine-DP	"	"	"	27	40	47	58
	Santolube 203-B	"	"	"	28	39	60	62
75% Calcium Chloride 25% Sodium Chloride	Santolube 203-C	"	"	"	24	48	61	53
	-	"	"	"	34	51	72	88
	Emulsifier STH	"	"	"	38	52	64	56
	Santolube 203-B	"	"	"	25	53	60	54
75% Calcium Chloride 25% Urea	Santolube 203-C	"	"	"	16	41	50	57
	-	"	"	"	29	47	47	51
	Emulsifier STH	"	"	"	17	34	42	48
	Triethylenetetramine	"	"	"	10	29	38	43
90% Calcium Chloride 10% Formamide	Santolube 203-B	"	"	"	21	39	42	45
	Santolube 203-C	"	"	"	6	20	32	41
	-	"	"	"	46	55	62	69
	Emulsifier STH	"	"	"	40	49	51	64
	Santolube 203-B	"	"	"	18	32	40	44
	Santolube 203-C	"	"	"	17	31	39	42

^a 1.0 Wt.-% of deicer mixture^b 10-20 mesh

Table XI

AVERAGE* CORROSION RATES AND EXPOSURE TIMES (4340 STEEL)

<u>Deicer</u>	<u>% Saturation</u>	<u>Corrosion, Mils/Year</u>	<u>Exposure, Hrs</u>
Control (Triple Distilled Water)	-	1.5	40
Calcium Chloride	10	5.4	42
	50	0.8	42
	100	0.4	42
75% Calcium Chloride	10	5.9	42
25% Acetamide	50	2.1	42
	100	1.1	42
75% Calcium Chloride	10	8.3	42
25% Sodium Chloride	50	2.6	42
	100	1.3	42
75% Calcium Chloride	10	6.3	42
25% Urea	50	1.6	42
	100	0.5	42
75% Calcium Chloride	10	8.5	42
25% Formamide	50	3.8	42
	100	2.5	42
90% Calcium Chloride	10	15.6	42
10% Formamide	50	4.9	42
	100	1.7	42
75% Ammonium Acetate	10	none	218
25% Acetamide**	50	none	218
	100	0.01	218
75% Ammonium Acetate	10	0.05	216
25% Urea**	50	0.01	216
	100	none	216
75% Tripotassium Phosphate	10	0.03	216
25% Formamide**	50	0.02	216
	100	0.01	216
Ammonium Acetate**	10	0.5	216
	50	0.4	216
	100	0.4	216
Tripotassium Phosphate**	10	0.01	216
	50	0.03	216
	100	0.02	216
Tetrapotassium Pyrophosphate**	10	none	216
	50	none	216
	100	none	216

*Three determinations

**Single determination

Table XII
SUMMARY OF CORROSION INHIBITOR DATA
(4340 Steel)

Inhibitor	Concentration (1)	Corrosion Rate, mils/year				
		Distilled Water	1000 ml Distilled Water + 0.15 g Inhibitor	CaCl ₂ (2)	75% CaCl ₂ 25% Formamide (2)	75% CaCl ₂ 25% Urea (2)
2-Mercaptobenzothiazole	0.1	2.6	0.5	4.4	19.9	5.1
Octadecylamine	0.1	1.7	0.4	5.1	9.8	5.7
Borax	0.1	1.7	0.9	5.8	12.7	9.3
Ethylene Dinitrilo	0.1	1.7	0.4	6.2	13.5	5.7
DuPont RP-2	0.1	1.7	0.2	4.4	9.4	6.3
Unconditioned IP-106 ⁽³⁾	0.1	0.6	0	5.5	6.7	5.5
SA ₁ F 1406 ⁽³⁾	0.1	0.6	0.2	4.9	6.0	4.8
Patchemco 153-0	0.1	2.6	0	3.5	6.8	2.9
	1.0	-	-	0.8	-	-
Patchemco 153	0.1	2.6	0	1.2	7.7	2.8
	1.0	-	-	2.3	-	-
Patchemco-T	0.1	2.6	0.1	2.7	1.8	1.9
	1.0	-	-	1.5	-	-
Patchemco-O	0.1	2.6	0.1	2.2	4.3	2.6
	1.0	-	-	1.2	-	-
HT-100	0.1	2.6	0.9	2.6	6.2	4.3
	1.0	-	-	3.3	-	-
Katapol PN-430	0.1	2.6	0.2	<0.1	6.4	3.6
	1.0	-	-	1.9	-	-
Emulsifier STH	0.1	2.6	0.3	1.4	2.4	0.3
	1.0	-	-	0.2	-	-
Willimid-513	0.1	2.6	0.4	2.4	5.8	1.6
	1.0	-	-	0.8	-	-
Victamine-C	0.1	2.6	0	1.9	3.1	1.1
	1.0	-	-	1.2	-	-
Aliquat-33	0.1	2.6	1.3	0.5	13.0	5.1
	1.0	-	-	4.2	-	-
Emcol E-12	0.1	2.6	0.5	4.9	11.7	4.9
	1.0	-	-	3.5	-	-
Hercules-Amine D	0.1	1.7	0.4	1.1	9.1	2.1
	1.0	-	-	2.9	-	-
Nalquat-0-8-13	0.1	0.6	0.2	2.7	3.5	0.1
	1.0	-	-	2.8	-	-
Triethylenetetramine	0.1	0.6	0.2	2.9	4.9	2.9
	1.0	-	-	1.4	-	-
Ethylenediamine	0.1	0.6	0.2	3.4	5.7	3.4
	1.0	-	-	1.6	-	-
Diethylenetriamine	0.1	0	0.1	2.8	5.8	3.0
	1.0	-	-	2.0	-	-
Guanidine nitrate	0.1	0.6	0.2	4.2	7.0	4.5
	1.0	-	-	3.5	-	-

Footnotes listed on page C-13.

Table XII (Cont'd)

Inhibitor	Concentration (1)	Corrosion Rate, mils/year				
		Distilled Water	1000 ml Distilled Water + 0.15 g Inhibitor	CaCl ₂ (2)	75% CaCl ₂ 25% Formamide (2)	75% CaCl ₂ 25% Urea (2)
Guanidine sulfate	0.1	0.6	4.5	3.7	10.3	4.4
	1.0	-	-	5.0	-	-
Katapone VV-328	0.1	1.3	0.6	2.9	6.5	3.2
	1.0	-	-	4.3	-	-
Gafac LO-529	0.1	1.3	0.1	2.3	5.7	2.6
	1.0	-	-	3.7	-	-
Gafac PE-510	0.1	1.3	0.3	3.4	12.1	2.1
	1.0	-	-	4.7	-	-
Textamine-DP	0.1	1.3	0.1	1.4	6.2	2.2
	1.0	-	-	0.9	-	-
Catanac-SP	0.1	1.3	0.2	3.2	8.5	3.8
	1.0	-	-	5.5	-	-
Hydrazine	1.0	-	-	4.4	-	-
Cathol	1.0	-	-	0.6	-	-
Diam-26	1.0	-	-	1.7	-	-
Diam-21D	1.0	-	-	2.4	-	-
Willimid-412A	1.0	-	-	0.9	-	-
Zinc dust	1.0	-	-	3.5	-	-
Sodium thiosulfate	0.1	2.6	-	5.3	37.1	6.8
	5.0	-	-	17.6	-	-
Sodium nitrite	0.1	1.7	1.5	5.2	43.6	5.6
	5.0	-	-	3.5	-	-
Sodium sulfite	0.1	1.7	9.1	4.8	13.0	5.3
	5.0	-	-	11.7	-	-
Santolube 203B	1.0	-	-	0.1	-	-
Santolube 203C	1.0	-	-	0.1	-	-
Santolube 333	1.0	-	-	2.6	-	-
Santolube 70	1.0	-	-	3.3	-	-
Lubrizol 344	1.0	-	-	1.7	-	-
Aeronox 9010	1.0	-	-	5.3	-	-
Aeronox MB	1.0	-	-	7.5	-	-
Melamine	1.0	-	-	8.4	-	-
Sodium aluminate	1.0	-	-	4.6	-	-
Armohib 28	1.0	-	-	3.1	-	-
Amoco Sulfonate-AA Purified	1.0	-	-	6.6	-	-

Footnotes

- (1) Wt. % deicer mixture.
 (2) 10% of saturation.
 (3) Proprietary compound.

