

Ice-Melting Properties and Storage Characteristics of Chemical Mixtures For Winter Maintenance

WILLIAM E. DICKINSON, Chief Engineer, Calcium Chloride Institute, Washington, D. C.

● THE PROBLEM of keeping roads clear for travel despite snow and ice is a relatively modern one. Prior to World War II only a few progressive states had extensive winter maintenance programs. With the increased highway investment of the present, and proposed for future highways, it is appalling that the system of interstate highways, along with other vital roads and streets, is not clear and available for year-round travel.

Although public pressure alone will bring about improved winter maintenance procedures, there is consolation to maintenance engineers that better winter maintenance pays for itself. This fact was recognized as early as 1941 by Michigan highway authorities.

Comparisons of winter maintenance costs and gas tax revenue from 1937 to 1941 in Michigan show that revenue for the eight non-winter months increased 16 percent, whereas the winter revenue increased 33 percent. An additional \$1.3 million in revenue represented additional mileage traveled, made possible by improved winter road conditions. These safer driving conditions were brought about by an increase of only \$600,000 in the winter road maintenance budget.

There are three basic procedures in winter maintenance, as follows:

1. Plowing.
2. Sanding.
3. Chemical application.

This report deals with the use of chemicals, the two customarily used being calcium chloride and sodium chloride. They offer distinct advantages of availability, low cost, and effectiveness. Well-established properties are as follows:

Property	Calcium Chloride	Rock Salt
Lowest freezing point	-58 F	-6 F
Moisture attraction	Deliquescent; attracts moisture from air and goes into solution	Non-deliquescent; does not attract moisture for solution
Heat of solution	Positive; liberates heat as it goes into solution	Negative; requires or takes on heat as it goes into solution

The ice-melting capacities of the two chemicals are shown in Tables 1 and 2, which reveal that, given unlimited time, sodium chloride melts more ice than Type 1 calcium chloride¹ down to 10 F (based on Type 2 calcium chloride this would be approximately 20 F). As to the rate of ice melting, the data show a considerably higher rate for calcium chloride.

With this established information on ice-melting properties of the two chemicals,

¹ ASTM-D98 and AASHTO-M-144: Type 1—regular flake, 77 percent min. CaCl_2 ; Type 2—concentrated flake, pellet or other granular, 94 percent min. CaCl_2 .

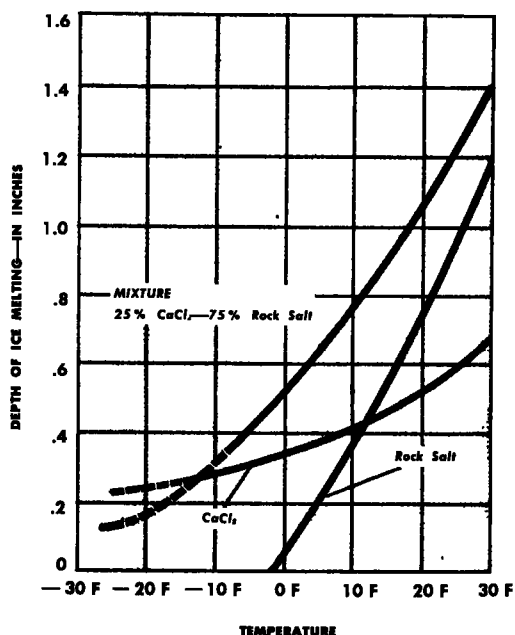


Figure 1. Depth of ice melting at 2 hr, by particles of equal weight.

and with increased use of chemicals in the field, it was logical that engineers would try to take advantage of the best properties of each by using them in combination. Initial field reports of the use of mixtures were variable, but encouraging enough for the Calcium Chloride Institute to undertake a research program, first in the laboratory and later in the field, to try to establish expected results under various conditions. An initial study showed that a 3-parts-salt-to-1-part-calcium-chloride mixture melted a greater depth of ice in 2 hr at all temperatures down to -10 F than did either of the two chemicals used alone (Fig. 1).

