ICE REMOVAL ON HIGHWAYS

AND

OUTDOOR STORAGE OF CHLORIDE SALTS

INVESTIGATION NO. 604

Progress Report - 1962

by
MATERIALS AND RESEARCH SECTION
MINNESOTA DEPARTMENT OF HIGHWAYS
in cooperation with
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SYNOPSIS

The efficient removal of accumulated ice and snow from highways is one of the largest problems confronting maintenance engineers in the northern areas. While mechanical equipment and abrasive materials have been used for many years to help make roadways safe for motor vehicle travel, the use of straight chemicals has recently gained popularity. However, little reliable field test data concerning the effectiveness of chemicals and mixtures and application rates of these materials have been available.

This study was undertaken to determine the comparative effectiveness of chloride salts and abrasive-chloride salt mixtures for ice removal. It was also desired to study the storage characteristics of sodium chloride, calcium chloride and mixtures of these materials.

Controlled field ice removal tests were run on 15 combinations of materials within three temperature ranges. Data were collected on thickness of ice; actual quantity and location of chemical or abrasive applied; and periodic condition of the ice with regard to amount of ice removed.

The outdoor storage characteristics of seven bulk materials and one packaged material under a light polyethylene sheeting were studied. The materials were sampled for moisture, crusting and caking for a period of 10 months.

A mixture of 1/3 $CaCl_2$& 2/3 NaCl appears to be one of the better, economical materials for ice removal. Also this mixture was found to store well in bulk for a period in excess of ten months.

Straight NaCl was found to be ineffective in clearing a wheel path within a 60 minute time period as compared to the mixture of 1/3 $CaCl_2$ & 2/3 NaCl. Also, NaCl cannot be stored outdoors in bulk longer than 2 months without considerable caking.

Mixtures of salt, with abrasive were found to be relatively ineffective for removing ice below about 15°F.

Further research on similar and additional chemicals should be conducted under well controlled field conditions.

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INTRODUCTION

The increased daily use of highways throughout the country has brought on a demand for safer and more efficient roadways for use during every season of the year. One of the largest problems confronting engineers charged with the maintenance of these streets and highways in the northern areas, is the efficient removal of accumulated ice and snow.

Years ago efforts to make roadways safe for motor vehicle travel consisted of the use of mechanical equipment to plow the roadways reasonably free of snow and the use of abrasives to provide some degree of traction on hills and curves. These efforts, however, were confined chiefly to the primary routes. In later years the use of abrasives became more widespread and it was found that through the use of a mixture of calcium chloride and an abrasive the freezing of the abrasive stockpiles was eliminated. Secondly, it was found the chemical also aided in the embedment of the abrasive material in the ice or compacted snow.

The use of straight calcium chloride and sodium chloride was begun on a limited scale in the late '20's and early '30's. Because of an apparent detrimental effect to Portland cement concrete pavement containing no entrained air, the use of straight chemicals was not recommended for general use[1] but was recommended where severe conditions existed. In areas where straight chemicals were found necessary it was advisable to plow off the resulting slush to minimize the damage.

More recently, the use of straight calcium chloride, sodium chloride and mixtures of these chemicals has gained popularity as compared with use of abrasives alone or use of abrasive-chloride mixtures. The primary reason for this popularity, it is believed, is the

[1] Tiney, B.C. 'Treatment of Icy Pavements' HRB Proc. Vol. 11

greater speed with which the straight chemicals provide a cleared wheel path and roadway. Furthermore, there are indications that the total cost of using chemicals alone, particularly in bulk, may be lower than the cost of using the abrasive-chemical mixtures, which involve handling of much larger quantities of materials.

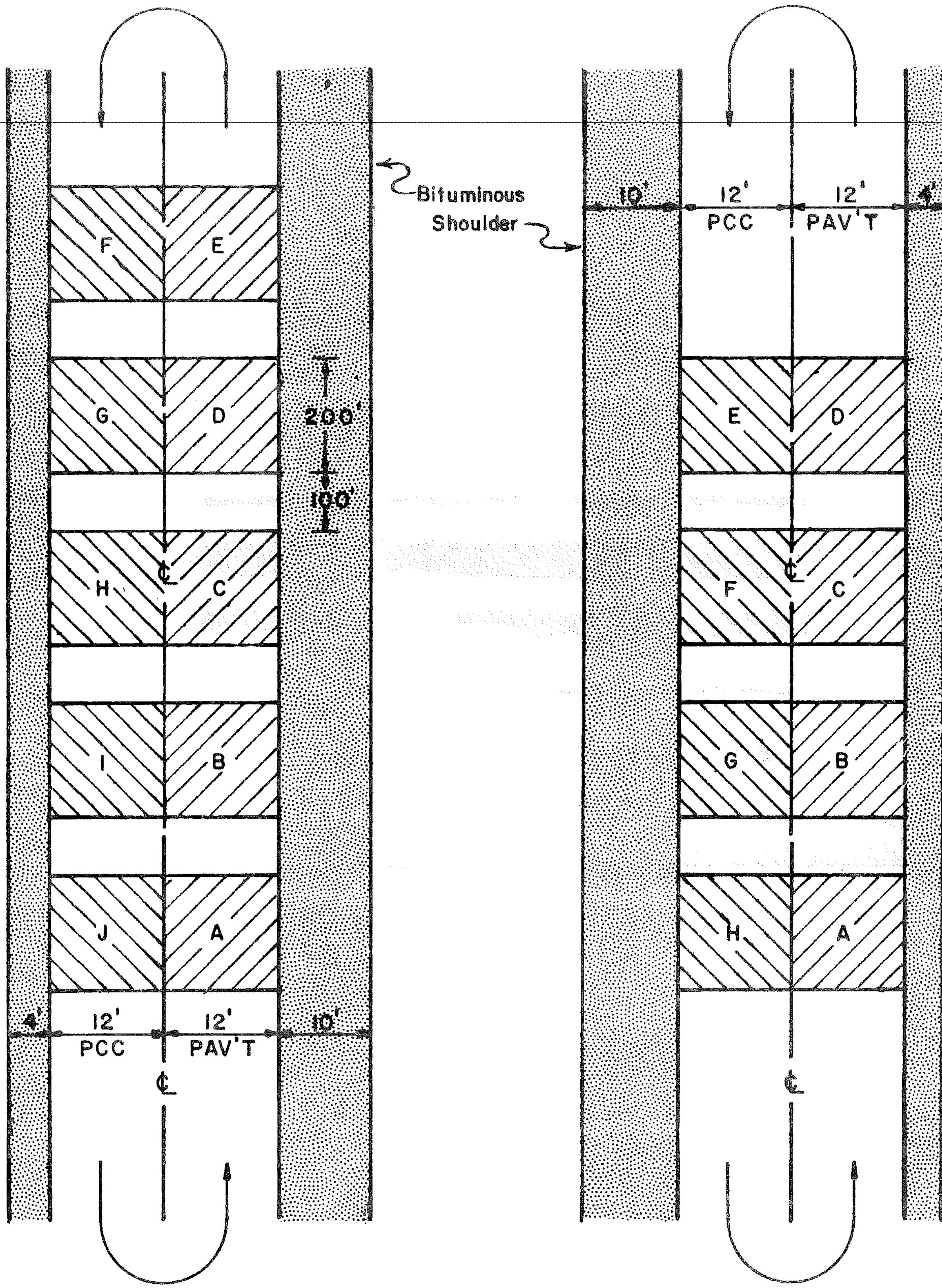
Little reliable published data are presently available concerning the effectiveness of these materials for actual highway use. Consequently, no recommended application rates based on field tests are available. Application thus far has largely been on a trial and error basis according to the judgement of the individual supervisor in charge of winter maintenance.