NOTE: Corrosion rate for 10% saturated CaCl₂ solution - 5.4 mils/year.

Table XIII
CORROSION RATE OF INHIBITED DELCERS AFTER GRANULATION - 4340 STEEL

Inhibitor (1)	Corrosion Rate, Mils/Year (3)									
	CaCl ₂	75% CaCl ₂ 25% NaCl	75% CaCl ₂ 25% Acetamide	75% CaCl ₂ 25% Formamide	90% CaCl ₂ 10% Formamide	75% CaCl ₂ 25% Urea	75% Ammonium Acetate	75% Ammonium Acetate	75% Tripotassium Phosphate	75% Formamide (2)
None	8.8	8.7	4.5	8.5	8.8	6.4	0.1	0.4	<0.1 (6)	
Bulsifier 5TH	0.3	0.7	0.3	1.7	0.4	0.5				
Willmid-513	1.5	1.1	2.2	3.9	4.3	1.0				
Victamine-C	3.8	2.2	2.5	3.4	1.8	1.6				
Hercules Amine D	2.8	4.3	1.0 (2)	2.1	9.5	2.9				
Triethylenetetramine	2.5	2.6	0.4 (2)	0.9	4.8	1.4				
Ethylenediamine	2.7	3.5	0.7 (2)	2.2	5.7	2.5				
Diethylenetriamine	3.9	3.4	0.3 (2)	2.6	5.8	2.3				
Textamine-DP	0.6	0.9	0.4 (2)	5.3	2.9	0.4				
Santolube 203-B	0.1	0.0	1.5 (2)	0.4	0.3 (5)	0.2 (2)				
Santolube 203-C	0.7	0.1 (2)	0.9 (2)	1.3	0.3 (5)	0.5 (2)				

(1) 1.0 Wt-% of delcer.

(2) Contained drying agent.

(3) Solution concentration - 10% of saturation.

(4) Pelletized with formamide only.

(5) Drying agent added - pelletized with water.

(6) Tripotassium phosphate and formamide reacted to evolve ammonia. Did not change corrosion properties.

Table XIV

SUMMARY OF CORROSION INHIBITOR SOLUBILITIES

Inhibitor	Mixing Solvent	Deicer Composition							
		CaCl ₂	75% CaCl ₂ 25% Acetamide	75% CaCl ₂ 25% NaCl	75% CaCl ₂ 25% Urea	75% CaCl ₂ 25% Formamide	90% CaCl ₂ 10% Formamide		
Emulsifier STH	Water	(1)	(1)	(1)	(1)	(2)	(1)		
Willmid-513	Methanol	(2)	(1)	(2)	(2)	(2)	(1)		
Victamine-C	Methanol	(2)	(1)	(2)	(2)	(1)	(1)		
Hercules-Amine D	Methanol	(1)	(1)	(1)	(1)	(1)	(1)		
Triethylenetetramine	Water	(2)	(2)	(2)	(2)	(2)	(2)		
Ethylenediamine	Water	(2)	(2)	(2)	(2)	(2)	(2)		
Diethylenetriamine	Water	(2)	(2)	(2)	(2)	(2)	(2)		
Texamine-DP	Methanol	(2)	(2)	(2)	(2)	(2)	(2)		
Santolube B	Water	(1)	(2)	(1)	(2)	(2)	(2)		
Santolube C	Water	(1)	(1)	(1)	(2)	(2)	(2)		

 (1) Did not go into solution 100% when inhibited deicer pellets dissolved in water.

(2) No apparent incompatibility.

APPENDIX D

STRESS CORROSION

Table XV

STRESS CORROSION - DIRECT LOADED 4240 STEEL TENSILE SPECIMENS

Deicer (a)	Inhibitor (b)	Time to Failure, hours			
		1	2	3	4
Calcium Chloride	-	0.6	1.1	53.1	0.1
"	Emulsifier STH	0.1	230+	0.1	200+
"	Textamine-DP	36.4	200+	102.9	110.9
"	Santolube 203-B	110.0	77.1	0.2	0.1
"	Santolube 203-C	9.4	9.7	0.6	2.0
75% Calcium Chloride	-	-	-	-	-
25% Sodium Chloride	Emulsifier STH	0.4	1.3	0.2	0.1
"	Santolube 203-B	6.7	0.4	0.6	34.2
"	Santolube 203-C	2.4	4.0	0.2	0.4
75% Calcium Chloride	-	-	-	-	-
25% Urea	Emulsifier STH	51.9	5.5	0.4	136.3
	Santolube 203-B	0.4	200+	5.5	1.6
90% Calcium Chloride	-	-	-	-	-
10% Formamide	Emulsifier STH	0.9	0.2	0.1	96.7
"	Santolube 203-B	4.0	2.5	12.8	1.5
"	Santolube 203-C	<48.1	3.5	<48.1	1.5
Distilled Water		260+	260+	260+	260+
Air		260+	260+	260+	260+

Footnotes listed on page D-2.

Table XV (Cont'd)

Delcer(a)	Inhibitor(b)	Time to Failure, hours			
		1	2	3	4
75% Calcium Chloride 25% Urea	-	-	-	-	-
	Emulsifier STH	51.9	5.5	0.4	136.3
	Triethylenetetramine	21.2	40.0	79.5	48.2
	Santolube 203-B	0.4	200+	5.5	1.6
	Santolube 203-C	0.3	13.0	4.4	6.6
Calcium Chloride(d)	Emulsifier STH	105.0	3.0	7.6	80.3
	Textamine DP	0.4	144.6	0.3	2.3
75% Ammonium Acetate 25% Urea	-	85.5	200+	200+	64.0
75% Ammonium Acetate 25% Acetamide	-	22.0	200+	49.6	63.1
75% Tripotassium Phosphate 25% Formamide	-	200+	16.9(c)	200+	200+

Footnotes

- (a) 10% by weight in deionized water.
 (b) 1% by weight of dry deicer mixture.
 (c) Specimen questionable. Very light surface corrosion hand polished from specimen prior to test.
 (d) Repeat determinations.

Table XVI

STRESS CORROSION -
DIRECT LOADED 7079-T6 ALUMINUM TENSILE SPECIMENS

Deicer*	Time to Failure, Hrs		
	Replicate		
	1	2	3
Distilled Water	200+	200+	200+
75% Tripotassium Phosphate 25% Formamide	200+	200+	200+
75% Ammonium Acetate 25% Urea	200+	200+	200+
Calcium Chloride	56.8	116.3	32.8

*10% by weight in deionized water.

APPENDIX E

EFFECTS OF DEICERS ON CONCRETE

Table XVII

CONCRETE COMPATIBILITY

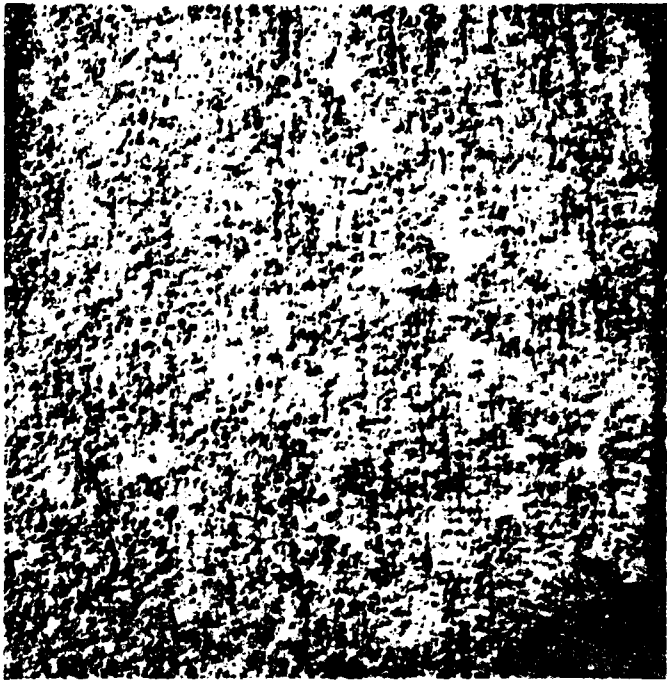
Deicer	Application Dosage, lb/ft ²	Average Thaw Time at Room Temp. *, min.	Remarks -
None	-	102	No scaling after 50 freeze-thaw cycles.
Calcium Chloride	0.125	52	No scaling after 50 freeze-thaw cycles.
75% Tripotassium Phosphate 25% Formamide	0.125	64	Very light scaling ob- served after 10 freeze- thaw cycles on one block - other block O.K. Moderate scaling both blocks after 50 cycles.
75% Ammonium Acetate 25% Urea	0.125	64	Light scaling both blocks after 50 freeze-thaw cycles.