The next step in the studies was sponsorship of research at the University of Minnesota, the Ohio State University and

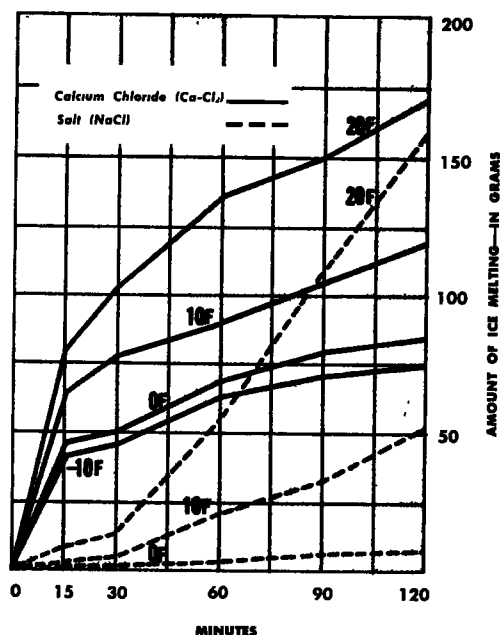


Figure 2. Amount of ice melted in 15 to 120 min; 350 gm ice in 7- by 11-in. pan; 40 gm chemical (based on 100 percent NaCl or CaCl₂). No NaCl reaction at -10 F.

TABLE 1
ICE-MELTING ABILITY OF CHEMICALS ON
A WEIGHT BASIS

Temp. °F	Ice Melted per pound of Chemical (lb)	
	77 % Flake CaCl ₂	Pure NaCl Granules
30	31.1	46.3
25	10.4	14.4
20	6.8	8.6
15	5.5	6.3
10	4.8	4.9
5	4.4	4.1
0	4.0	3.7
-6.5	3.7	3.2
-10	3.5	-
-20	3.2	-
-30	2.9	-

TABLE 2
POUNDS OF ICE MELTED PER POUND OF CHEMICAL¹

Temp. °F	15 Min		30 Min		1 Hr		6 Hr	
	Cal. ²	Sod.	Cal. ²	Sod.	Cal. ²	Sod.	Cal. ²	Sod.
0	1.3	0.07	1.7	0.1	2.0	0.3	2.3	1.9
10	1.7	0.5	2.0	0.9	2.4	1.6	2.8	3.8
20	2.5	1.6	3.1	2.6	3.8	4.1	5.3	7.5
26	2.6	1.8	3.4	2.9	4.4	4.3	7.1	9.5

¹ Chemical applied at the rate of 0.8 lb per sq yd.

² Type 1 calcium chloride (77 % min. CaCl₂).

in Michigan, tied in with field experiments. Except for Michigan, field testing was lacking; but the total contribution of the studies was considerable. For example, at the University of Minnesota, as reported by Kersten et al. (1), tests were run on the amount of ice melted in 15 to 120 min at varying temperatures. These tests confirmed the faster ice-melting action of calcium chloride at all temperatures and the greatly reduced effectiveness of salt at lower temperatures (Fig. 2).

Field studies in Michigan (see Appendix) showed that there was an average increase of 63 percent in clear area on icy pavements 2 hr after applications of a mixture of 67 percent salt and 33 percent calcium chloride. Indications are that at a shorter time interval, mixtures would be more effective even at the high temperatures encountered (25 F to 31 F) where salt normally does its best job. With lower temperatures and other factors entering in, the greater effectiveness of calcium chloride-salt mixtures would undoubtedly be more pronounced.

Due to a lack of cooperation from the weather, the field experiments conducted at Ohio State University in cooperation with the Ohio Department of Highways were limited. Eberhart's (2) review of the research previously done represents a valuable reference as to basic properties of calcium chloride and sodium chloride, some of which has been previously referred to. A further contribution in the Ohio report (2) is an analysis of the importance of relative humidity as a factor influencing the length of time required to initiate the melting process by chemicals.

The report analyzes the ability of each of the chemicals to attract moisture at various relative humidities. It states that calcium chloride melts ice faster because of its greater moisture-attracting ability and that the presence of moisture acts to speed the initial ice melting. Sodium chloride requires a relative humidity of 75 to 100 percent to attract moisture easily. Calcium chloride will attract moisture easily with relative humidities of 46 to 60 percent at temperatures of -15 F to +32 F. The vapor pressure of saturated calcium chloride solutions is less than the vapor pressure of saturated salt solutions at any temperature and calcium chloride melts ice faster at any temperature.

While these sponsored studies were under way considerable field information was being gathered. One of the best sources of information on the use of chemicals and



Figure 3. Maintenance personnel of the Ohio Turnpike Commission check free-flowing pile of chemical mixture after several weeks storage under tarpaulin.