This study consisted of two basic parts - Ice Removal and Outdoor Storage of Chloride Salts. The ice removal portion was undertaken to determine the comparative effectiveness of chloride salts and abrasive-chloride salt mixtures in the removal of a controlled amount of ice from pavements under field conditions. The tests were conducted within three temperature ranges and using a controlled amount of vehicular traffic. The outdoor storage portion of the study was undertaken to determine the storage characteristics of sodium chloride, calcium chloride and of mixtures of these chemicals when stored outdoors under polyethylene sheeting. The bulk storage of these materials was of prime concern; however, packaged sodium chloride was included to study the problem of caking in some types of paper bags.

ICE REMOVAL

The Test Site

The test site selected for this portion of the study was a short section of unopened interstate highway. The facility is a four lane divided Portland cement concrete paved roadway with bituminous surfaced shoulders. Only one roadway of the divided highway was used for the study, the layout of which is shown in Figure 1.



1960-1961 Test track

1961-1962 Test track

Fig 1 Layout of Test Sections

The test sections were 200 feet in length with a distance of 100 feet between test sections to provide a "track-off" area and to minimize carry-over from one test section to another. An overall view of the site during a test is shown in Figure 2.

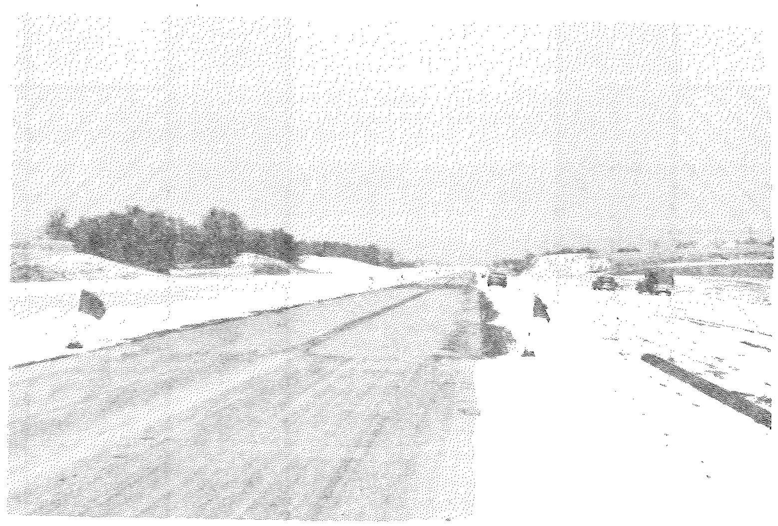


Figure 2 Overall view of test site

Originally it was planned to run the tests primarily on a bituminous surfaced roadway, however, difficulities in obtaining a suitable test site prevented this. Only one test was performed on a bituminous pavement, that being in the 1961 - 62 series of tests on the 10 foot bituminous surfaced shoulder of the interstate highway.

Site Preparation

Prior to each test, the site was cleared of snow using snow plows and power brooms. Next, copper constantan thermocouples, AS & W Wire Gauge No. 25, were installed on the roadway surface to measure the ice temperatures throughout the test periods. Figure No. 3 shows a typical thermocouple installation with the thermocouple tip about five inches from the expansion joint near the black tape.

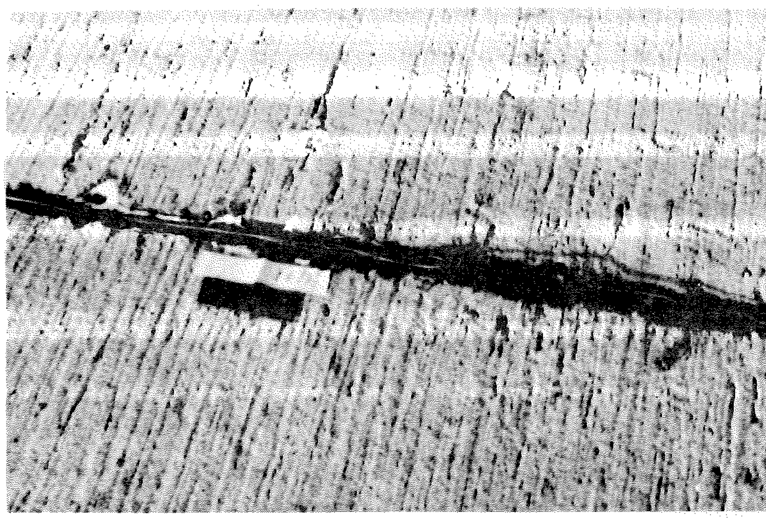


Figure 3 Typical thermocouple installation.