*Room Temperature 75°F ± 3°F
Ice and blocks frozen at -10°F

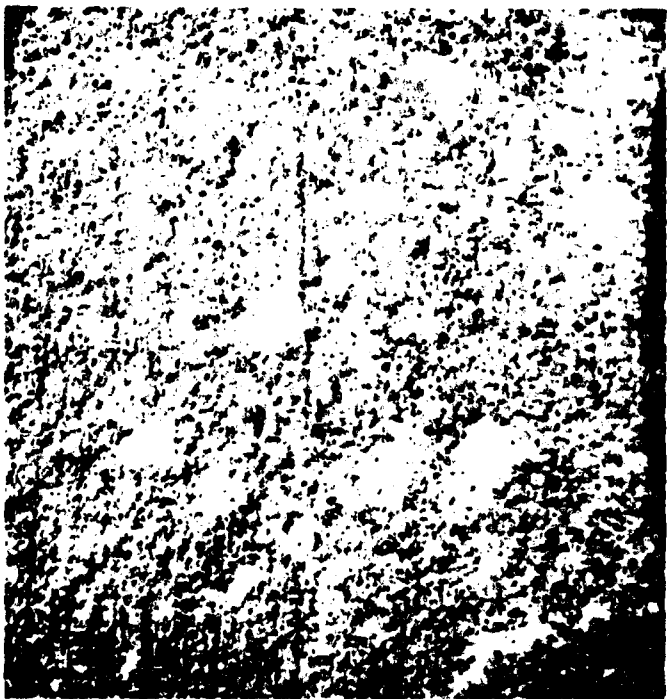
Table XVIII
pH OF AQUEOUS DEICER SOLUTIONS

<u>Concentration, Wt. %</u>	<u>75% Tripotassium Phosphate 25% Formamide</u>	<u>75% Ammonium Acetate 25% Urea</u>
0 (Deionized water)	6.04	6.04
16.1	11.6	6.1
14.0	11.6	6.1
10.0	11.6	6.1
4.0	11.6	-
2.0	11.6	-
1.0	11.5	6.1
0.5	11.4	-
0.25	11.2	-
0.10	10.8	-
0.05	10.5	-
0.01	9.7	6.1
0.001	7.2	-

NOTE: Solutions prepared from pelletized deicers used for concrete compatibility evaluations.



BEFORE



DISTILLED WATER

Figure 10. Concrete Compatibility Specimens.

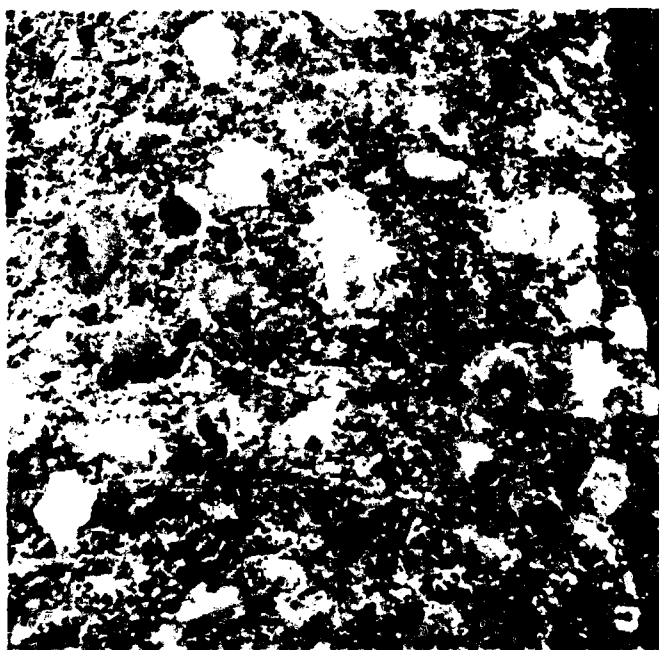


CALCIUM CHLORIDE



**75 TRIPOTASSIUM PHOSPHATE
25 FORMAMIDE**

Figure 11. Concrete Compatibility Specimens.



**75 AMMONIUM ACETATE
25 UREA**

Figure 12. Concrete Compatibility Specimens.

APPENDIX F

FORMULATION AND STORAGE CHARACTERISTICS

Table XIX

DEICER GRANULATION DATA

<u>Deicer</u>	<u>Mls of H₂O Added to Form Desired Pellets</u>	<u>Gms Drying Agent/100 Gms Deicer(a)</u>	<u>4-10 Mesh Pellet Yield, % (b)</u>
Calcium Chloride	5	None	65
75% Calcium Chloride 25% Sodium Chloride	5	None	52
75% Calcium Chloride 25% Acetamide	10	4	35
75% Calcium Chloride 25% Formamide	None(c)	4-8	60
90% Calcium Chloride 10% Formamide	None(c)	None	55
75% Calcium Chloride 25% Urea	5	None	75
75% Ammonium Acetate 25% Acetamide	3	8-12	35
75% Ammonium Acetate 25% Urea	None	4-8	35
75% Tripotassium Phosphate 25% Formamide	11	9.5	65

 {a} Generally true - exceptions noted in Table XIII, Appendix C.

{b} Average yield obtained from 100 grams deicer.

{c} Formamide sufficient to pelletize - exceptions noted in Table XIII, Appendix C.

Table XX

STORAGE EFFECTS ON DEICER MELTING RATE

<u>Deicer</u>	<u>Storage Conditions</u>	<u>Dosage Rate, lb/ft²</u>	<u>% Melted After Minutes</u>				<u>Remarks -</u>
			<u>15</u>	<u>30</u>	<u>45</u>	<u>60</u>	
75% Tripotassium Phosphate 25% Formamide	-	0.25	30	53	58	53	Determined at -10°F.
	7 days at -10°F (bagged)	0.25	25	32	45	53	Deicer slightly frozen in bag.
	7 days at 100°F - 100% R.H.* (bagged)	0.25	13	19	33	51	1.7% weight loss.
	24 hours at 100°F open container	0.25	33	44	48	52	8.5% weight loss.
75% Ammonium Acetate 25% Urea	-	0.25	29	45	54	57	Determined at -10°F.
	7 days at -10°F (bagged)	0.25	25	37	44	52	Deicer slightly frozen in bag.
	7 days at 100°F - 100% R.H. (bagged)	0.25	25	36	42	57	1.5% weight gain. Pellets agglomerated.
	24 hours at 100°F open container	0.25	7	14	27	44	8.5% weight loss.

*R.H.- relative humidity.