TABLE 3

RESULTS OF FIELD TEST A, BULK STORAGE TESTS, DRY ROCK SALT AND TYPE 1 REGULAR CALCIUM CHLORIDE

Conditions of Tests:

Stockpiles in abandoned structure 500 ft from Detroit River, open on sides, but protected by roof from direct rain or snow.
 Stockpiles placed on tar paper on dirt floor.
 Stockpiles varied from 500 to 800 lb of mixed materials.

Building sufficiently open to maintain same temperature and humidity as outside.
 Stockpiles placed October 14, 1957 and observed monthly for 6 months.
 Mixing done in small concrete mixer.

Test Pile	% Dry Rock Salt	% Calcium Chloride	Condition After Six Months
1	100	0	No loose salt layer on top of crust. 1 - 1½-in. extremely hard crust, (difficult to break). Free flowing underneath.
2	85	15	1-in. loose salt layer on top of crust. ¾-in. hard crust, (easily broken). Free flowing underneath.
3	75	25	¾-in. loose salt layer on top of crust. ¾-in. hard crust, (easily broken). Free flowing underneath.
4	65	35	1-in. loose salt layer on top of crust. ¾-in. medium hard crust, (easily broken). Free flowing underneath.
5	50	50	½-in. loose salt layer on top of crust. ¾-in. soft crust, (easily broken). Free flowing underneath.
6	0	100 Type 2	½-in. gummy material on top of crust. 1-in. hard crust, (easily broken). Free flowing underneath.
7	0	100 Type 1	No loose layer on top of crust. 1½-in. soft crust, (easily broken). Free flowing underneath.

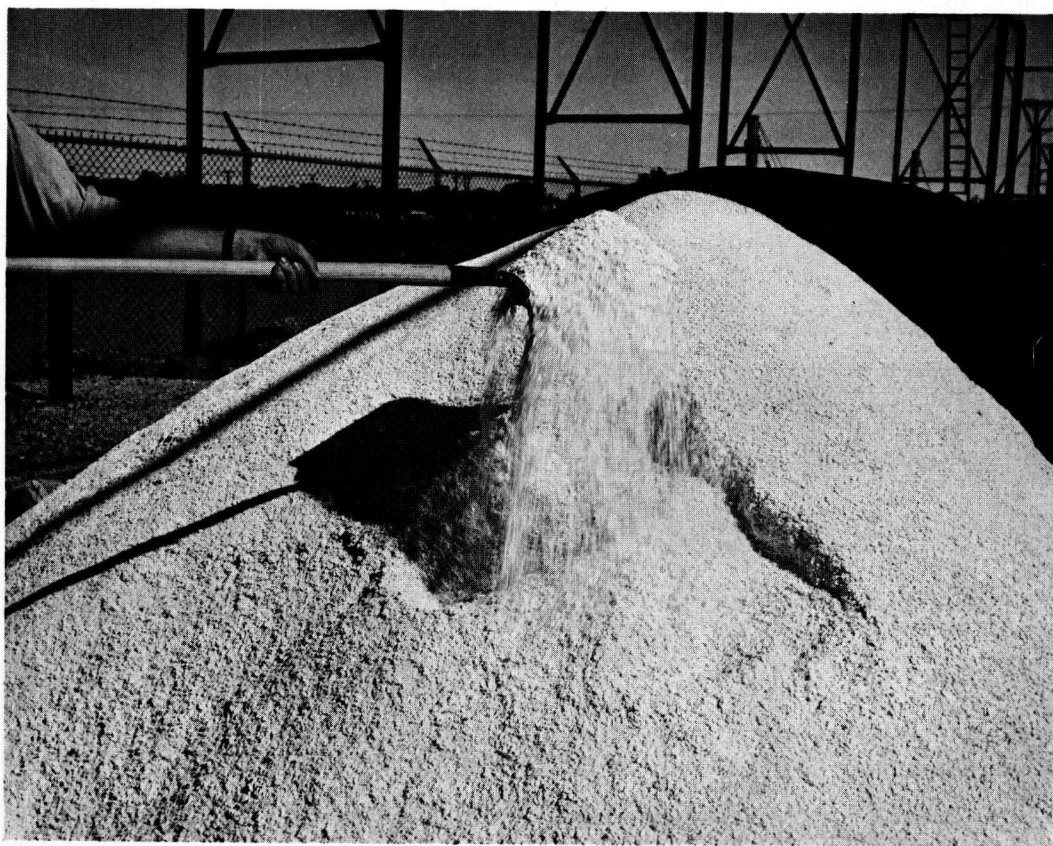


Figure 4. Completely dry and free-flowing condition of Type 1 calcium chloride after several months outside storage under polyethylene cover.

