A Laboratory Study of Ice Removal By Various Chloride Salt Mixtures

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● A MAJOR PROBLEM of highway maintenance departments in northern areas concerns keeping roads usable during the winter months; roads made slippery by ice must be made safe for normal traffic speeds. There are two principal methods of treatment utilized by most maintenance crews on icy highways. If the immediate use of the highway is of prime importance the use of abrasives to furnish traction is one solution. In some cases this may not be a complete solution, however, as the abrasive may be whipped off by traffic or wind and the ice will remain. A more desirable treatment is to remove the ice or compacted snow which has caused the slippery condition. This can be accomplished by the application of chemicals which lower the melting point sufficiently to transform the ice into water which then drains off. The two chemicals commonly used for this purpose are sodium chloride and calcium chloride.

There is a considerable difference in the melting qualities of these two chemicals with respect to such things as effective temperatures and rate at which melting proceeds. There have been several instances where maintenance crews applied sodium and calcium chloride together and reported better results than those obtained with either one alone. The study reported herein was initiated as an attempt to obtain more information on the melting qualities of chlorides, both individually and in various combinations. Appendix A is a brief explanation of the melting process as affected by salts.

It was first attempted to devise certain laboratory tests or procedures which would be indicative of the action which might occur when salts were applied to ice on an actual highway. It was planned that if certain relationships and comparisons could be obtained by these laboratory tests, they would be checked by making observations on actual highways with treatments of similar types of salt mixtures. Although weather conditions for such field correlation studies were never obtained in the period of study, it is thought that the development of the laboratory procedures may be of some interest and value, and this paper is restricted to these tests.

The original planned study might be considered to have had 3 parts. The first consisted of certain measurements of the melting caused by application of salts to ice, with variables such as mixture composition, temperature, and dosage rate. Recognizing that there is more involved in ice removal on highways than just melting, the second part of the investigation was the attempt to devise testing procedures which give consideration to the weakening of the bond between an ice sheet and a portland cement or asphaltic concrete surface, and also to the effect of the wheel action of traffic. These 2 parts constituted the laboratory studies. The third part of the study was the intended field observations and correlation with the laboratory results.

MELTING TESTS

The first series of tests were relatively simple and consisted of determining the effect of certain variables on the amount of ice melted by dosages of sodium chloride, calcium chloride in both flake and pellet form, and mixtures of sodium and calcium chloride. The effect of such things as the thickness of the ice sheet, the quantity of salt, the temperature, and the time were investigated. An example of the type of results obtained is shown in Figure 1. From curves such as these, composite curves could be assembled to show various comparisons, such as is shown in Figure 2. Tables 1 and 2 of Appendix B present some of the data from the melting tests.

These tests gave the following general results: (1) the quantity of melting was independent of the ice thickness; (2) the amount of melting varied directly with the quantity of the added salt; (3) the amount of melting varied with the amount of calcium

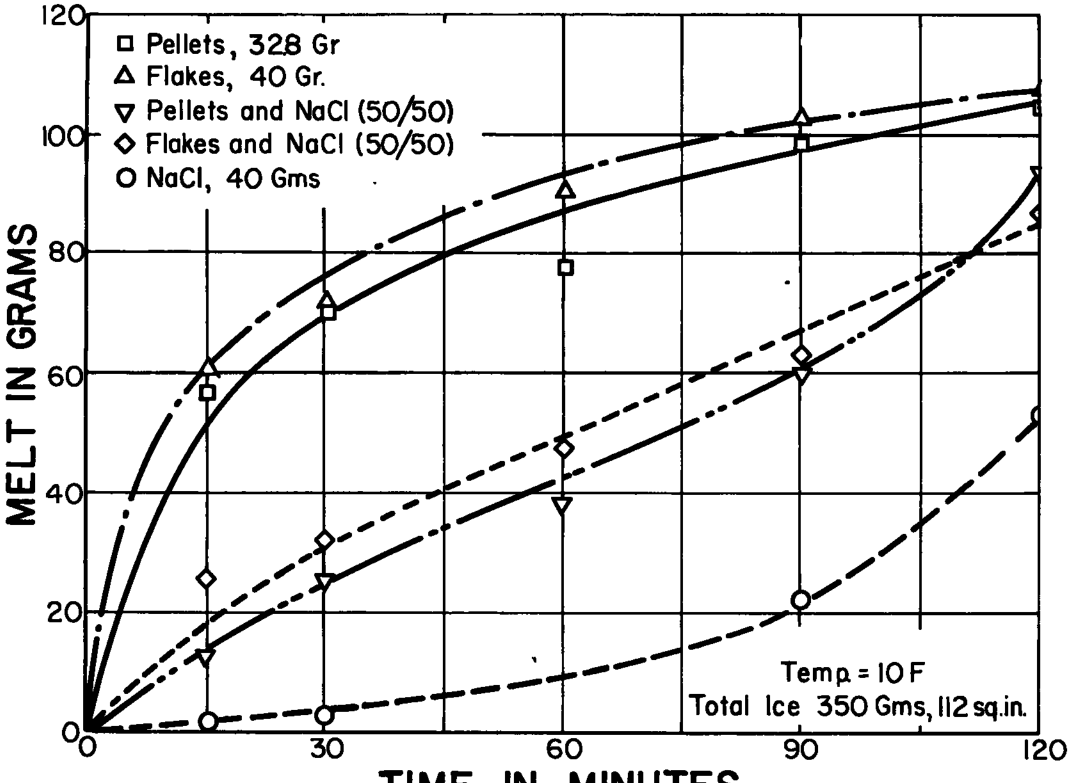

Figure 1. Typical melting test results.

chloride in sodium-calcium chloride mixtures; (4) the amount of melting in a given time was greater at higher temperatures; and (5) with calcium chloride the rate of melting was initially rapid with a subsequent slow-down, and with sodium chloride the rate was initially slow with a later speed-up, so that a time might be reached where the rate with sodium chloride equalled or became greater than that with calcium chloride; the exact comparison was dependent on the temperature.