APPENDIX G

REVIEW OF DEICER PROGRAM WITH AIR FORCE REPRESENTATIVES

REVIEW OF DEICER PROGRAM WITH AIR FORCE REPRESENTATIVES

The deicer program was reviewed at midpoint with Air Force representatives and our approach to the problem was discussed in detail. No additional avenues for investigation were suggested. However, several comments made by Air Force personnel were of particular interest to this program:

1. The Air Force considers chemical deicing a supplement to mechanical removal of snow and ice. Application of deicer material to a runway will be limited to intermittent ice areas left by mechanical snow removal equipment. With this concept, the entire runway will not need to be "salted" and deicer materials with relatively high cost per pound may still be practical.
2. The Air Force feels that -10°F is a good target temperature for an effective deicer; however, 0 to $+20^{\circ}\text{F}$ is perhaps even more realistic and practical on a broad geographical basis. Based on their experience, the Air Force sets -10°F as a goal for their aircraft deicing fluids since ice formation from atmospheric condensation is negligible below this temperature (there simply isn't that much water in the cold air).
3. Transformation of ice to slush would not satisfy Air Force deicer requirements because some of their operational aircraft require a completely clean runway for take-off.
4. The RCAF allows no chloride-containing materials to be used on their runways. Their solution to the problem consists of spraying water on a runway, followed immediately by a sand application before the water freezes. This apparently provides a satisfactorily abrasive surface but has the obvious disadvantage of requiring clean-up as soon as the surface begins to break up, to prevent ingestion of the sand into aircraft propulsion systems.

APPENDIX H

AIRPORT ICING INFORMATION

AIRPORT ICING INFORMATION

One of the common hazards encountered in aircraft operation during the winter is ice formed on runways during snow and ice storms. Not only is runway icing a very definite threat to aircraft during landing and take-off but it also places a large economic burden on airports where an icing condition exists frequently or is prolonged.

In addition, snow and ice accumulations are hazardous to automobile, truck, bus, and pedestrian traffic and may restrict customer travel to and from the airport.

The information included here is provided to help define the magnitude of the icing problem. Each group of data has been segregated as to source, and pertinent excerpts are given.

- A. Source: Final Report, Contract No. FA-WA-4685
Benefit Cost Analysis of Airport Snow, Ice,
and Slush Removal
March 1964, Project No. 415-2S
Systems Analysis and Research Corporation
Boston, Massachusetts, and Washington, D. C.

(1) Snow.- Snow removal methods can be classified as mechanical, chemical, and thermal. With minor exceptions, only the mechanical methods were found to be in use at airports. The exceptions are almost all on the passenger side of the terminal in the use of salt or calcium chloride on streets and sidewalks. In a very few cases, heated roadways were found, but these were of limited area and invariably prompted by very special design problems.

Chemicals are used only on the passenger sides of terminals because no inexpensive, non-corrosive chemicals are available. A number of the airport managers indicated that short of a very great reduction in costs of thermal systems, the most valuable contribution to snow removal techniques would be the introduction of cheap, harmless chemicals which would melt snow, slush, and ice. The requirements are stringent, however, since they must not harm any of the many aircraft construction materials, nor vegetation, wild life, people, cargo, and so forth. In addition, they must be cheap. No such materials exist in quantity today.

The universally used method of snow removal is that of mechanically moving it from where it falls to where it is out of the way. This is done by a combination of plowing, blowing, loading, and hauling the snow.

Ramp areas are cleared after runways and taxiways and usually treated somewhat differently since the widths and slopes of these areas are usually such as to make plowing less straightforward and convenient. Many obstructions such as finger piers, blast fences, and the like, make it difficult not only to move snow but to find a place to put it. Usual practice, therefore, is to pile the snow and then load and haul it using front loading tractors and dump trucks. It is dumped in any unused area of the field where it won't interfere with operations.

(2) Slush.- Slush is handled by plowing, blowing, and sweeping it from runways and turnoffs. High speed equipment is much more effective in handling slush than low speed equipment. For gathering slush for a high speed blower, a broom is especially suitable. On taxiways and other surfaces where aircraft speeds are much lower and damage to the aircraft surfaces is not a problem, slush removal is not necessary unless temperatures are expected to drop enough to produce freezing. If that is likely, slush is handled by the same methods and equipment as used for cleaning snow from the runways.

(3) Ice.- Ice proved to be somewhat less of a problem than the study personnel had originally expected. The airport managers indicated that a major reason why ice was only a moderate problem was that preventative measures, in the form of stricter snow and slush removal standards which were instituted for the jets, mean that there is much less chance of ice forming.

Ice, once formed, is a problem particularly if it is permitted to form in ridges. Here again, however, larger airports with more widespread runway configurations have yielded benefits in the ice area. Modern airport design standards call for a minimum of runway and taxiway crossings, where ice ridges are most apt to form if windrows from passes down the various runways are not very carefully cleared away.

When ice does form, it is not removed but rather sanded. In this particular area there exists disagreement as to the value of heating the sand or grit used and also as to whether ordinary sand or proprietary grit are superior. There did not appear to be any advantage of sand over grit or vice versa.

Within the range of the accuracy of the data available it was estimated that the total dollar penalties to both operators and users of clearing operations in 1962-1963 approximated 900 thousand dollars. A possible comparable cost for the future period (1975) was estimated to be approximately 3 to 4.5 million dollars depending on reasonable variations in weather environment.

The total dollar penalty to airport users was found to be approximately five to six times that imposed on the airports themselves.

Table XXI presents reported snow removal costs to selected airports.

Table XXI

REPORTED SNOW REMOVAL COSTS

	<u>Buffalo</u>	<u>Chicago</u>	<u>Cleveland</u>	<u>Denver</u>	<u>Minneapolis</u>	<u>Idlewild</u>	<u>Pittsburgh</u>	<u>Washington</u>
Annual Cost \$(000)*	\$ 33.7	130.0**	26.3	13.5	77.7	250.0***	-	37.6
Hourly Wage Buffalo Crew	\$ 2.81	3.08	2.92	2.73	2.81	2.75	3.01	-
Hourly Wage Washington Crew	\$ -	3.33	3.12	3.02	3.00	2.93	3.15	2.77
Inst. Runway (ft ² -000)	847	3422	936	1502	2000	2829	1200	1374
Annual \$/ft ²	3.98	3.90	2.81	.899	3.88	8.84	-	2.74
Avg. Annual Snow in Inches	106.8	36.1	50.1	60.3	40.8	30.0	41.5	15.9
Annual \$/ft ² /in.	.0372	.105	.0561	.0149	.0951	.295	-	.172

*Average 1960-1961, 1961-1962, 1962-1963 winters.

**1960-1961, 1961-1962 estimated average = \$90,000.

***1960-1961 only.

B. Source: Technical Analysis of Salt (Sodium Chloride)
for Ice and Snow Removal
Published by: Salt Institute
33 North LaSalle Street
Chicago, Illinois

Shown in Table XXII are the areas in which freezing conditions may be encountered. While snowfall is not necessarily indicative of icing conditions, the information is informative in that both precipitation and low temperatures are involved.

C. Source: An Analysis of Snowfall and Persistence
Data for Seven Cities
American Oil Company
New Product Development
November 1, 1962

The need for removal is usually dictated by snow persistency in a given area. Where it is common for snow to persist on the ground from one snowfall to another, the possibility always exists for accumulations to quickly and unexpectedly reach levels that can cause widespread economic loss.

Regions of the United States with Snowfall

Snowfall occurs, generally, throughout the United States, except in southern Florida and the lower elevations of southwestern Arizona and southern California as shown in Figure 13. The shaded area of this map indicates the portion of the United States where:

1. Snowfall normally occurs every winter.
2. There will be occasional severe storms.
3. Snow cover persistency can occur for long periods.

While sizeable areas are subjected to recurring snows that leave appreciable ground coverage, the problem of forecasting the need for snow control is complicated since:

1. The frequency and intensity of snow storms are largely unpredictable.
2. The period of snow persistency on the ground is a function of a wide range of uncontrollable variables.