mixtures under excellent control has been the Ohio Turnpike. L. G. Byrd, Maintenance Engineer, has experimented with various combinations during the past three years. The present winter maintenance procedures on the Turnpike are based on the use of both direct chemicals, salt-calcium chloride mixtures (Fig. 3), abrasives, and plowing. There are four basic storm conditions which merit one of these treatments. These are described and issued as a basic guide for each maintenance section on the Turnpike, thus utilizing the best procedure available for conditions encountered.

STORAGE

Having established the value of mixtures under certain conditions and with an increasing interest in their use from the field, the next problem was how to make the combinations easy to use. Initially the two chemicals were mixed at the time of use. This was not the most desirable method, as storms tend to strike in the middle of the night. The ideal situation would be to have the chemicals premixed and immediately available for use. The question then arose as to whether bulk calcium chloride and salt mixtures could be stored successfully.

The Calcium Chloride Institute, through its members, investigated the problem during the winter of 1958. Calcium chloride can be stored in bulk when protected from direct precipitation. Indications are that practical proportions (2 to 1, or 3 to 1) of salt to calcium chloride can be premixed and stored without difficulty (Fig. 4) with the following restrictions:

TABLE 4
RESULTS OF FIELD TEST B, BULK STORAGE TESTS, ROCK SALT WITH VARYING MOISTURE CONTENT AND TYPE 2 CONCENTRATED CALCIUM CHLORIDE

Conditions of Tests:

Stockpiles in an exposed location on a lime lake in Ohio, protected by tarpaulin for the only cover
Stockpiles placed directly on hardened lime lake.

Stockpiles placed March 26, 1958, and observed and photographed on April 24 and May 29.
Stockpiles were 1,000 lb of mixed materials
Mixing done in small concrete mixer.

Test Pile	% Moisture in Salt	% Salt	% Chloride	Condition After One Month	Condition After Two Months
1	0	90	10	1-in. salt layer on surface. 1-1½-in. crust. Free flowing underneath.	1-in. salt layer on surface. 2-in. hard crust. Free flowing underneath.
2	0	80	20	¼-½-in. salt layer on surface. ½-in. crust, (easily broken). Free flowing underneath. Some calcium chloride on surface.	1-in. salt layer on surface. 1½-in. crust, (easily broken). Free flowing underneath. No calcium chloride on surface.
3	2	75	25	¼-½-in. salt layer on surface. ½-in. crust. Free flowing underneath. Some calcium chloride on surface.	¼-in. salt layer on surface. 1½-in. hard crust. Free flowing underneath. No calcium chloride on surface.
4	4	75	25	¼-in. salt layer on surface. 1-2-in. crust. Free flowing underneath (slight set).	¼-in. salt layer on surface. 1½-2-in. crust. Material slightly set just underneath the crust. Interior free flowing.
5	4	65	35	¼-½-in. salt layer on surface. ½-¾-in. crust. Interior free flowing with hard clusters, (easily broken.)	¼-in. salt layer on surface. ¾-in. hard crust. Interior free flowing with hard clusters, (easily broken).
6	6	65	35	¼-½-in. salt layer on surface. ½-1-in. hard crust. Interior firm but breakable. Some calcium chloride on surface.	¼-in. salt layer on surface. 3-4 in. hard crust on surface. Secondary crust of 3-in. that is firm but breakable. Interior free flowing. No calcium chloride on surface.
7	6	72	28	¼-½-in. salt layer on surface. Pile set to a depth of at least 5 in. Difficult to break.	¼-in. salt layer on surface. Pile completely set.
8	6	55	45	¼-in. salt layer on surface. 1-in. crust. Underneath fairly free flowing but contains small hard clusters.	¼-in. salt layer on surface. 3-4 in. hard crust. Interior free flowing but contains some small hard clusters.



Figure 5. General view of Field Test B, with various mixture stockpiles that had been tarpaulin covered and observed for two months. Storage tests were also conducted in sheds at rear.

1. Salt (and calcium chloride) must be dry (less than 2 percent surface moisture).
2. The mixed chemicals must be protected from direct rain.