Two additional thermocouples were used to measure air temperature - one was placed in a 2 inch diameter black tube 12 inches in length; the second was placed in a Florence Flask. All thermocouple readings were measured with a Leads and Northrup laboratory potentiometer. For comparison, a mercury thermometer was also used for measuring air temperature. A tabulation of the average ice and air temperatures and cloud cover conditions is given in Table 1.

TABLE NO. 1

TABULATION OF ICE AND AIR TEMPERATURES

	Date	Pavement	Conditions			
	of	Surface	Temperature °F			
Test No.[1]	Test	Type	Ice	Air	Av.	Cloud Cover
H-1	1-6-61	PCC[2]	32	32	32	Sunny
H-2	1-23-62	Bit.[3]	28	24	26	Variable Cloudiness
M-1	1-19-61	PCC	27	12	19.5	Cloudy
M-2	1-11-62	PCC	13	11	12	Cloudy[4]
M-3	2-1-62	PCC	23	12	17.5	Cloudy
M-4	2-7-62	PCC	24	9	16.5	Bright Sun
L-1	1-27-61	PCC	15	8	11.5	Partly Cloudy
L-2	1-16-62	PCC	12	6	9	Moderate Sun
L-3	3-2-62	PCC	15	10	12.5	Slightly Sunny

[1] Letter refers to temperature range. Number refers to test series.

[2] Portland Cement Concrete

[3] Bituminous

[4] Started snowing during the test.

After installation of the roadway thermocouples, water was applied to the test sections using a trailer-mounted water tank and spray bar distributor. The output of the distributor was calibrated and a reasonable speed of the vehicle determined to apply the necessary quantity of water in several passes to produce an ice thickness approximately 1/16 inch over a width of about 10 feet. Figure 4 shows the equipment and method used to ice the road. The air temperature at the time of ice formation was generally below 15°F.

A period of at least one hour was provided for the ice to become completely formed before the chemicals and abrasives were applied.

Figure 4 Applying water to ice the road.

Ice Removal Materials

The ice removal materials selected for comparison in this study were: Sodium Chloride (Rock Salt and Evaporated Salt); Type I and Type II Calcium Chloride flakes; Calcium Chloride pellets; mixtures of Calcium Chloride and Sodium Chloride; a mixture of Calcium Chloride and sand; and a mixture of Sodium Chloride and sand. The materials used are identified in the tabulation shown in Table 2.

The sodium chloride and calcium chloride used in this study met the requirements of AASHO Designation M143-54 and M144-55 respectively. The sand used met the gradation requirements of AASHO Designation M6-51.

TABLE NO. 2

MATERIALS

Material No.	Sodium Chloride		Calcium Chloride			
	Rock Salt	Evaporated	Pellets[a]	Type I[b] Flakes	Type II[c] Flakes	Sand
1	1					
2			1			
3				1		
4		1				
5	3/4		1/4			
6	2/3		1/3			
7	3/4			1/4		
8	2/3			1/3		
9			1/2			1/2
10	1/2					1/2
11	1/2		1/2			
12	1/2			1/2		
13					1	
14	1/2				1/2	
15	3/4				1/4	

[a]AASHO M 144-57 Concentrated Pellet Calcium Chloride - 94% minimum purity.

[b]AASHO M 144-57 Regular Flake Calcium Chloride - 77% minimum purity.

[c]AASHO M 144-57 Concentrated Flake Calcium Chloride - 94% minimum purity.

Originally, tests were contemplated on a more extensive variety of chemical mixtures. However, after performing three field tests during the winter of 1960-61 and analyzing the results of these; it was decided to eliminate some of the variations in mixtures since the comparative ice removal action between mixtures was not too apparent. Also at this time it was decided to include mixtures of chemicals and abrasives in the 1961-62 program of tests since the use of mixtures of these materials is quite common.

Application of Chemicals and Abrasives

In this study the application of chemicals and abrasives was, to a certain extent, a variation of the practices commonly used by maintenance engineers. In the State of Minnesota, straight chemicals are commonly applied in a narrow band along the centerline of two lane roadways. Abrasives are applied by vehicles straddling the centerline and spreading the material with a disc spinner over both lanes in a single operation; although in some cases, single lane spreading operations are required and used.

In this study chemicals were applied in a narrow band approximately three feet out from the centerline using the chemical dribbler shown in Figures 5, 6 and 7.

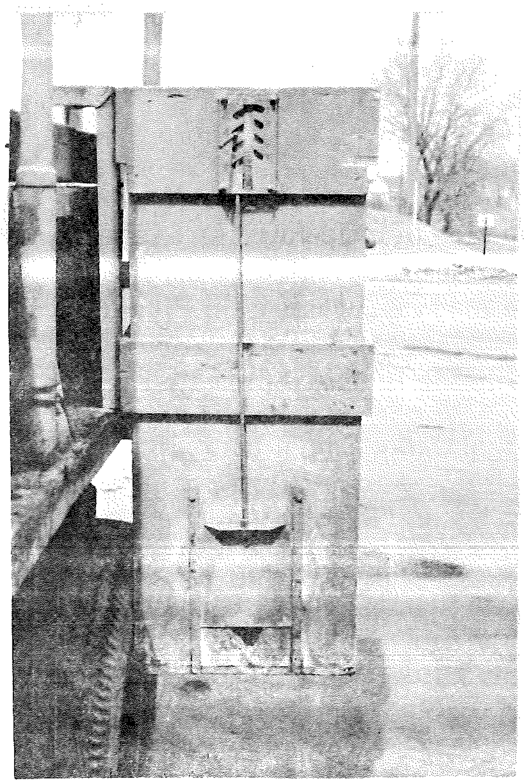


Figure 5 Chemical dribbler.