Some attempts were also made to measure penetration rates of the crystals or pellets of the different salts. These tests, however, involved certain difficulties and the results were rather meager. It was thought that rate of penetration might have some bearing on ice removed on a road, but that this effect, if present, should be a factor which would affect the results in the drop tests and wheel tests described later.

DROP TESTS

One of the more important considerations in ice removal is the destruction of the bond between the ice layer and the road surface. Once the bond is broken it is much easier for the ice to be bladed off or thrown off by traffic. It was desirable to devise some test which would measure the relative effectiveness of chlorides to destroy this bond at various temperatures. The first of these tests was very elementary and consisted only of attempts to scrape ice from the pan after specified periods of chloride treatment. This was unsuccessful for several reasons: the human element of measuring scraping force was dominant, the metal surface on which the tests were made was very smooth and a good conductor of heat resulting in little similarity to field conditions; and a few spots where the chemical did not reach could affect the entire tests. Consequently, this test was discontinued.

Some of the shortcomings in the first test helped in the development of the "drop

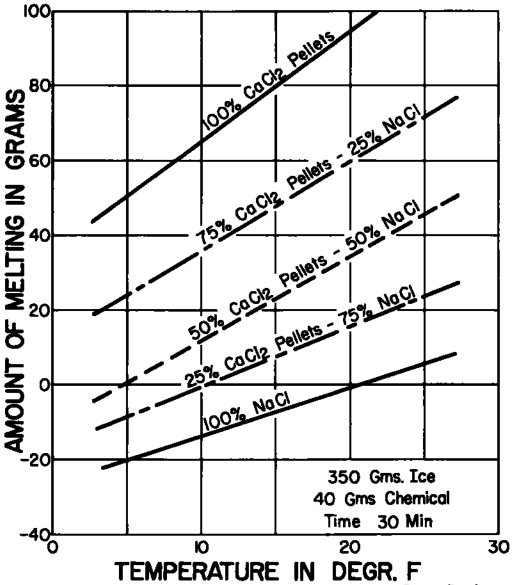

Figure 2. Melting for mixtures of calcium chloride pellets and sodium chloride. Note: In these tests the chemical was added after the pan was weighed. If this chemical was not all dissolved, a portion of it would remain on the ice at the conclusion of the test. This caused the negative value of ice melting at the lower temperature.

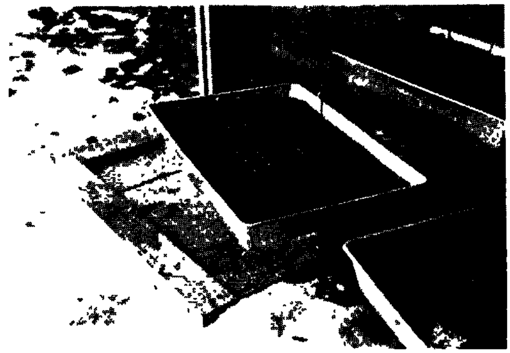

Figure 3. Drop test pan; asphaltic concrete.

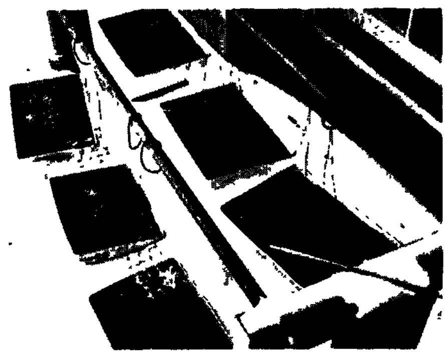

Figure 4. Drop test in progress.

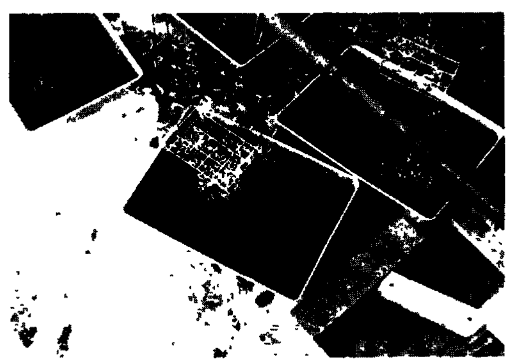

Figure 5. Ice on mesh after failure.

test." For this test a series of pans were filled with a bituminous pavement mixture which was compacted to form a surface similar to that of an actual highway pavement. The amount of material added to the pan was controlled so that the total weight was 9 lb. A 3- by 4-in. wire mesh with 1-in. openings was then placed on the center of the bituminous surface and a thin layer of ice was allowed to freeze on the surface; the ice covered and included the wire mesh. Wires were attached to the mesh and the pan was suspended from a rack by these wires (Fig. 3). A specified dosage of chemical was applied to the ice surface and the time of this application recorded. When the chloride had melted and penetrated to a sufficient degree, the weight of the pan would break the bond of the ice, causing the pan to drop away from the mesh (Fig. 4). This time was also recorded, giving the time required for the chemical to cause failure.