Details of the field tests on bulk storage are shown in Tables 3 and 4. Field Test A involved various proportions of dry salt and calcium chloride, stored in open piles under a roof, the building being open on the sides. Results from Field Test A (Table 3) are summarized as follows:

1. In all cases, materials underneath the crust remained as dry and workable as when placed in position. The crust served as a protecting cover.
2. With the exception of the 100 percent rock salt, the crust, although quite hard in some cases, was sufficiently thin to allow easy break-through to the protected portion. The loose material on the surface over the crust (in the cases of salt and chloride mixtures) appeared to be made up of salt particles. Apparently the calcium chloride dissolved and moved away from the surface, forming a crust below the surface and leaving salt particles on the surface.
3. The condition of the stockpiles did not change much, if any, after a month or so. There was indication that after two or three months the crust thickness decreased somewhat on piles No. 2 through No. 5. In fact, these four piles all had the same crust thickness of $\frac{3}{4}$ in. on the average at the end of the fifth and six months.
4. Both Type 1 and Type 2 calcium chloride stored better outside under shed cover than did straight rock salt.
5. Mixtures of dry salt and Type 1 calcium chloride stored better outside under shed cover than did straight salt.

Field Test B involved various combinations of salt and calcium chloride. The moisture content of the salt varied from 0 to 6 percent. Piles were in the open, tarpaulin covered, on bituminous pads. Results from Field Test B (Table 4) are summarized as follows:

1. The proportion of 20 percent calcium chloride to 80 percent salt containing little or no moisture resulted in a mixture which withstood two months storage very well (Fig. 5). The $1\frac{1}{2}$ -in. crust which formed was easily broken and the material underneath the crust was free-flowing. The proportion of 10 percent calcium chloride to 90 percent salt resulted in a 2-in. crust, which was very hard and difficult to break. The material under the crust was free-flowing.
2. The mixture of 25 percent calcium chloride and 75 percent salt containing 2 per-

cent moisture resulted in a $1\frac{1}{2}$ -in. hard crust after two months storage. The crust was difficult to break; material underneath was free-flowing (Fig. 6).

3. The mixture of 35 percent calcium chloride and 65 percent salt containing 4 percent moisture resulted in a $\frac{3}{4}$ -in. hard crust. The interior was free-flowing, but contained a few hard clusters. The proportion of 25 percent calcium chloride to 75 percent salt resulted in a $1\frac{1}{2}$ - to 2-in. crust, which was also very hard. The material just underneath this crust was slightly set, but the interior was free-flowing.

4. The mixture of 28 percent calcium chloride and 72 percent salt containing 6 percent moisture resulted in a pile that was completely set. The proportion of 35 percent calcium chloride to 65 percent salt resulted in a 4- to 6-in. hard crust with a secondary crust of 3-in. thickness which was firm but breakable. The interior was free-flowing. The proportion of 45 percent calcium chloride to 55 percent salt resulted in a 3- to 4-in. hard crust. The interior was free-flowing, but contained some small, hard clusters.

Tentative recommendations for storage of mixtures based on these field tests are: Type 1 or Type 2 calcium chloride can be used in the following proportions with rock salt containing moisture up to 4 percent:

1. For salt containing little or no moisture, a 4-to-1 or 3-to-1 mixture of salt to calcium chloride should be used to achieve good storage characteristics.

2. For salt containing 2 percent moisture, a 2-to-1 mixture of salt to calcium chloride is indicated. This will give a $\frac{1}{2}$ -in. crust and be free-flowing underneath.

3. Up to 4 percent salt moisture, a 3-to-2 mixture of salt to calcium chloride is indicated. This will give a crust not exceeding $\frac{3}{4}$ in., and with the interior material free-flowing.

Thorough field mixing is recommended, as the tests were based on almost ideal mixing methods.