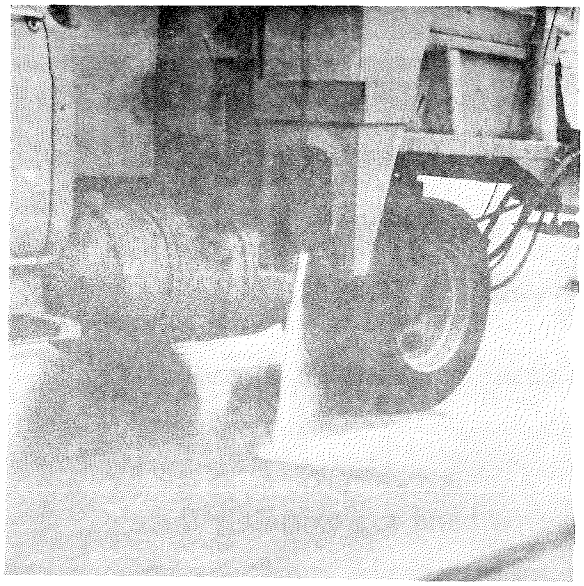


Figure 6 Dribbler applying evaporated salt.

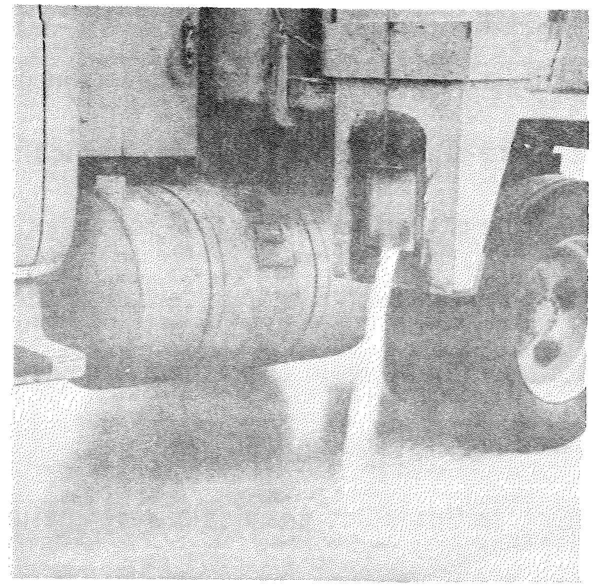


Figure 7 Dribbler applying a mixture of calcium chloride and sodium chloride

In Figure 6, the application of evaporated salt is shown to produce a very narrow band of chemical on the roadway, whereas in Figure 7 the mixture of calcium chloride and sodium chloride is shown to scatter considerably. Similar scattering was noted with straight calcium chloride pellets as well as with rock salt. The calcium chloride flakes, however, scattered less than the calcium chloride pellets or rock salt but more than the evaporated salt.

Equipment used for applying the abrasive mixtures is shown in Figure 8. This equipment produced the least degree of uniformity of applied materials to the roadway although it is probably one of the more extensively used pieces of winter maintenance equipment.

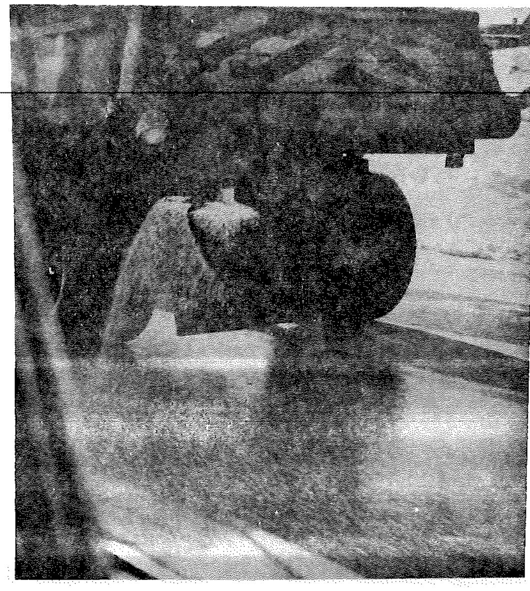


Figure 8 Disc spinner applying abrasive mixture.

The width of application of abrasives varied from about 3 feet to 10 feet; however, most applications were between 3 and 8 feet wide.

Traffic

Simulated traffic over the test sections consisted of three vehicles of mixed traffic operating with a one minute headway between vehicles travelling at 15 to 20 mph. The vehicles were: one 3-ton dump truck, one 1/2 ton pickup truck, and one passenger car. This volume of traffic corresponds approximately to 1440 vehicles per lane per day. Traffic began immediately after all materials were placed and the conditions of spread recorded. Because the vehicle headway remained constant, the data are analyzed on a time basis rather than vehicle coverage.

Collection of Test Data

The observed data were collected by two rating teams consisting of two raters for each team. Observations were made and recorded by the rating teams at fifteen minute intervals throughout the test period. The observations included such items as width, length and thickness of ice, actual quantity and location of chemical or abrasive applied, formation of brine, and condition of the ice with respect to the amount of removal. A typical rating sheet is shown in Figure 10 and the observed and calculated data are given in Tables 3 and 4.

As noted on the typical rating sheet (Figure 10) and on Table 4 Observed Ice Removal Data, certain arbitrary standards were established to record the degree of ice removal. The first of these standards was called "pitted". This condition existed when only the ice immediately under the particles of chemical became melted. The second condition was called "pocked" and is typified by Figure 9. In this case the initial pits have enlarged and bare pavement is beginning to show through.