Table XXII

CLIMATES OF SELECTED NORTHERN CITIES

City	Month	Average Daily Temperature - °F			Average Monthly Precipitation - Inches			
		Maximum	Minimum	Monthly Average	Monthly Maximum	24 Hour Maximum	Snow - Sleet	
							Monthly Total	Days of 1.0 Inches or More Snowfall
Hartford	Dec.	39.0	20.2	29.6	45.3	18.2	7.5	2
	Jan.	36.1	17.9	27.0	40.1	13.6	10.7	3
	Feb.	37.9	18.2	28.1	32.7	19.0	11.9	3
Chicago	Dec.	35.3	20.6	28.0	33.3	10.0	10.0	3
	Jan.	32.7	17.1	24.9	20.8	6.6	6.9	2
	Feb.	35.0	19.8	27.4	16.6	8.3	7.0	2
Indianapolis	Dec.	38.8	23.4	31.1	8.2	5.6	4.3	2
	Jan.	37.1	20.5	28.8	15.0	5.6	4.1	2
	Feb.	39.8	23.1	31.5	10.3	4.5	3.7	1
Portland	Dec.	34.5	15.7	25.1	35.1	21.0	11.4	3
	Jan.	30.7	10.6	20.7	35.3	13.8	19.6	5
	Feb.	31.6	11.3	21.5	35.3	20.8	17.4	4
Boston	Dec.	39.7	25.8	32.8	26.8	12.3	7.5	2
	Jan.	36.5	21.6	29.1	35.7	16.7	12.0	4
	Feb.	36.5	21.8	29.2	35.3	16.5	12.3	3
Detroit	Dec.	35.7	23.2	29.5	24.0	6.8	6.6	2
	Jan.	33.1	19.3	26.2	21.1	8.9	8.2	3
	Feb.	33.8	19.6	26.7	14.7	5.6	7.7	3
Minneapolis	Dec.	27.2	11.5	19.4	25.0	9.8	7.7	2
	Jan.	23.1	6.1	14.6	17.0	7.6	6.6	2
	Feb.	27.0	9.4	18.2	15.4	9.3	8.0	2

Table XXII (Cont'd)

City	Month	Average Daily Temperature - °F			Average Monthly Precipitation - Inches			
		Maximum	Minimum	Monthly Average	Snow - Sleet		Days of 1.0 Inches or More Snowfall	Total Water
					Monthly Maximum	Monthly Total		
St. Louis	Dec.	43.5	28.8	36.2	10.5	2.9	1	2.43
	Jan.	41.0	25.6	33.3	10.6	3.6	2	2.32
	Feb.	44.8	28.5	36.7	9.3	3.1	1	1.88
Buffalo	Dec.	35.3	22.6	29.0	51.1	17.6	5	2.92
	Jan.	32.4	18.5	25.5	50.6	19.1	6	2.78
	Feb.	32.2	17.1	24.7	43.7	16.6	5	2.59
New York	Dec.	42.4	28.9	35.7	29.0	6.0	2	3.07
	Jan.	39.9	25.8	32.9	26.2	7.4	2	3.46
	Feb.	40.1	25.3	32.7	37.9	9.1	2	3.13
Cleveland	Dec.	37.5	24.3	30.9	28.9	11.1	5	2.29
	Jan.	36.0	20.9	28.5	18.7	10.6	4	2.38
	Feb.	36.4	20.8	28.6	20.7	9.7	4	2.12
Pittsburgh	Dec.	37.7	24.1	30.9	11.2	5.6	2	2.51
	Jan.	36.6	21.3	29.0	9.3	6.9	3	2.77
	Feb.	38.3	21.3	29.8	8.3	4.3	1	2.37
Milwaukee	Dec.	32.7	18.7	25.7	26.5	9.5	3	1.48
	Jan.	29.2	14.5	21.9	28.4	11.5	3	1.58
	Feb.	31.8	16.6	24.2	9.9	6.3	2	1.27

AVERAGE ANNUAL NUMBER OF DAYS WITH SNOW GROUND COVER

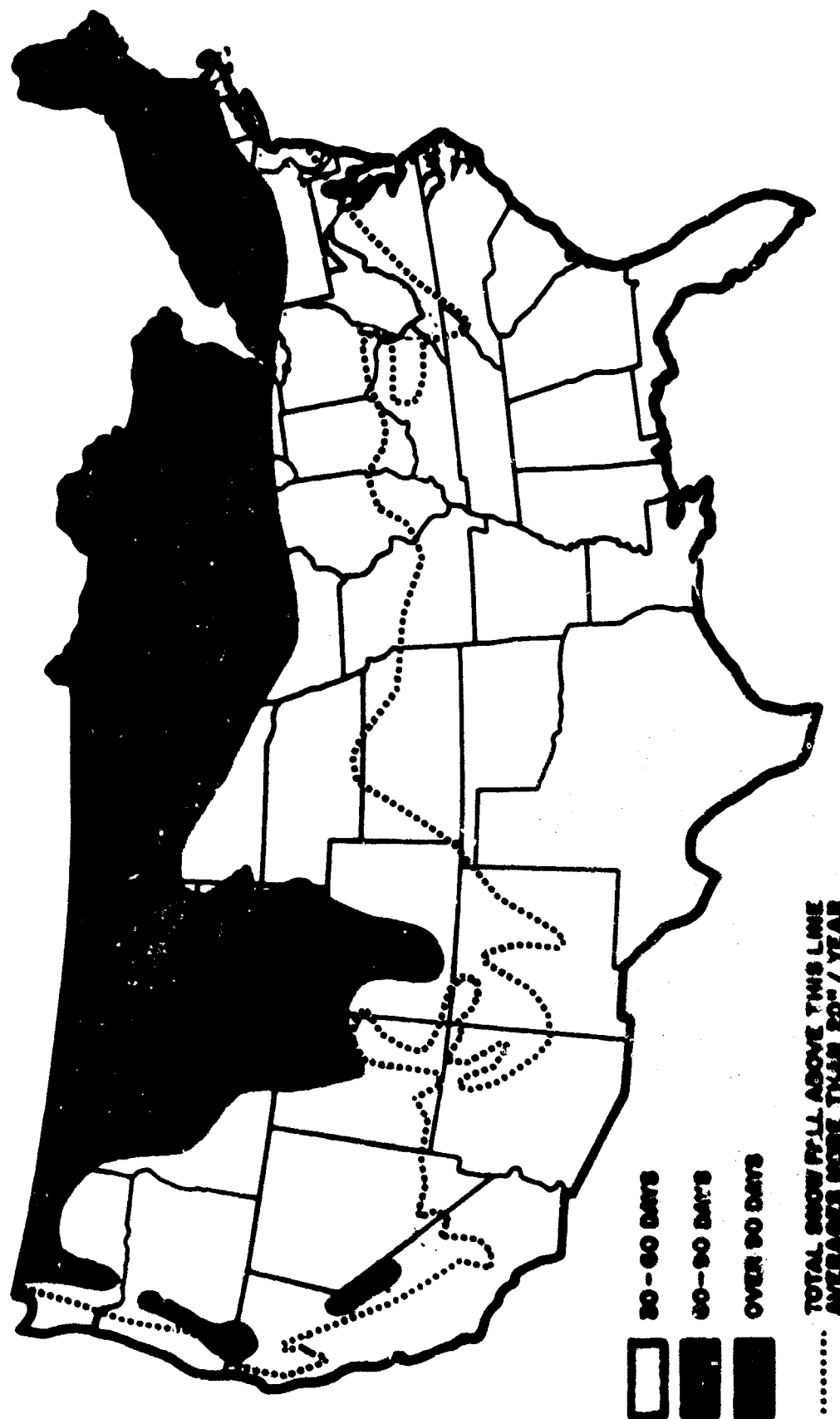


Figure 13

D. Source: Technical Report EP-105
Glaze, Its Meteorology and Climatology,
Geographical Distribution and Economic Effects
Headquarters, Quartermaster Research &
Engineering Command, U. S. Army
Quartermaster Research & Engineering Center
Natick, Massachusetts

Definition and Physical Properties

(a) Definition.- As defined officially by the U. S. Weather Bureau (Haynes, 1947), glaze consists of "....homogeneous, transparent ice layers which are built upon horizontal as well as on vertical surfaces either from supercooled rain or drizzle, or from rain or drizzle, when the surfaces are at a temperature of 32°F or lower." Before 1916, such terms as "sleet", "ice storm", "glazed frost", "silver thaw", "glare ice", and "glaze" had been used interchangeably by many people; the greatest confusion was the widespread use of the word "sleet" for both raindrops frozen solid while still falling through the air and ice formed on objects by rain freezing after it had fallen.