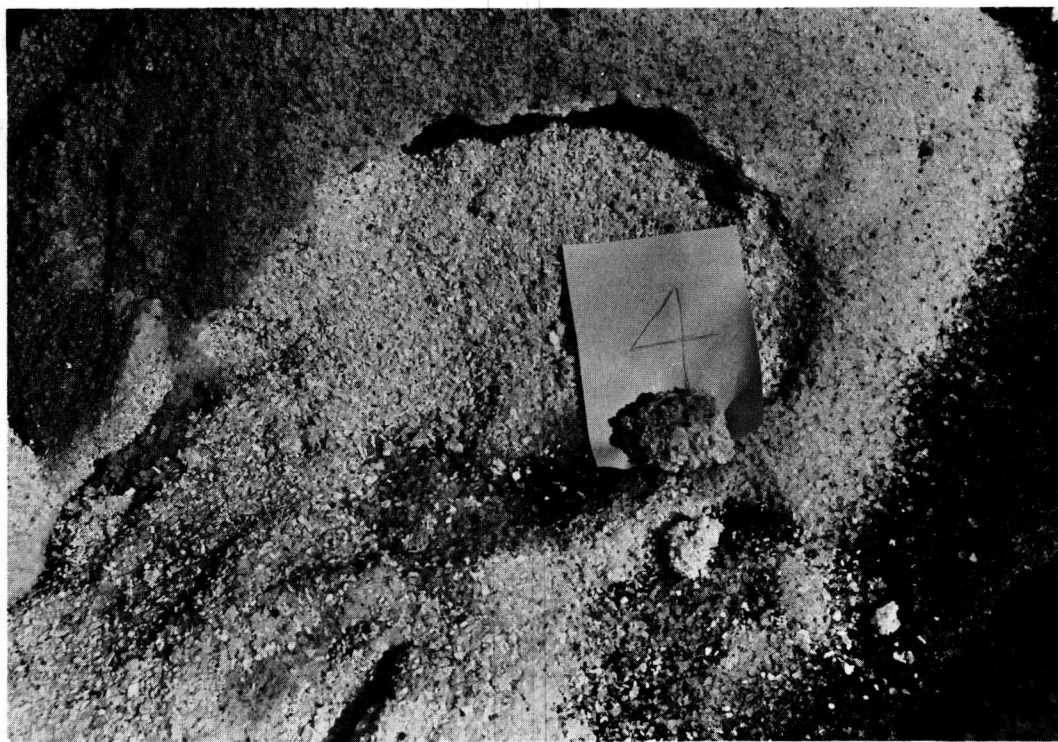


Figure 6. Condition of test pile 4 in Field Test B, with mixture of three parts dry salt to one calcium chloride under 1- to 2-in. crust.

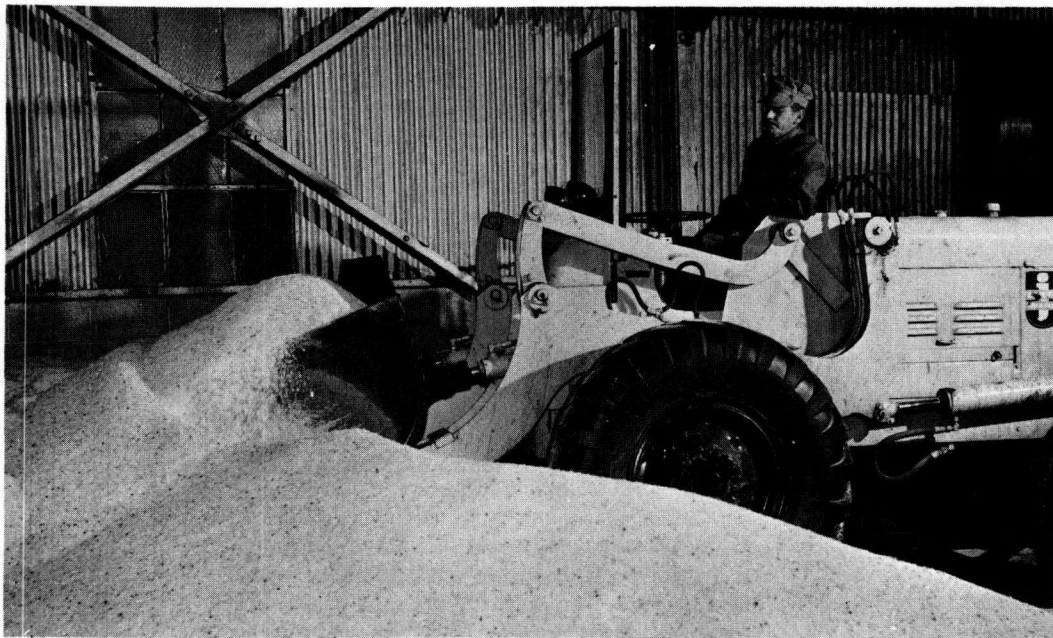


Figure 7. Front-end loader is used to pre-mix bulk salt and calcium chloride at the Sidney Division, Ohio State Highway Department.