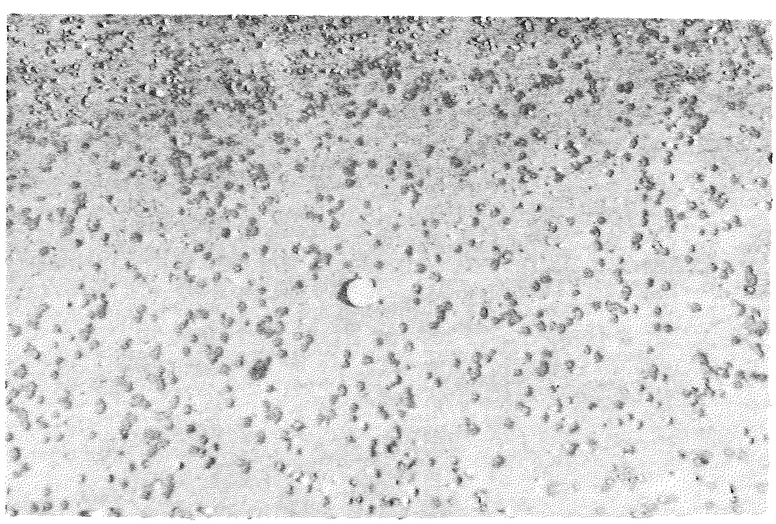


Figure 9 Pocked condition.

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SECTION E

ICING DATA:

Date: 2/1/62 — Air Temp. Beg. 16 °F.
Surf. Condition (Not used) — Air Temp. End 15 °F.
Water Applied 600 Gal.
Width of Ice 11½' Ft. — Thick. of Ice 1/16 In.
Remarks

SALT APPLICATION DATA:

Date: 2/1/62 — Humidity (Not Determined)
Initial Surf. Cond. (Not Used)

Chemical Used NaCl (Rock Salt) — Salt Application Rate 263 #/lane/mile
Rel. Length of Appl/-Beg. +6 — Width of Application 3½' to 4½'
End +15 — Location of Application 1'-5½' + ½'-4'
Traffic: 1440 vplpd — Remarks

ICE REMOVAL RATING:

Time	Formation of Brine	Condition of Ice: Total	IWT	OWT	Width Affected	Cleared Area	Flaking Off	Tracking Off Section	General Comments
15	G	—	Hc - Sc	Brine Running	5' 1'-6'	15% IWT	—	80'	—
30	D	—	Sc - Cl	✓	✓	1'-5' 90%	—	100'	—
45	✓	—	Cl	✓	✓	1'-5' 100%	—	✓	S. end 3' Cl 1'-4'
1:00	✓	—	✓	Some Slush	✓	✓	—	✓	✓
1:15	✓	—	✓	✓	✓	✓	—	✓	✓
1:30									
1:45									
2:00									
2:15									
2:30									
2:45									
3:00									
3:15									
3:30									
3:45									
4:00									

Note:
G = Good
D = Done
Hc = Honeycombed
Sc = Scabby
Cl = Clear

Figure 10 A typical rating sheet.

TABLE NO. 5

OBSERVED AND CALCULATED DATA

Icing Data				Chemical and Abrasive Application						
Test No.[1]	Average Width (feet)	Computed Thickness (inches)	Planned (lb per lane-mile)	Test Section Applied 60-61[2]	Test Section Applied 61-62	Measured Width (feet)	Measured Length (feet) Total	Measured Length (feet) On Ice	Computed Weight[3] (lb per lane-mile)	Computed Weight[3] (lb per sq yd)
H-1-1	9	.075	250	A		4.0	208	187	240	0.10
H-2-1	8	.056	275		E	3.5	157	157	350	0.17
M-1-1	10	.075	250	A		4.0	190	190	263	0.11
M-2-1	9	.077	275		E	4.5	215	200	256	0.10
M-3-1	12	.045	275		E	4.0	209	194	263	0.11
M-4-1	9	.078	275		E	4.5	137	137	402	0.15
L-1-1	9	.075	250	A		4.0	170	170	294	0.13
L-2-1	8	.055	350		E	4.0	139	139	503	0.21
L-3-1	8	.065	350		E	2.5	242	197	289	0.19
H-1-2	9	.075	250	D		4.0	235	194	213	0.09
H-2-2	8	.056	275		A	3.5	198	198	278	0.14
M-1-2	10	.075	250	D		2.5	223	190	224	0.15
M-2-2	9	.077	275		A	3.5	204	200	270	0.13
M-3-2	12	.045	275		A	5.0	202	197	272	0.09
M-4-2	9	.078	275		A	4.5	175	175	314	0.12
L-1-2	10	.075	250	D		4.0	240	200	208	0.09
L-2-2	8	.055	350		A	3.5	235	200	298	0.15
L-3-2	9.5	.065	350		A	6.0	200	200	350	0.10
H-1-3	9	.075	250	J		3.0	231	200	217	0.12
H-2-3	8	.056	275		B	3.0	147	141	374	0.21
M-1-3	10	.075	250	J		3.0	186	186	269	0.15
M-2-3	9	.077	275		B	3.5	212	200	259	0.13
M-3-3	12	.035	275		B	4.0	187	187	294	0.13
M-4-3	9	.078	275		B	3.0	160	160	344	0.19
L-1-3		.075	250	J		1.5	202	198	248	0.29
L-2-3	8	.055	350		B	2.8	162	162	432	0.27
L-3-3	9.5	.065	350		B	3.5	180	180	389	0.19
H-2-4	8	.056	275		G	3.0	169	169	325	0.19
M-2-4	9	.077	275		G	4.0	170	170	324	0.14
M-3-4	12	.045	275		G	2.5	202	196	136	0.19
M-4-4	9	.078	275		G	2.5	202	200	272	0.19
L-2-4	8	.055	350		G	2.5	144	144	486	0.33
L-3-4	9.5	.065	350		G	2.0	220	200	318	0.27
H-1-5	9	.075	250	B		6.0	227	180	250	0.06
H-2-6	8	.056	275		F	3.5	137	137	401	0.20
M-1-5	10	.075	250	B		4.0	200	200	250	0.16
M-2-6	9	.077	275		F	4.0	182	182	302	0.16
M-3-6	12	.045	275		F	4.0	174	174	302	0.13
M-4-6	9	.078	275		F	6.0	150	150	367	0.14
L-1-5	9	.075	250	B		4.5	191	191	263	0.10
L-2-6	8	.055	350		F	4.3	143	143	490	0.19
L-3-6	9.5	.065	350		F	3.5	210	200	333	0.16
H-1-7	9	.075	250	G		2.5	226	200	250	0.17
H-2-8	8	.056	275		C	3.5	139	139	396	0.19
M-1-7	10	.075	250	G		3.5	189	189	265	0.13
M-2-8	10	.077	275		C	4.0	196	196	281	0.12
M-3-8	11	.045	275		C	4.0	181	181	304	0.13
M-4-8	9	.078	275		C	2.5	137	137	401	0.27
L-1-7	9	.075	250	G		3.0	191	185	279	0.15
L-2-8	8	.055	350		C	2.5	140	140	500	0.34
L-3-8	9.5	.065	350		C	5.0	204	200	344	0.34
H-2-9	8	.056	275		H	10.0	241	200	157	0.04
M-2-9	9	.077	275		H	7.0	210	190	261	0.06
M-3-9	11.5	.045	275		H	9.5	227	200	167	0.04
M-4-9	9.5	.078	275		H	5.0	215	190	177	0.09
L-2-9	8	.055	350		H	2.8	195	177	244	0.15
L-3-9	9.5	.065	350		H	5.5	191	191	249	0.08
H-2-10	8	.056	275		D	8.0	133	133	323	0.07
M-2-10	10	.077	275		D	5.0	189	159	228	0.08
M-3-10	10.5	.045	275		D	3.0	221	200	194	0.11
M-4-10	9	.078	275		D	5.5	215	200	200	0.06
L-2-10	8	.055	350		D	2.7	183	183	376	0.24
L-3-10	9.5	.065	350		D	4.0	210	170	256	0.11
L-1-11	9	.075	250	C		4.0	207	200	258	0.11
H-1-11	9	.075	250	C		7.0	231	179	259	0.06
M-1-11	10	.075	250	C		4.0	210	193	230	0.10
L-1-12	9	.075	250	I		3.0	200	200	250	0.14
H-1-12	9	.075	250	I		2.5	255	200	216	0.14
M-1-12	10	.075	250	I		4.0	206	194	243	0.10
L-1-13	9	.075	250	E		1.5	193	193	258	0.29
H-1-13	9	.075	250	E		1.5	224	194	223	0.25
M-1-13	10	.075	250	E		1.5	206	200	243	0.27
L-1-14	9	.075	250	H		3.5	200	200	250	0.12
H-1-14	9	.075	250	H		2.5	231	188	222	0.15
M-1-14	10	.075	250	H		3.5	153	153	325	0.15
L-1-15	9	.075	250	F		3.0	208	193	258	0.15
H-1-15	9	.075	250	F		2.0	246	200	203	0.17
M-1-15	10	.075	250	F		4.0	196	196	255	0.11