The above items refer only to deposits of ice on surfaces and should be carefully distinguished from the precipitation responsible for the formation of the ice. This precipitation may be described by: light freezing drizzle, moderate or heavy freezing drizzle, light freezing rain, and moderate or heavy freezing rain.

(b) Physical Properties.- The definitions of glaze cited above are primarily genetic in nature and say little about the morphology of the ice. Physical description in the U. S. Weather Bureau definition, for example, is limited to the use of the adjectives "homogeneous" and "transparent", and in the British definition to the use of the adjective "smooth".

Glaze is somewhat related to two other forms of ice, rime and hoarfrost, but differs from them chiefly by its greater density. The high density of glaze results from the fact that the drops of precipitation responsible for its formation are large enough and freeze slowly enough to enable them to flow together before freezing, thus occluding almost all air from the formation.

Another important physical characteristic of glaze is its ability to cling tenaciously to surfaces on which it forms. It does so more readily than rime or hoarfrost because there are more particles in contact with the surface and because it adheres closely to the form of the object (Byers, 1944). The fact that glaze is hard and lacking in friability adds to this tenacity.

Process of Glaze Formation

(a) Temperature Conditions

(1) Combinations of air and precipitation temperatures.- In "The Ice Storms of New England", C. F. Brooks (1914) states there are "....a number of combinations of different conditions of air temperature, rain temperature, and temperature of the object relative to freezing which may produce [glaze]":

I. Temperature of the air below 32°F.

II. Temperature of the air above 32°F.*

A. Temperature of the rain** below 32°F.

1. From passing through a stratum of cold air.
2. From cooling by evaporation in non-saturated air.

B. Temperature of the rain above 32°F but temperature of the object below 32°F.

1. From residual cold.
2. From cooling by evaporation in non-saturated air.

In most cases of glaze formation, the temperature of the air, precipitation, and surface are all at or below 32°F. In fact, it probably can be said that a coat of glaze heavy enough and long-lasting enough to menace aircraft operations forms only under these conditions.

Figure 14 shows glaze storms over the 1928-1953 period.

(2) Surface air temperature.- Observational evidence supports the contention that most glaze forms when the temperature of the air is below 32°F. This same evidence also shows that, although glaze can occur at temperatures far below 32°F, the vast majority of cases are grouped within a rather narrow range between 32°F and 25°. Temperature conditions observed during freezing precipitation at 95 Weather Bureau stations between 1939 and 1948 show that the mean minimum air temperature during glaze formation at most stations was around 25° to 28°F.

*Most of the conditions listed under II are also considered to be capable of occurring under I.

**It is assumed that the word "rain" can refer to fog, drizzle, rain itself, or a mixture of any or all of these with any solid form of precipitation.

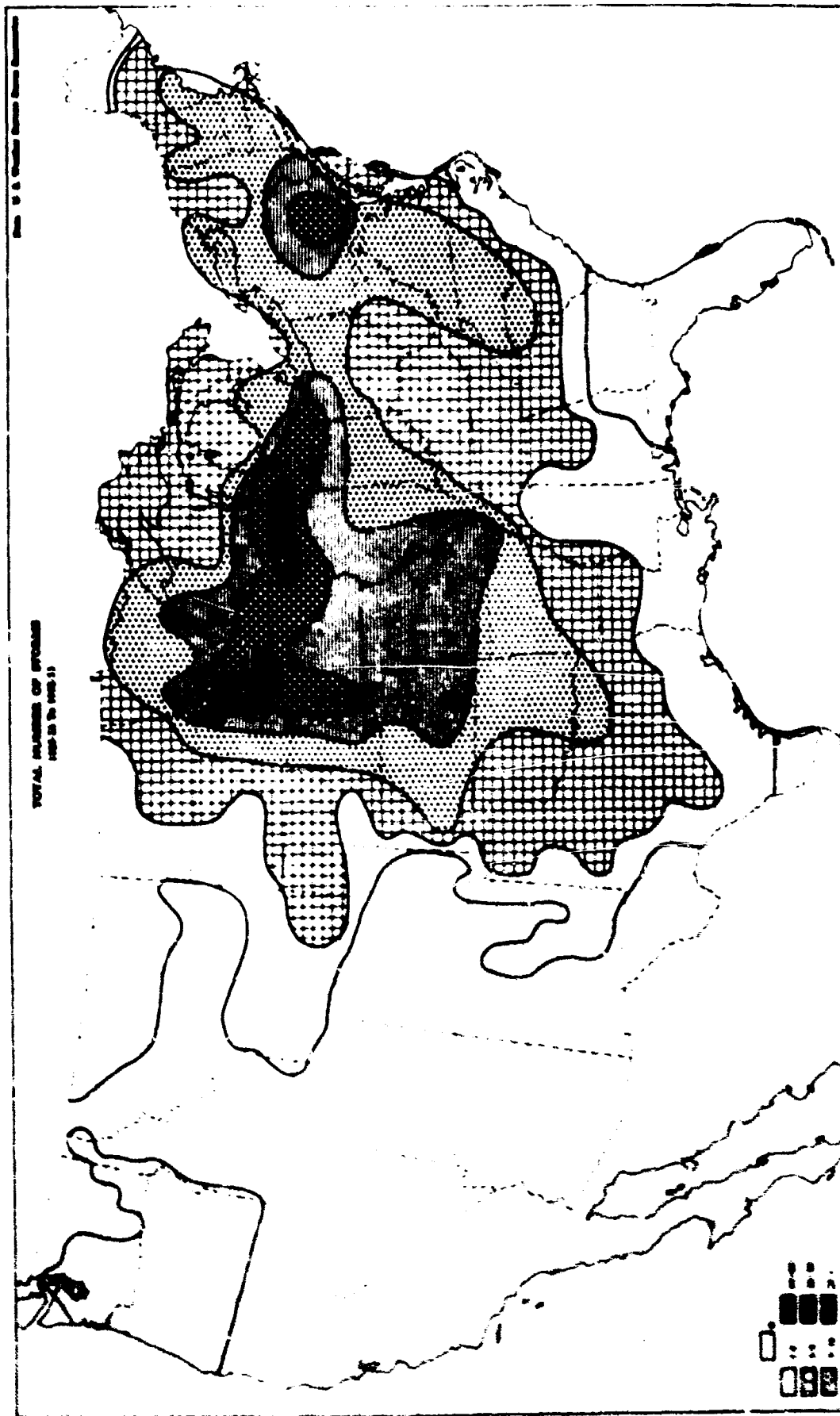


Figure 14

(b) Types of Ice

(1) Snow glaze.- Of greater importance than true glaze because of its considerably higher frequency of occurrence, is what might be called "snow glaze". This originally falls as snow and at first does not seriously hamper automobile and truck traffic. The coefficient of friction of newly fallen snow on highway surfaces, even after some compaction, is sufficiently high to permit passage of most vehicles if caution is used. Steep grades may pose a problem, but even these sometimes may be negotiated if the vehicle is equipped with snow-tread tires or chains and the driver is experienced in winter driving.

However, changes frequently occur in such a snow layer to make it comparable to glaze in density and slipperiness. These changes can be brought about in two ways, frequently in combination. First, there is compaction from the weight of passing vehicles. If traffic is heavy enough, it takes but a short time to compress a layer of snow into a sheet of nearly solid ice. Added to the factor of weight is the heat generated by the friction of tires on the snow. This causes the snow crystals to melt, and when refreezing takes place, as it does almost immediately if the air temperature is below freezing, dense, amorphous ice will form. Road intersections and bridge and hill approaches, where cars are likely to be stalled or stopped temporarily and must spin their wheels to gain momentum, are particularly prone to the formation of hard, slick ice from this frictional effect.

Second, a layer of snow frequently is changed into a sheet of solid ice when snow thaws during the afternoon when air temperature rises above 32°F and then freezes at night. Ice formed in this manner is often almost identical to true glaze in composition; that is, it is solid and amorphous in nature with few vesicles to make it friable. However, it does not form as rapidly as true glaze and its formation can be anticipated through the presence of the snow cover; consequently, precautionary measures, such as the application of abrasives and chemicals, can usually be taken before conditions become too dangerous.