As indicated by Test B, for rock salt containing high moisture content (above 4 percent and up to 6 percent), a 1-to-1 mixture of salt and Type 2 calcium chloride should be made.

The successful storage of mixtures under the foregoing restrictions is based on sound reasoning. Calcium chloride added in increasing amounts to salt with increasing moisture contents absorbs the excess moisture and keeps material underneath free-flowing.

Evidence of the interest in mixtures, and opportunity to learn more from field experience is found in a number of tests during the winter of 1958. Some of the major ones are indicated in Table 5.

TABLE 5

Location	Description
New York Thruway (Weedsport Section)	30 miles to use 3 salt-1 calcium chloride. Involves 4,800 tons of mixtures. Mostly direct, but in combination with abrasives when desired. To be compared with adjacent 10-mile section, where straight salt will be used.
Massachusetts Department of Public Works (near Walpole and Norwood)	Five 4,000-ft sections. Four chemical sections with variable proportion and quantities per mile. One section with sand and chemical mixture.
Connecticut Highway Department	Four test sections in two districts, with chemical mixtures direct and in combination with abrasives.
Ohio Highway Department	Sidney Division is premixing on 2:1 basis for comparison with straight salt (Fig. 7).
City of Philadelphia	Calcium chloride being mixed with salt for faster action.

In addition to those listed, many cities and states are experimenting with chemical combinations on a less formal basis.

Another test series under way involves heavy chemical treatments of abrasives. Direct chemical application is increasing, but there is always a need for abrasives under certain conditions of traffic and weather. Storage characteristics of abrasives with greater than the normal amount of chemical treatment are still needed.

The tests can be outlined as follows:

1. Materials proportions (by weight):

9 abrasive—1 chemical.
3 abrasive—1 chemical.
1 abrasive—1 chemical.

2. Moisture contents of abrasives:

Sand and limestone—0, 3, 6 percent.
Cinders—0, 7, 14 percent.

3. General:

Size of piles—1,000 lb total weight.
Storage—open, no cover.
Blank—1 untreated pile, dry when stored.
Observations—monthly through winter to determine crusting and condition of pile underneath. Temperature and precipitation from nearest weather station.

Thus, in addition to the information reported here, there will be additional findings from the tests continuing during 1959. Meanwhile it is felt that maintenance engineers can profit from a relatively new procedure involving mixtures of chemicals. It has already been most helpful in answering the needs for improved, high-speed maintenance on modern heavily-traveled streets and highways.

REFERENCES

1. Kersten, M. S., Pederson, L. P., and Toddie, A. J., Jr., "A Laboratory Study of Ice Removal by Various Chloride Salt Mixtures." This Bulletin, p. 1 (1959).
2. Eberhart, J., "An Evaluation of the Relative Merits of Sodium Chloride and Calcium Chloride for Highway Ice Treatment." Ohio State University Eng. Exper. Sta.

Appendix

CALCIUM CHLORIDE SALT MIXTURE FOR TREATMENT OF ICY PAVEMENTS

H. G. MINIER, Superintendent-Manager, Washtenaw County Road Commission, Ann Arbor, Michigan—Field tests were conducted on selected sections of roads and streets in Washtenaw County, Michigan, during January and February 1957. Washtenaw County is in the southeastern part of the Lower Peninsula of Michigan. The University of Michigan is located at the county seat, which is Ann Arbor. The average winter temperatures range from about 25 F to 35 F. There are 14 or 15 snowstorms that exceed 1 in. of snow, plus many others which are less than 1 in. or a freezing rain variety which call for the use of chemicals.

Both bituminous and concrete surfaces were tested. Mixtures of rock salt and calcium chloride Type 1 (flakes) and Type 2 (pellets) in several proportions were spread on the selected sections. Separate crews and equipment were used for the study. The chemical materials were pre-mixed and bagged by the manufacturer to insure accurate

control of the quantities. The material used was purchased by the Michigan State Highway Department. The rate of application and method of spreading followed regular Michigan practices for the area.

Engineering students from the University of Michigan recorded information on weather, road conditions, mixtures used, traffic, and results each time a mixture application was made. Accurate weather data (such as humidity, temperature, wind, sky conditions, and snowfall) were obtained from the weather station at near-by Willow Run Airport.