The failure was caused by a combination of melting and bond destruction. In many cases (Fig. 5), large sheets of ice came off with the mesh whereas in others, such as the middle mesh on the left in Figure 4, very little ice came off with the mesh. In each test, pans with 9 different salt combinations were used and the entire test was repeated at a variety of temperatures. The salt combinations used were calcium choride flake, calcium chloride pellets, sodium chloride, and 25 to 75, 50 to 50, and 75 to 25 percent combinations of both flake and pellets with sodium chlorides. For each chemical application a graph was plotted of temperature vs time of drop (Fig. 6). These were

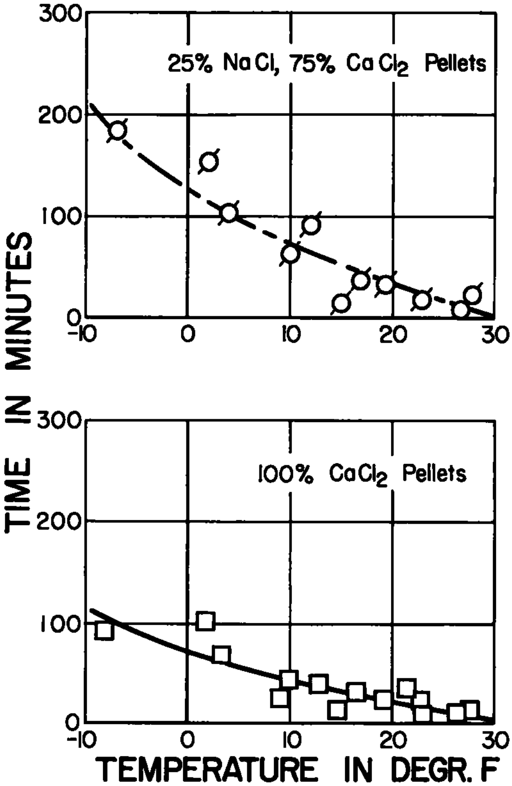

Figure 6. Typical drop test results. Bituminous surface; 40 g chemical; 200 g ice.

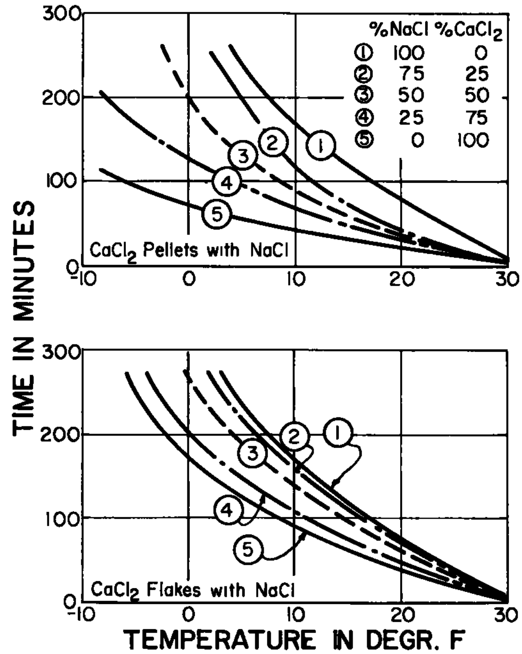

Figure 7. Composite drop test curves. Bituminous surface; 40 g chemical; 200 g ice.

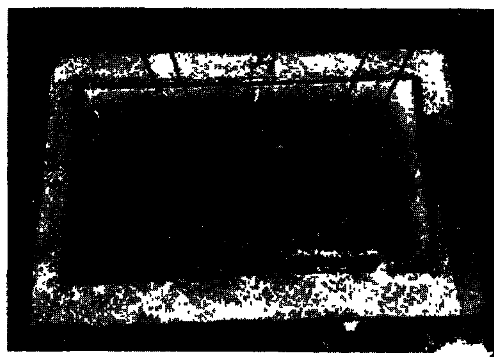

Figure 8. Drop test pan; portland cement concrete.

then combined to show the relative curves of the various treatments. These curves are shown in Figure 7.

In these tests, some difficulty was experienced with the bituminous mixture in the pans. In several cases some of the brine leaked around the edges of the pan leaving less chemical solution to act on the remaining ice. There was also considerable pitting and deterioration of the bituminous surface due to repeated freeze and thaw. In a second series of drop tests some of these faults were corrected by using a concrete surface. Air-entrained concrete was used for better resistance to freeze and thaw and a lip was formed around the outside to prevent loss of solution during the test. One of these pans in shown during the test in Figure 8. The results of these tests were also plotted as temperature vs time (Fig. 9). These curves were again combined in groups of pellet-sodium chloride mixtures and flake-sodium chloride mixtures and are presented in Figure 10.

Several distinct trends are indicated by these graphs: (1) the time of drop increases appreciably with decreasing temperature; (2) sodium chloride has a much longer drop time than the various mixtures at the lower temperatures but this difference becomes less at temperature near the freezing point; and (3) the mixtures do not seem to affect the time of drop in any way except in direct proportion to the quantity of each chemical.