(2) Ice from flooding streams or roadside seepage.- Another form of ice which resembles glaze is formed when water from flooding streams or roadside seepage flows onto a road surface and then freezes because of a drop in temperature. Ice of this type can be exceedingly dangerous because it is usually limited to a few spots along a road and unless ample warning of its possible existence is given, it may cause the motorist to meet with sudden and unexpected disaster.

APPENDIX I

ANNOTATED BIBLIOGRAPHY

ANNOTATED BIBLIOGRAPHY

Literature Search: Scope and Coverage

Topics searched included:

- Deicing
- Freezing, preventing
- Ice, preventing
- Ice, removing
- Melting

The literature search was based on indexes of Chemical Abstracts, Volumes 1 through 56 (June 1962). Reports were searched by ASTIA under the heading "De-icing Runways". In addition, a bibliography on "The Prevention of the Accumulation of Snow, Ice, and Slush on Runways, Taxiways, and Ramps" was provided by Mr. Arthur Hilsenrod, the SRDS project manager.

Emphasis was on compositions of products which have been tested for melting ice. Incidental references to practices of application, or to deleterious effects such as corrosion of metal objects and scaling of concrete surfaces were noted, but a detailed search on these subjects was not made.

Summary

A dozen references to compositions were found. These included modifications of or mixtures with mainly sodium chloride, calcium chloride, urea and formamide. Two articles describe studies of compositions by analysis of heats of solution, phase diagrams, and other physical-chemical properties. Some attention has also been paid to the shape and density of the solid deicers as influencing their rate of action. One novel approach which is radically different is the use of a gas-evolving solid chemical such as a borohydride or an aminoborane, claimed to break up the ice surface.

Practices and problems in application have been noted in four references, none of which were available for review.

Corrosion from deicers is a serious problem and, at least up to 1956, has not been controlled by the use of inhibitors. In this respect, the optimistic laboratory tests have not been supported by field experience.

Finally, the harmful effect of deicers on concrete surfaces has been reported by a number of groups including highway engineers and cement scientists. The common deicers sodium chloride and calcium chloride both have harmful effects on concrete. Protective action at present utilizes an oil coating for the concrete.

BIBLIOGRAPHY

Compositions

1931

S. Keoleian, "Ice-melting composition", U.S. Patent 1,825,151, Sept. 29, 1931; C.A. 26, 269.

The composition consists of NaCl 25%, NH_4Cl 50%, and MgSO_4 25%. Silica sand and water also may be added.

A. C. White and C. E. Clason, "Ice-rotting composition", U.S. Patent 1,787,887, Jan. 6, 1931; C.A. 25, 787.

An ice-rotting substance such as CaCl_2 is mixed with a bouyant material such as powdered cork to form air-including agglomerated granules which will float on water. U.S. 1,787,888 describes ice-rotting compounds formed from an ice-rotting material such as CaCl_2 and a heat-absorbing material such as lampblack which absorbs heat from the rays of the sun.

1951

M. Thuilleaux, "Fusion of ice or snow by means of chemical agents", Ind. chim. belge 16, 109-19 (1951); C.A. 45, 10004.

The fundamental principles involved in the use of the chlorides of Na, Ca, and Mg to melt ice or snow are reviewed. Data are included on cryohydric points and solubilities, heat of soln., elec. conds., corrosiveness, and hygroscopicities. It is concluded that, from a purely tech. point of view MgCl_2 and CaCl_2 are superior to NaCl. The latter, however, is most commonly used, probably for economic reasons.

1956

I. G. Poppoff (Stanford Research Inst.), AD-97,917, "Prevention of Ice Formation on Radomes, Progress Report Sept. 1-Oct. 1, 1956".

The effectiveness of aqueous nickel chloride solution and mixtures of isopropanol and ethylene glycol at -8°C

was investigated. A tabulation is given of the concentrations of anti-icing agent required to prevent ice formation for nickel chloride (30% by wt. aqueous solution) and ethylene glycol-isopropanol mixtures.

1957

P. J. Hearst (U. S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, Calif.), "Deicing Materials for Military Runways", Technical Memorandum M-124, Project NY 000003-4.02.

Various noncorrosive chemicals were investigated to determine their suitability and effectiveness as materials for melting ice on runways. Properties studied included: the ability to lower the freezing point of water, the heat of solution, and the rate of melting ice. It was found that in order to have a reasonably high rate of melting ice, a deicing material must be heavier than water. Formamide containing 20 percent urea and 5 percent water as freezing point depressants is the best deicing material found for use at temperatures as low as -18 degrees centigrade (0 degrees Fahrenheit). This mixture is effective at still lower temperatures if a certain amount of slush formation can be tolerated and if it is applied at temperatures no lower than about -18 degrees centigrade. At much lower temperatures ammonium acetate may be a satisfactory deicing material.

1958

E. R. Pounder, M. P. Langleben and M. A. Smith (McGill University, Canada), AD-162,969, "Ice Research Project, Annual Report for 1957".

Ice formed from a melt containing small quantities of certain organic solvents and traces of a variety of long-chain organic materials has a mechanical strength as low as 5 to 10% of that of normal ice, frozen from pure water or water containing the usual traces of inorganic salts. This effect offers a possible method of de-icing under conditions where the use of salts such as calcium chloride is ruled out by their corrosiveness. Preliminary tests on airport runways show some promise of a method of combatting freezing rain conditions. Further study of impure ice, using a polariscope, has shown an interesting variation with depth of the orientations of the optic axes of crystals in an ice sheet. This has led to a theory of the details of the freezing process in still water and water disturbed by currents. Sea ice studies have been made, largely in the field, seeking to correlate the

various independent variables with the properties of this peculiar material. Some progress has been made, both in theoretical understanding of the properties of sea ice and also in the direction of simple tests which will permit quick prediction of the mechanical strength of an ice sheet.

1959

Anon., "Ice Melting Compound", Street Eng. 4 (8), 54, August 1959; not available.

1960

D. J. White (Central Experimental and Proving Establishment, Canada), AD-241,551, "Runway Ice Control Using Crystal Urea, Interim Report May 1960".

Experimental field tests were conducted on a chemical, known commercially as Crystal Urea, to determine the characteristics of this chemical for removing ice from roadways. The potential of this chemical as a means for removing ice from aircraft runways and other airfield surfaces was also assessed. Crystal Urea mixed with sand, in various proportions, was spread on ice covered roads at RCAF Station Rockcliffe throughout the Winter of 1959-60, and evaluated in comparison with Calcium Chloride and Highway (Rock) Salt de-icing agents. It was concluded that Crystal Urea is effective in removing ice at temperatures above 10°F., but is not as effective as Calcium Chloride or Salt. In addition, Crystal Urea is considerably more expensive than Calcium Chloride and therefore cannot be economically justified for use as a de-icing agent. It was further concluded that Crystal Urea is potentially suitable as a runway de-icing agent, and could be used in conjunction with existing (sand-bonding) RCAF emergency ice control methods, provided current laboratory tests prove favourable.

1961

G. C. Schilberg (Pittsburgh Plate Glass Co.), "Sodium chloride-calcium chloride compositions", U.S. Patent 2,988,509, June 13, 1961; C.A. 55, 25104.

The deicing ability of NaCl-CaCl₂ mixtures is enhanced by a process which produced particulate, porous compns. contg. 0.05-5 parts by wt. NaCl/part CaCl₂ and whole bulk density is 25-50 lb./cu.ft. Thus, NaCl 2, flake CaCl₂ (contg. 80% CaCl₂ by wt.) 0.66, and H₂O 0.21 lb. is mixed and warmed gently to 45°, whereupon the mixt. becomes plastic and

putty-like. It is then extruded into thin ribbons, cut into pieces <1 in. long and 0.25-0.5 in. in diam., and dried gently at 110°. This and similar products penetrate ice at a faster rate and to a greater depth than mere NaCl-CaCl₂ and CaCl₂-rock salt mixts.

1962

Anon. (Solvay and Cie), "Anti-snow and ice composition", Belg. Patent 522,801, Sept. 24, 1962.