[1] Letter refers to temperature range. First Number refers to test series. Second Number refers to material type (see Table 2).
[2] Years 1960 and 1961
[3] Actually applied to the ice.

TABLE NO. 4

OBSERVED ICE REMOVAL DATA

Test No.[d]	100% Brine Formation (Minutes)	Minutes Required for Ice Removal in 18-inch Wheel Path (Pitted) 10%	(Pocked) 15%	(Honeycombed) 40%	(Scabby) 55%	(Clear) 80%	Minutes for Outer Wheel Track to Have 55% Removal (Scabby)	80% Removal (Clear)
H-1-1	45	15	20		30	30	45	90
H-2-1	30				15	30	75	(f)
M-1-1	30		10	45	75	(f)		
M-2-1	(e)	15	30	(f)				
M-3-1	30			10	30	30	(f)	
M-4-1	45		15	45	(f)			
L-1-1	(e)	15	50	(f)				
L-2-1	60		15	40	(f)			
L-3-1	45			15	45	(f)		
H-1-2	45				15	30	45	75
H-2-2	30				15	30	(f)	
M-1-2	30			15	(f)			
M-2-2	(e)		15	40	60	(f)		
M-3-2	30				15	15	(f)	
M-4-2	45			15	45	(f)		
L-1-2	(e)	10	25	45	(f)			
L-2-2	60			10	30	45		
L-3-2	60		15	30	45	90		
H-1-3	45	15	20	30	30	45	45	90
H-2-3	30				15	30	(f)	
M-1-3	45			15	(f)			
M-2-3	30		10	(f)				
M-3-3	20				15	15	(f)	
M-4-3	30			15	45	(f)		
L-1-3	(e)	15	25	50	(f)			
L-2-3	60			10	15	45		
L-3-3	30		10	25	60	(f)		
H-2-4	30				15	15	(f)	
M-2-4	(e)	(f)						
M-3-4	30				15	45		
M-4-4	15				15	60		
L-2-4	30				15	75		
L-3-4	45				15	60		
H-1-5	45				15	30	75	120
H-2-6	30				15	15	(f)	
M-1-5	45		10	45	120	(f)		
M-2-6	30					15	(f)	
M-3-6	30			10	15	30	(f)	
M-4-6	(e)		15	40	75	(f)		
L-1-5	(e)	15	40	(f)				
L-2-6	75		15	30	45	(f)		
L-3-6	45				15	30		
H-1-7	30	15	20	30	45	60	60	75
H-2-8	20				20	30	(f)	
M-1-7	60		15	50	(f)			
M-2-8	(e)	10	20	40	(f)		(f)	
M-3-8	30					15		
M-4-8	45			15	30	30	(f)	
L-1-7	(e)	15	25	75	90	(f)		
L-2-8	75			15	30	(f)		
L-3-8	60		15	45	(f)			
H-2-9	(e)		15	(f)				
M-2-9	(e)	15	30	(f)				
M-3-9	45			15	45	(f)		
M-4-9	(e)	15	25	75	(f)			
L-2-9	(e)	15	30	45	(f)			
L-3-9	60		30	45	60	90		
H-2-10	30				15	45		
M-2-10	(e)	15	(f)					
M-3-10	30				15	45		
M-4-10	(e)		15	40	(f)			
L-2-10	(e)	5	15	60	(f)			
L-3-10	60	15	60	(f)				
L-1-11	60	15	30	(f)				
H-1-11	15	30	(f)					
M-1-11	45	15	30	60	(f)			
L-1-12	(e)	15	45	(f)				
H-1-12	45	15	(f)					
M-1-12	30	15		30	(f)			
L-1-13	45	15	(f)					
H-1-13	45					30		
M-1-13	30			15	60	(f)		
L-1-14	45		15	30	45	(f)		
H-1-14	(e)	10	30	45	(f)			
M-1-14	60	15		30	60	(f)		
L-1-15	(e)	10	30	(f)				
H-1-15	60	15	(f)					
M-1-15	60	15	30	75	(f)			