There are a few difficulties in the interpretation of these graphs. The test is of such a nature that there is a wide scattering of points when the original data are plotted. The curves drawn through these points are thus somewhat arbitrary and should be interpreted as general trends rather than statistical analyses. In comparison of the two series of tests there are several points which must be clarified. Even though the area covered by the ice was greater in the first series, the thickness of the ice was approximately the same and the quantity of chemical was proportional to the surface area. The factor should not, then, have any effect on the time of drop. In the first series equal weights of calcium chloride pellet and flakes were used. Because of the difference in calcium chloride content in these two chemicals (94 percent in pellets, 77 percent in flakes), the weight of flakes used in the second series was increased to give an amount of calcium chloride equal to that in the pellets. This would tend to equalize the test results for these two chemicals. It should also be pointed out that the first series was run on a bituminous surface and the second series on a concrete surface. This might have an effect on the time of drop due to differences in the adhesion of ice to bituminous and concrete surfaces.

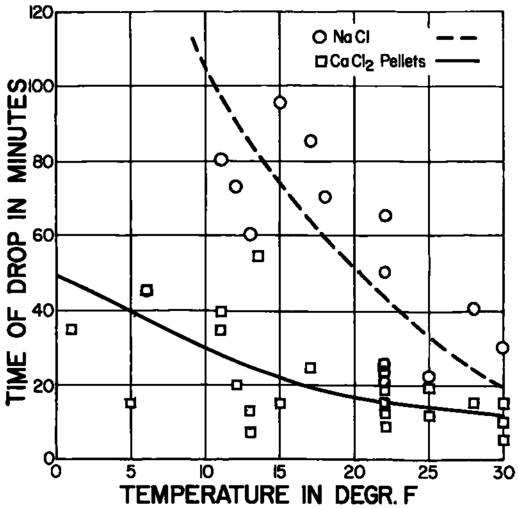

Figure 9. Typical drop test results. Concrete surface; 24 g chemical; 150 g ice.

Detailed data of the drop tests are given in Tables 3 and 4 of Appendix B.

The exact significance of these generalized drop test results is not known. It had been hoped to gain some information on this by correlation with field tests on actual highways. The general results do show a logical sequence as to the effect of mixture and temperature.

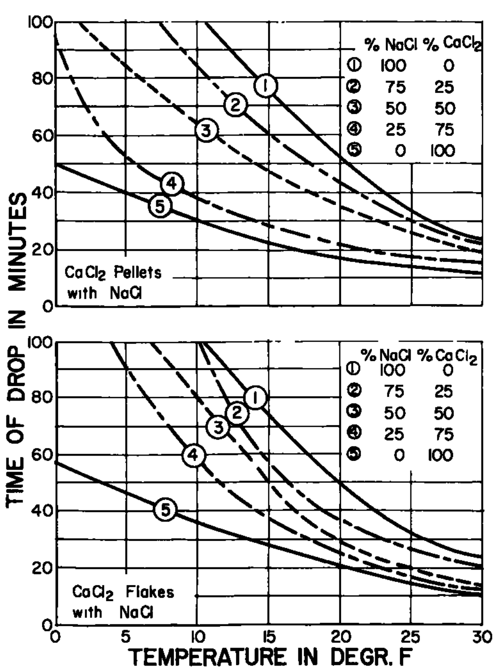

Figure 10. Composite drop test curves. Concrete surface; 150 g ice; 24 g chloride (24 g sodium chloride, 24 g calcium chloride, 29 g calcium chloride flake).

WHEEL TESTS

One factor which was absent in both the melting and drop tests was that of traffic. Since this is important in the removal on a highway, it was believed a test should incorporate this factor if at all possible. The machine shown in Figure 11 was obtained from the Minnesota Highway Department and was adapted for this study. A ring of concrete was covered with a thin ice coating and then treated with a specified amount of chemical. After a short period to permit some penetration of the salt, the ring was set in motion and the wheel lowered onto the track to simulate the action of traffic on a highway. The ice sheet was observed periodically and estimates were made of the percentage of track area cleared. Only one treatment could be run at a time and since the machine had to be kept out-of-doors, the number of tests was limited by the length of the freezing season. The number of chemical combinations was therefore cut down to 5—cal-

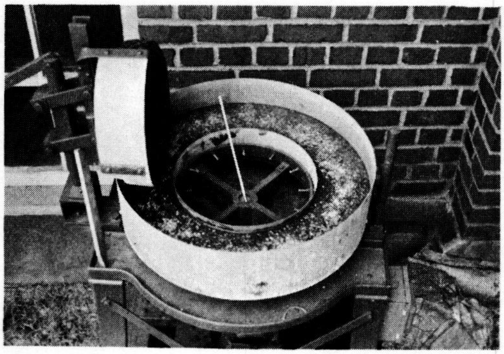

Figure 11. Wheel test machine.

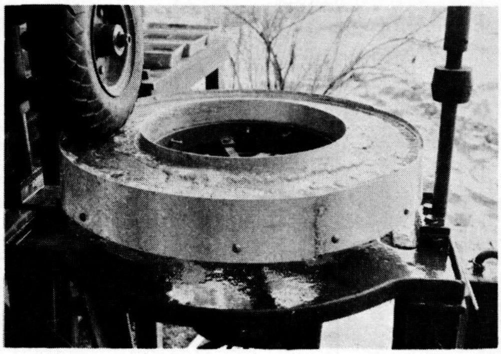

Figure 12. Circular track surface after period of testing.

cium chloride pellets, calcium chloride flake, sodium chloride, and 50-50 mixtures of sodium chloride with pellets and with flake. There was no control over temperatures; those used were the normal range of winter temperatures in Minnesota.