Anti-snow and ice composition suitable for road and rail treatment comprises NaCl and as corrosion inhibitor a mixture comprising (a) an ester soluble in all proportions in mineral oils obtained from a 12-18 C fatty alcohol laurate. The composition also prevents caking of the salt.

R. J. Grantham (Callery Chem. Co.), "Gas-evolving protective coating", U.S. Patent 3,019,114, Jan. 30, 1962; C.A. 56, 13043.

The title coatings, useful in protecting metal surfaces from oxidative deterioration and in breaking up adherent ice coatings on catwalks, ladders, ship decks, and superstructures, and prep'd. by adding 0.1-10% of an amine borane, alkali metal borohydride, or alk. earth borohydride to a protective film-forming compn. The borohydrides generally evolve gas more rapidly and have a shorter active life than the amine boranes, so that combinations of the 2 types may be used to produce modified gas-evolution characteristics.

Undated

Anon. (Salt Institute, Chicago), "Salt for Ice and Snow Removal"; not available.

Practices of Techniques

1948

E. G. Moody, "Snow and ice removal practices in Michigan municipalities", Michigan Municipal League Information Bulletin No. 58, 1948, 19 pp.; not available.

1955

Anon, "Ice and Snow on Runway", ICAO Circular 43-AN/38. Contains snow and ice problem at airports. Considers, anti-skid brakes, special tires, braking parachutes, reverse thrust for aircraft.

Considers numerous ground techniques such as raised runways, heating, sanding, use of arresting gear.
Contains articles -

1. "Snow Handling on Canadian Airports" by D. B. Rees, Air Services, Department of Transport, Canada, Ottawa, Ontario.
2. Report on procedure for correction of minimum runway length under winter conditions at Oslo Airport, Fornebu by O. Kellerud, Airport Manager Oslo, March 1959.
3. Snow Removal at Air Bases, Directorate of Air Bases, France 1953.

1960

Charles M. Ganger, Samuel L. Sola, James R. Dowty, Townsend Engineering Products, Santa Ana, Calif., "The Removal or Prevention of Snow, Ice and Debris", Report No. 472, Bureau of Research and Development under Project OA1-8121, Contract FAA/BRD-67, November 18, 1960.

Airports' reports on the survey to determine the nature of any existing problems on the subject of snow, ice and debris removal; determines the methods of operation employed, equipment being used; critical area, etc., to assist in the establishment of guide lines for possible future research and development on the subject of snow, ice and debris removal.

1961

Anon. (Air France), "Deicing of, and Snow Removal from, Runways, Auxiliary Roads and Parking Areas of Airports; not available.

Corrosion

1950

J. A. Temmerman and A. Sterlin, "Control of corrosion by salt used for de-icing highways", Corrosion 6, 391-4 (1950); C.A. 45, 1002.

The use of NaCl for ice and snow control on streets and highways has caused concern with respect to increased corrosion of automobile bodies. Chromate inhibitors were not considered owing to their toxicity, but good results

were obtained in lab. tests on NaCl solns. over 9% NaCl by wt. contg. a proprietary (Nalco No. 818-C) inhibitor (polyphosphate-nitrite base formula) to the extent of 1 to 2% by wt. of the NaCl. In dil. solns. (1% NaCl) 1% inhibitor caused increased corrosion as compared with the uninhibited soln.; this was not true for higher inhibitor concns. The use of salt contg. this inhibitor on Rochester streets for 2 seasons has caused a complete absence of complaints from automobile owners, in comparison to the numerous earlier complaints.

1952

F. E. Kulman, et al. (Consolidated Edison Co. of N.Y., Inc.), "Corrosion by deicing salts", Corrosion 8, 225-6 (1952); C.A. 46, 7506.

This committee was organized to investigate corrosion caused by de-icing salts to metallic equipment above and below the ground surface and to study and recommend mitigation measures. Field investigations over the past 8 yrs. have shown the complexity of this problem. Chromate and phosphate inhibitors incorporated in the de-icing salt in concns. of approx. 1% by wt. have not prevented the corrosion to the extent that lab. alternate immersion testing would indicate.

1956

R. J. Wirshing (General Motors Corp.), "Effect of De-icing Salts on the Corrosion of Automobiles", Highway Research Board Bulletin No. 150, January 1956, 4 pp.

Corrosion is more prevalent on cars used in cities where salt is spread on icy streets. Whether or not inhibitors are used (as in Rochester, N.Y.) has little effect.

Scaling

1936

H. F. Gonnermann, A. G. Timms and T. G. Taylor, "Effect of calcium and sodium chlorides on concrete when used for ice removal", J. Am. Concrete Inst. 8, 107-22 (1936); C.A. 31, 1177.

Concrete (35 days old) or normal mix and without protective coating will scale badly on repeated removal of ice with NaCl or CaCl₂. Protective treatments with boiled linseed oil, thinned with turpentine, are commended where exposure of concrete to these salts or their solns. is considered.

1952

K. Walz (Tech. Hochschule, Stuttgart, Ger.), "Salts used for removing ice and snow, and their effect on paving and other materials", Werkstoffe u. Korrosion 3, 49-54 (1952); C.A. 46, 7681.

$MgCl_2$ should not be used on concrete surfaces since it attacks the cement particles. $CaCl_2$ and $NaCl$ are not harmful when spread evenly and not too frequently. With frequent spreading of salt, peeling and disintegration of the surface must be expected. The resistance of concrete to attack by the salts is improved by adding various materials to the concrete or by oil impregnation. On tar, asphalt, or stone pavements, no harmful effect is observed. Salt deposits on unprotected steel structures cause rusting. Vegetation is not adversely affected by the use of the salts. The amt. of rusting on vehicles depends chiefly on the status of the surface coatings and their upkeep. Lab. tests indicate that there is practically no damage to rubber, leather, and fabrics under normal conditions.

1956

G. J. Verbeck and P. Klieger (Portland Cement Association), "Studies of 'Salt' Scaling of Concrete", Highway Research Board Bulletin No. 150, January 1956, 13 pp.

"Salt" scaling (or more appropriately "deicer scaling") is caused by such deicers as calcium chloride, sodium chloride, urea or ethyl alcohol.

The mechanism of scaling appears to be physical rather than chemical. The most severe scaling occurred when the thaw solution was refrozen on recycling, rather than replacing it with fresh water and then freezing. Low concentrations of deicer may cause more scaling than 8-16% concentrations.

A. G. Timms, "Resistance of concrete surface to scaling action of ice-removal agents", Natl. Acad. Sci.-Natl. Research Council, Publ. No. 416, 22-50 (1956); C.A. 53, 1672.

This report is a resume to date of investigations conducted to test materials and procedures for protecting concrete pavements against scaling and disintegration caused by $CaCl_2$ and other thawing agents used for ice removal. Both lab. and field tests have shown that concrete contg. more than 4% air is substantially more resistant to scaling than non-air-entrained concretes and concretes contg. less than 5% air. Cured concrete

can be rendered more resistant to salt scaling by coating it with a mineral oil. Scaling resistance is improved in both air-entrained and non-air-entrained concretes by vacuum treating the surfaces of the placed concrete.

1962

W. E. Grieb, G. Werner, and D. O. Woolf, "Resistance of Concrete Surfaces to Scaling by De-Icing Agents", Highway Research Board Bulletin No. 323, January 1962, pp. 43-62.

This paper reports the results of tests on more than three hundred 16- by 24- by 4-in. slabs subjected to outdoor freezing and thawing with calcium chloride. A previous paper reported results of tests on some of these slabs exposed to 51 cycles of freezing and thawing. These tests were continued to 154 cycles.

Additional tests were made to study the effect of various protective coatings and various admixtures on the scaling of concrete caused by de-icing agents. These tests indicate that surface protective coatings were, in general, of little benefit in preventing scaling.

Some of the admixtures tested were beneficial in preventing scaling. However, the increased resistance to scaling in most cases appears to be related to the air content and the water-cement ratio of the concrete.

The surface protective coatings tested included silicones, latexes, and curing materials. The admixtures included air-entraining agents, fly ashes, silicones, and latexes.