Data were obtained on seven separate storms during the period of study. However, an analysis was made on only five storms, as it was felt that the heavy snowfall (5 to 7 in.) and drifting during the remaining two storms would be inconsistent with the results of the other five. The temperature range, averaged between the start of the snowfall and the second hour check after application of the mixture, varied between 31 F and 25 F for the five storms, and the humidity varied between 94 and 74 percent. The snowfall for the five storms varied between 1.1 and 2.0 in.

There were no marked differences noted between the results obtained on either concrete or blacktop pavement. However, the results are too inconsistent to evaluate any great difference between the addition of 25 or 33 percent calcium chloride to salt. It was found also that there was no great difference between the use of calcium chloride pellets and calcium chloride flakes.

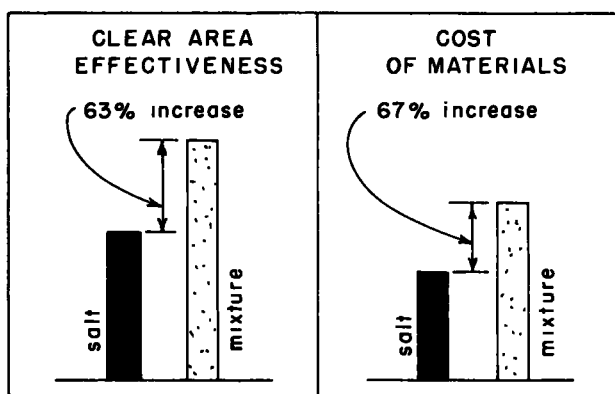


Figure 8. Comparison of clear pavement area and costs between the salt alone and the 2-to-1 salt-calcium chloride mixture.

The clear pavement area two hours after application, based on the average of five storms and both pavement types, was 62 percent for the 66 percent-salt-33 percent-calcium-chloride-flakes mixture and 38 percent for the salt alone. In other words, there was 24 percent more clear pavement at the end of two hours using the 2-to-1 salt-calcium chloride mixture, or the calcium chloride-salt mixture was 63 percent more effective than the salt alone.

Effectiveness, however, must be balanced with the economic aspects of the situation. During the tests all sections received the equivalent of 500 lb per mile per application. The costs of the materials applied at that rate amount to \$2.75 per mile for salt and \$4.58 per mile for the 2-to-1 salt-calcium chloride mixture. Figure 8 is a comparison between clear pavement area and costs. For the 63 percent increase of effectiveness, the cost of material increases 67 percent.

Other sections of the country would show different comparisons adjusted to the price differential between salt and calcium chloride. Washtenaw County is fortunate to be located so close to the salt mines at Detroit.

Because of the number of variables (such as humidity, temperature, sky coverage, snowfall, time, traffic, and type of pavement), a correlation between a variable or variables and mixtures cannot be evaluated with any consistency on the limited number of tests. The tests did bear out the laboratory studies, in that the mixtures of salt

and calcium chloride were more effective than salt alone. Under the conditions of these tests the best results were obtained from the mixture of 2 parts salt and 1 part calcium chloride flakes, by weight.

Further tests should be conducted in this study. As mentioned earlier, there are too many variables to compare and evaluate to reach a conclusion based on the five tests. There is inconsistency in the results; however, correlations are beginning to appear which further tests should bear out. The data to be collected in these tests should include the following:

1. Weather Conditions:
 - (a) Temperature.
 - (b) Humidity.
 - (c) Sky conditions (cloudy or clear).
 - (d) Wind velocity.
2. Pavement Conditions:
 - (a) Ice or packed snow.
 - (b) Thickness of ice or packed snow.
 - (c) Uniform or variable.
3. Treatment:
 - (a) Time of day.
 - (b) Proportions used on each section.
 - (c) Length of sections.
 - (d) Rate of application.
4. Traffic:
 - (a) Vehicles per hour.
 - (b) Average speed.
 - (c) Type of vehicle.
5. Results:
 - (a) Length of time to clear.
 - (b) Variation in removal pattern.
 - (c) Photographs.

The necessity for close observations should be stressed. There should be no doubt as to what information is required, or the way it is recorded. Evaluation of the pavement condition after application should be standardized to insure consistency of observations between different observers or different storms. The success of future studies is dependent on the accurate observation of the pavement condition and close timing of the inspections.