Two of the preliminary difficulties in this test were the loss of brine during the test and the human element in estimating the percentage of ice removal. The first of these was overcome to a reasonable degree by the construction of higher baffles around the ring, providing a better seal between concrete and baffle, and by slowing down the speed of rotation of the track. The human element in estimation was never eliminated entirely but was minimized by experience. A view of the track after a period of testing is shown in Figure 12. This gives an indication of the type of surface for which the estimates of ice removal had to be made.

After each test, the values for percent area cleared were plotted against time. These curves were then plotted on a graph along with others of the same chemical application with each curve representing a different temperature (Fig. 13). In these tests, the salt was allowed to act for 15 min before the track was set in motion. This accounts

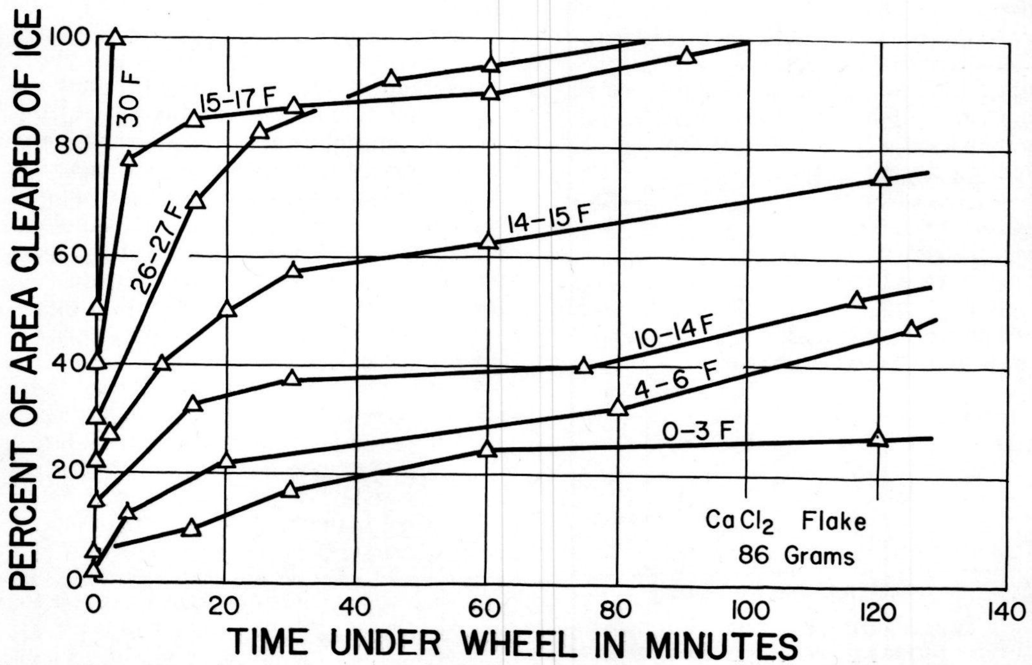

Figure 13. Typical wheel test results. Chemical application equivalent to 400 lb/mi on a 1-ft strip; ice thickness, 1/8 in.; temperature as indicated.

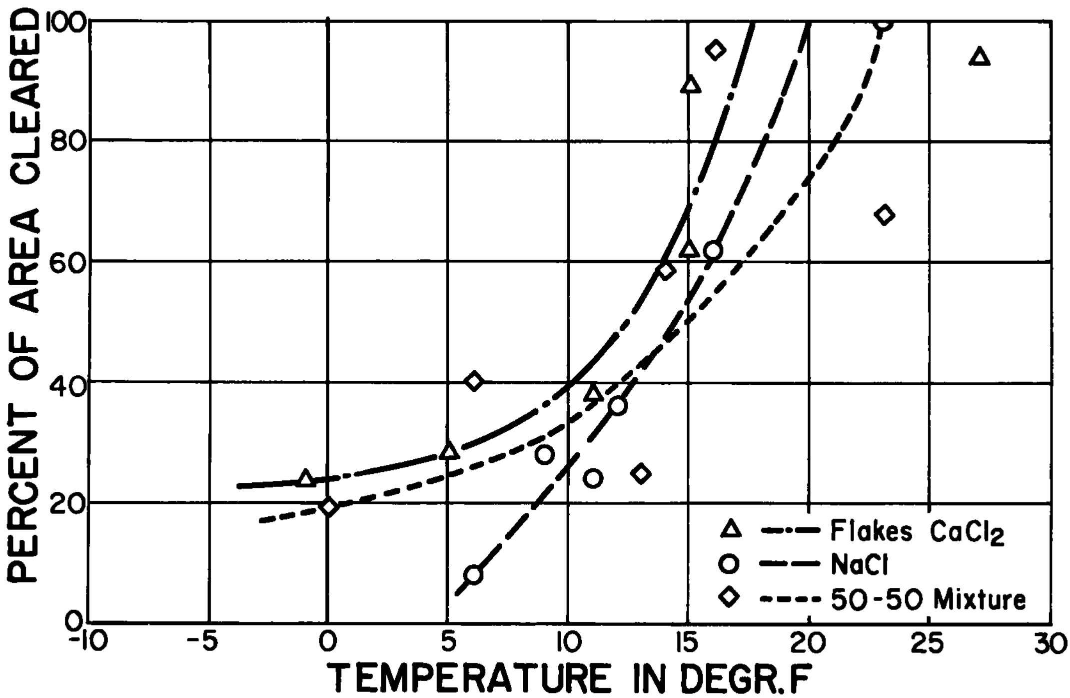

Figure 14. 60-minute removal under wheel at various temperatures.

for the percentage clear at 0 min under the wheel. As might be expected, these tests show a higher percentage of clear area in a given time at higher temperatures, although there are some irregularities. The rate at which ice removal is occurring at various times and temperatures can also be ascertained.