[d] Letter refers to temperature range. First Number refers to test series. Second Number refers to material type (see Table 2).

[e] Formation of brine was incomplete at the end of the test.

[f] Condition was not achieved within the time period of the test.

As melting continues, the holes begin to interconnect as shown in Figure 11 and the third condition, "honeycombed", is achieved. Approximately 40% of the ice has melted when the condition "honeycombed" exists.

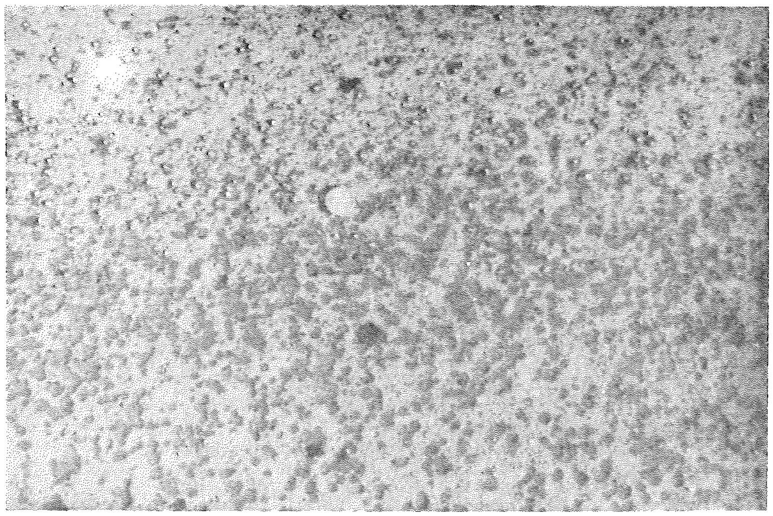

Figure 11 Honeycombed condition.

The fourth condition was called "scabby" and is typified in Figure 12.

Figure 12 Scabby condition.

In this condition only separate fragments of the ice remain on the roadway and approximately 55% of the ice has melted. Beyond the "scabby" condition a "clear" condition was usually achieved where at least 80% of the ice had melted and a definite clear wheel path was provided.

Temperature Ranges

For the purpose of this report only three temperature ranges are considered; and, in each case, the temperature of the air is the controlling factor. The low temperature range (0^{o}F. to 10^{o}F.), medium (10^{o}F. to 20^{o}F.), and high (20^{o}F. to 32^{o}F.) are referred to as L, M. and H respectively. As an example, L-3 would indicate the third test series in the lowest temperature range. It was observed that the ice temperature as measured by the thermocouple was generally significantly higher than the air temperature.

Analysis of the Data

Since this portion of the study had so many uncontrolled variables such as, temperature, wind, humidity, etc. the results are not repeatable. Therefore, the graphical plots presented herein are considered to be trends based upon mean values of the observed and calculated data.

Figure 13 shows a plot of the volume of ice melted by sodium chloride (rock salt) in cubic feet per lane mile vs. time in minutes (vehicle headway remaining constant) for three conditions of average ice and air temperature.

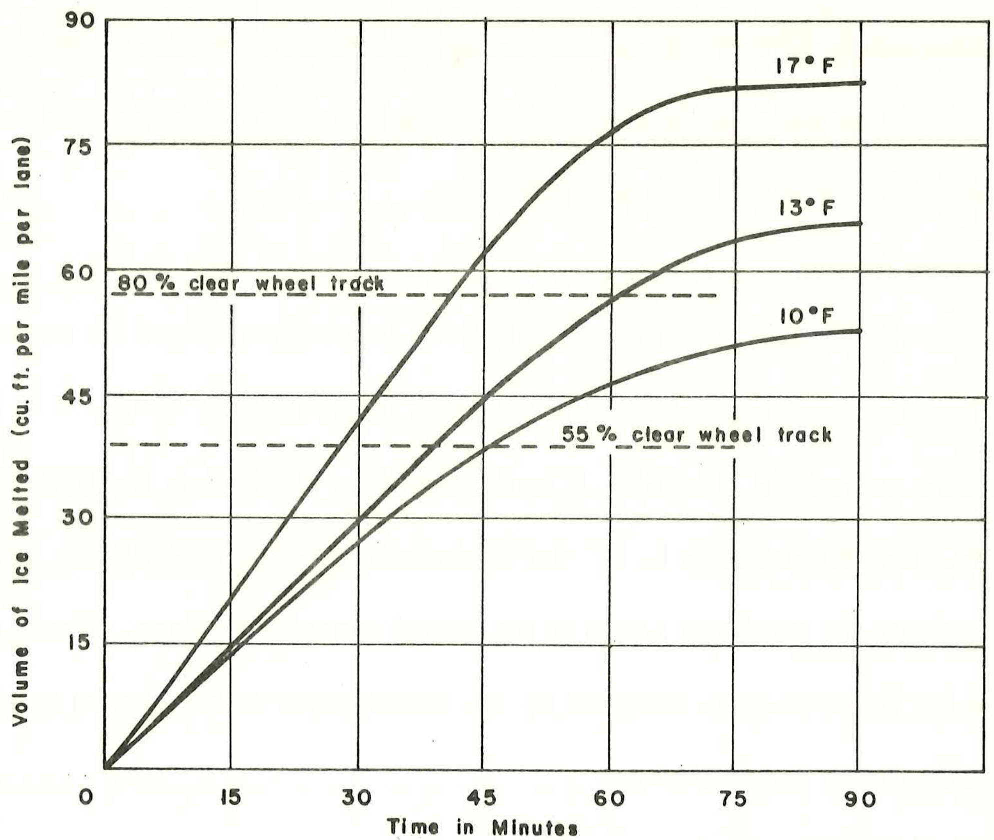

Fig. 13 Rate of Ice Removal for NaCl (Rock Salt)