The curves such as those of Figure 13 were used to determine the percent of area clear at times of 30 and 60 min. These values were plotted against temperature for each of the various treatments; one of these plots is shown in Figure 14. It can be seen that there are some inconsistencies in the results, and hence the curves as drawn are considered to be average trends. Figure 15 shows the trends for the three salts (sodium chloride and flake and pellet calcium chloride) for 30- and 60-min periods. Again, some scattering of points is obvious. These may be due to variations in judgment of cleared area, but there also may have been some factors which were not measured which caused these differences. Such items as relative humidity, wind, variation of temperature during test, and variations in ice thickness may have been involved. On the 30-min curve there is seemingly very little difference in the removal at temperatures above 15 deg. At temperatures below 15 F, the flake and pellet calcium chloride give very similar results.

FIELD TESTS

The value of any laboratory test depends on its correlation to actual field results; this makes field tests an important segment of any study such as this. Arrangements were made with the Minnesota Highway Department for the application of these chemical combinations on icy highways during the winters of 1955-56 and 1956-57. Nine equal sections of pavement were staked out an a spreader was obtained which was capable of applying the chemicals in any combination desired. Traffic counts were arranged and thermometers were placed to obtain temperature of air and highway surface.

These preparations were all wasted, however, due to lack of suitable weather conditions. During the 2 winters, there were only 3 times when slippery conditions occurred. Two of these were brought about by hard-packed snow. These made proper evaluation

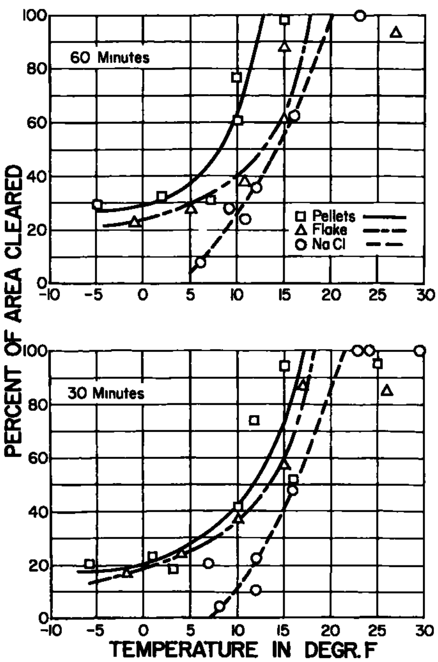

Figure 15. Ice removal by chlorides in wheel test at 30- and 60-minute intervals.

difficult due to variations in thickness, effect of shade late in afternoon, necessity to estimate removal and compare separated areas after lengthy intervals, and general lack of removal because of low temperatures. The third field test was on a thin film of ice at a temperature around 30 deg. On this test all applications provided excellent removal in a short time and no differentiation could be made as to the effect of varying the chemical.

SUMMARY

Laboratory test including measurements of amount of melting, a combined melting and breakage of bond between ice and slabs, and a test incorporating the added action of a revolving wheel have been used to study ice removal by sodium chloride, flake and pellet calcium chloride, and mixtures. These tests have shown that the results with mixtures of sodium and calcium chloride are practically always intermediate between those for tests with the straight salts. It is considered that the wheel test most nearly approached field conditions. There were some inconsistencies obtained in individual tests, however, and additional investigation with this apparatus is suggested. A definite need exists for observations on actual highways and correlation of such observations with laboratory results.

ACKNOWLEDGMENTS

The laboratory work described herein was performed in the Soil Mechanics and Highway Engineering Laboratories of the Civil Engineering Department of the University of Minnesota. The authors acknowledge the cooperation and assistance of the Minnesota Highway Department and the Calcium Chloride Institute. C. K. Preus and Myron Jones of the Highway Department and Harry Smith and William Dickinson of the Calcium Chloride Institute particularly aided the work.

Appendix A

MECHANICS OF ICE MELTING BY CHLORIDES

The following is a brief statement or explanation of the manner in which salts melt ice. This is not intended to be a rigid or complete explanation, but is an attempt to give a layman's understanding of the physical chemistry involved. It helps to give a basis for understanding some of the physical chemistry involved. It helps to give a basis for understanding some of the actions which were found to occur in the experiments described in this paper.

The physical characteristic of chlorides which enables them to remove ice from highways is their ability to lower the freezing point of water and thus prevent and reverse the formation of ice. This lowering of the freezing point is caused by a lowering of the vapor pressure of the solution. Whenever a substance exists in 2 states which are in contact with each other, as for example water and ice, there is a constant interchange of molecules between the two states. This interchange of molecules creates what is called vapor pressure.

If the vapor pressure of the solid is greater than that of the liquid, more molecules will leave the solid state than will return and the solution will become entirely liquid; and conversely if the vapor pressure of the liquid is greater than that of the solid, more molecules will enter the solid state than will leave and the solution will become entirely solid. The freezing point is that point at which the vapor pressure of the liquid equals the vapor pressure of the solid.

In a solution, if the solute is more soluble in the liquid than in the solid, the solute molecules will remain in the liquid, resulting in fewer molecules of solvent for a given volume and hence a lower vapor pressure. When the vapor pressure of the liquid becomes lower than that of the solid, the solid state will change to liquid until a new equilibrium point is reached. Both calcium chloride and sodium chloride are more soluble in water in the liquid state than in the solid state.

Vapor pressures decrease with a decrease in temperature and values for pure ice and for pure water have been determined for various temperatures. The amount of reduction in vapor pressure caused by the addition of various solutes has been also determined. Using this information, the freezing point of a solution can be found in the following manner:

1. Compute the strength of the solution in terms of grammolecules of salt per liter of water.
2. Using standard physical chemistry handbook talbes, determine the percentage reduction in vapor pressure of this solution.
3. Find the temperature at which the vapor pressure of pure water when reduced by the percentage determined in 2 equals the vapor pressure of pure ice.

Calculations of this type have been made and show that a 10 percent calcium solution has a freezing point of approximately -5. 5 C while a 10 percent sodium chloride solution has a freezing point of approximately -7 C. This indicates a greater lowering of the freezing point by sodium chloride than by calcium chloride in 10 percent solutions; this is in agreement with the fact that there are more ions present per gram in sodium chloride. Field tests indicate better results at low temperatures with calcium chloride than with sodium chloride, but these solutions are more concentrated than 10 percent. This difference is explained by the difference in solubility of the two chemicals at lower temperatures. at 0 C it is possible to dissolve only 357 g of sodium chloride in one liter of water as compared to 595 g of calcium chloride. This greater solubility produces solutions of greater strength and therefore lower freezing points than those obtainable with sodium chloride.

Two other qualities affect the melting characteristics of these two chlorides. Both are concerned with the rate of melting rather than the total amount of melting. The first step in the melting process is the formation of a liquid solution. Here the calcium chloride holds the advantage in that it forms hydrates and thus draws moisture from the air to form the initial solution much faster than sodium chloride which is not deliquescent.

The other characteristic involved is the heat of solution. Heat is required to transform ice into water and must be supplied from either the surrounding air or from the solution. Heat is also involved in dissolving a solute into a solvent and this heat is called the heat of solution. Calcium chloride in the anhydrous form produces 17,990 calories of heat when 111 g are dissolved in 7,200 g of water. The same amount of calcium chloride in the form with two hydrates (flake) produces 10,040 calories: On the other hand, to dissolve this quantity of sodium chloride in this much water would require an additional 2,400 calories from some other source. This would have its greatest effect on the initial melting when the chemical is just going into solution.

Appendix B

TABULATIONS OF LABORATORY DATA

TABLE 1

30-MINUTE MELTING TESTS

112 sq in. surface area; 350 g ice; 40 g chemical

100 % $CaCl_2$ 0 % NaCl Temp. (F)	Am't. (g)	75 % $CaCl_2$ 25 % NaCl Temp. (F)	Am't. (g)	50 % $CaCl_2$ 50 % NaCl Temp. (F)	Am't. (g)	25 % $CaCl_2$ 75 % NaCl Temp. (F)	Am't. (g)	0 % $CaCl_2$ 100 % NaCl Temp. (F)	Am't. (g)
				Pellets					
2	59	2	17	2	-4	2	-13	6	-23
9	65	9	34	9	+17	9	-5	9	-10
9	60	9	32	9	7	10	-10	11	-15
12	64	11	49	11	17	13	+2	14	-9
14	69	14	47	15	19	16	15	14	-11
14	56	16	39	18	25	18	19	17	+4
18	95	17	58	18	24	20	27	19	0
18	93	18	54	20	42	20	9	20	0
23	106	24	77	20	30	26	26	27	+6
		24	59	25	47				
				Flake					
2	51	2	25	3	9	6	-14	6	-23
9	65	9	36	10	15	12	+3	9	-10
10	65	10	35	13	23	16	5	11	-15
13	72	13	44	15	24	16	7	14	-9
14	68	14	50	17	20	18	22	14	-11
14	66	15	43	18	37	20	18	17	+4
18	82	19	31	19	37	22	27	19	0
18	74	19	28	20	36	27	27	20	0
22	88	20	43	25	39			27	+6
		23	72						
		23	58						

TABLE 2

MELTING TESTS: VARIABLE TIME

112 sq in. surface area; 350 g ice

Chemical[a]	Temp. (F)	Amount of Melting in Grams 15 min	30 min	60 min	120 min
6	-23	26	23	36	52
7	-23	3	-	3	6
8	-23	25	41	49	69
9	-23	6	11	11	21
1	-10	21	24	41	50
3	-10	32	47	57	61
6	-10	36	49	66	76
7	-10	-	1	6	10
8	-10	44	46	60	73
9	-10	11	12	13	36
1	0	45	48	56	75
2	0	18	31	34	44
3	0	42	56	72	75
4	0	15	19	24	47
5	0	-	7	9	21
6	0	20	40	59	76
7	0	10	19	25	41
8	0	46	57	73	99
9	0	22	32	34	57
10	0	1	2	6	3
1	+10	58	71	79	106
2	+10	13	26	38	94
3	+10	61	73	91	108
4	+10	26	32	47	87
5	+10	2	3	-	54
6	+10	56	68	86	-
7	+10	24	44	54	88
8	+10	73	81	101	106
9	+10	29	45	57	65
10	+10	2	1	23	37
1	+20	68	69	86	139
2	+20	26	51	95	163
3	+20	60	92	104	141
4	+20	31	68	100	152
5	+20	20	18	43	150
6	+20	63	94	146	156
7	+20	11	31	87	153
8	+20	92	110	141	180
9	+20	49	58	70	120
10	+20	7	24	55	161

[a] Note: Legend for Mixture of Chemicals

Chemical No.	$CaCl_2$ Pellet %	Wt	$CaCl_2$ Flake %	Wt	NaCl %	Wt
1	100	32.8	0		0	
2	50	16.4	0		50	20
3	0		100	40	0	
4	0		50	20	50	20
5	0		0		100	40
6	100	40	0		0	
7	50	20	0		50	20
8	0		100	48.8	0	
9	0		50	24.4	50	20
10	0		0		100	40

TABLE 3

DROP TEST DATA: BITUMINOUS PANS

112 sq in. surface area; 200 g ice; 40 g chemical

100 % $CaCl_2$ 0 % NaCl Temp. (F)	Time (min)	75 % $CaCl_2$ 25 % NaCl Temp. (F)	Time (min)	50 % $CaCl_2$ 75 % NaCl Temp. (F)	Time (min)	25 % $CaCl_2$ 75 % NaCl Temp. (F)	Time (min)	0 % $CaCl_2$ 100 % NaCl Temp. (F)	Time (min)
				Pellets					
-8	90	-7	180	-6	300+	-6	300+	-6	300+
+2	100	+2	150	+3. 5	60	+10	360	+8	300
3. 5	65	4	100	10	130	12	90	10	140
9. 5	25	10	60	12. 5	115	13	60	13	160
10	40	12	90	13	50	17	35	15	95
13	35	15	13	15	20	23	35	19	100
15	12	17	35	17	30	28	25	19	75
17	30	19. 5	30	20	30			23	55
19. 5	22	23	26	23	20			27	25
22	30	27	8	23	15			28	45
23	20	28	20	27	6				
23	15			28	40				
27	8								
28	10								
				Flakes					
-6	300+	-6	300+	-6	300+	-6	300+	-6	300+
10	80	5	120	7	240	8	280	8	300
12. 5	105	10	80	10	80	10	110	10	140
18	60	12	65	15	180	12. 5	115	13	160
23	20	18. 5	70	15	90	13	140	15	95
27	8	23	20	18. 5	75	15	90	19	100
		27	45	23	35	18. 5	75	19	75
		28	45	27	35	23	55	23	55
				28	45	27	25	27	25
						28	45	28	45

TABLE 4

DROP TEST DATA: CONCRETE PANS

66 sq in. surface area, 150 g ice; 24 g chemical[a]

100 % $CaCl_2$ 0 % NaCl		75 % $CaCl_2$ 25 % NaCl		50 % $CaCl_2$ 75 % NaCl		25 % $CaCl_2$ 75 % NaCl		0 % $CaCl_2$ 100 % NaCl	
Temp. (F)	Time (min)	Temp (F)	Time (min)	Temp. (F)	Time (min)	Temp. (F)	Time (min)	Temp. (F)	Time (min)
Pellets									
-2	65	-2	45	+5	85	+5	47	+6	45
-2	45	+2	100	11	55	11	100	11	110
+1	35	11	20	12	64	12	60	11	80
5	15	12	25	13	55	13	40	12	73
6	45	13	40	13	25	16	64	13	60
11	35	13	33	15	46	17	45	15	95
11	40	13	30	16	75	18	35	17	85
12	20	17	25	17	45	22	64	18	70
13	55	18	15	18	30	22	45	22	65
13	13	22	45	22	40	22	40	22	50
13	7	22	23	22	23	22	20	22	25
15	15	22	15	22	15	25	23	22	22
17	25	22	13	25	19	28	30	25	22
22	17[b]	25	19	28	30	30	30	28	40
22	20	28	30	30	30	30	23	30	30
25	19	30	30	30	23				
25	12	30	13						
28	15								
30	15								
30	10								
30	5								
Flake									
-2	45	+5	49	+11	70	+11	100	+6	45
-2	32	11	20	12	64	12	60	11	110
0	20	12	37	13	85	13	85	11	80
+1	46	13	65	13	40	13	40	12	73
+1	37	13	14	13	7	16	64	13	60
5	28	13	4	15	66	17	45	15	95
6	25	15	85	17	45	18	35	17	85
12	20	17	45	18	20	22	40	18	70
13	44[b]	18	20	22	30	22	23	22	65
15	68	22	45	22	23	22	20	22	50
17	50	22	40	22	15	25	22	22	25
17	20	22	23	25	19	28	30	22	22
22	17[b]	22	14	28	30	30	30	25	22
25	19	25	19			30	23	28	40
25	12	28	15					30	30
28	30	30	30						
30	10	30	13						
30	5								

[a] Total weight of chemicals was 24 g in all tests with pellets. Flake weights were increased by $^{29}/_{24}$ to give equal chloride content, but NaCl weights were not changed so total weight of chemicals in tests with flake was variable between 29 g for 100 percent flake and 24 g for 100 percent NaCl.

[b] Average of five tests. All others single tests.