As indicated by the curves, sodium chloride, with its relatively high eutectic point of $-6^{o}F.$, appears to melt ice at a rate highly dependent upon the average of the ice and air temperature. From the observed data an equation was developed to give a reasonable estimate of the volume of ice which can be melted at a terminal period of ninety minutes and within a temperature range of

10 to 20°F. This formula is:

$$V = \frac{R^{1/2} T^{1.5} k}{I}$$

where V = the volume of ice melted in cubic feet per lane mile.

R = rate of applied salt in pounds per lane mile.

T = average of the air and ice temperature in °F.

I = thickness of ice in inches.

k = a constant with a value of 32.

The small exponent of R, rate of salt application, indicates that the rate of rock salt application is of small concern in the rate of ice removal. On the other hand, the large exponent for T, temperature, indicates that in the case of rock salt, the amount of melt is primarily dependent on the average of ice and air temperatures. The equation also shows that as the ice thickness increases the total amount of melt decreases.

Calcium chloride pellets and flakes have an eutectic point of -58.5°F. Therefore, they do not appear to be as dependent on temperature as sodium chloride for their ice removal rate. Figure 14 is a plot of the volumes of ice melted by calcium chloride pellets at three application rates and with the curves adjusted for temperature differences. The curves show that the amount of thawing is primarily dependent on the amount of calcium chloride applied.

An end point equation showing this relationship for volume of ice melted with $CaCl_2$ was derived and is given as:

$$V = \frac{R^2 \, T \, k}{(I)^{0.8}}$$

where V = volume of ice melted in cubic feet per lane mile.

R = rate of application of chloride in pounds per lane mile.

T = average of the air and ice temperature in ^{o}F.

I = thickness of ice in inches.

k = a constant with a value of 6.15×10^{-6}

In this formula the rate of ice removal varies as the square of the rate of application of calcium chloride. Therefore, it appears that the more chemical applied the faster the ice will melt.

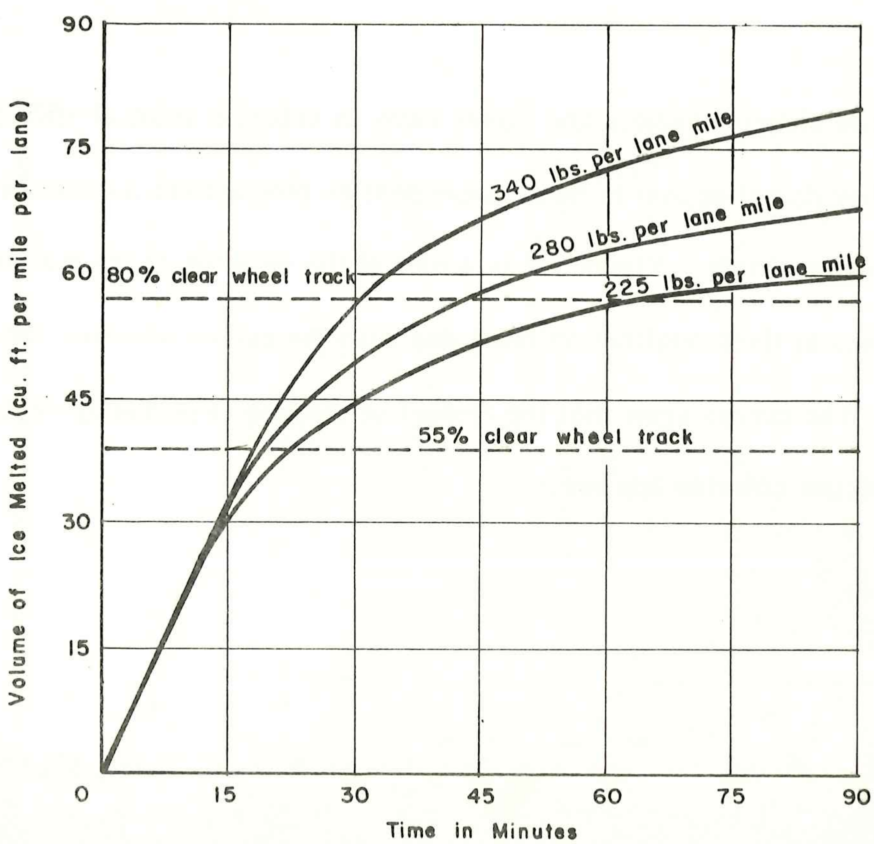

Fig. 14 Rate of Ice Removal by Calcium Chloride Pellets with Temperature Adjustment

The relative rates of ice removal by calcium chloride and sodium chloride are shown graphically in Figures 15, 16, and 17. The comparison at 17°F. shows that initially the Ca Cl_2 is more effective but as the action progresses the rate of melting decreases while that of the rock salt remains more nearly constant up to about one hour and eventually overtakes the rate of the calcium chloride. As shown in Figure 16 the rate of ice removal by rock salt at lower temperatures does not approach that of the Ca Cl_2 pellets. From Figures 16 and 17 it may be concluded that sodium chloride is relatively ineffective below 10°F in clearing a wheel path within a reasonable period of time.

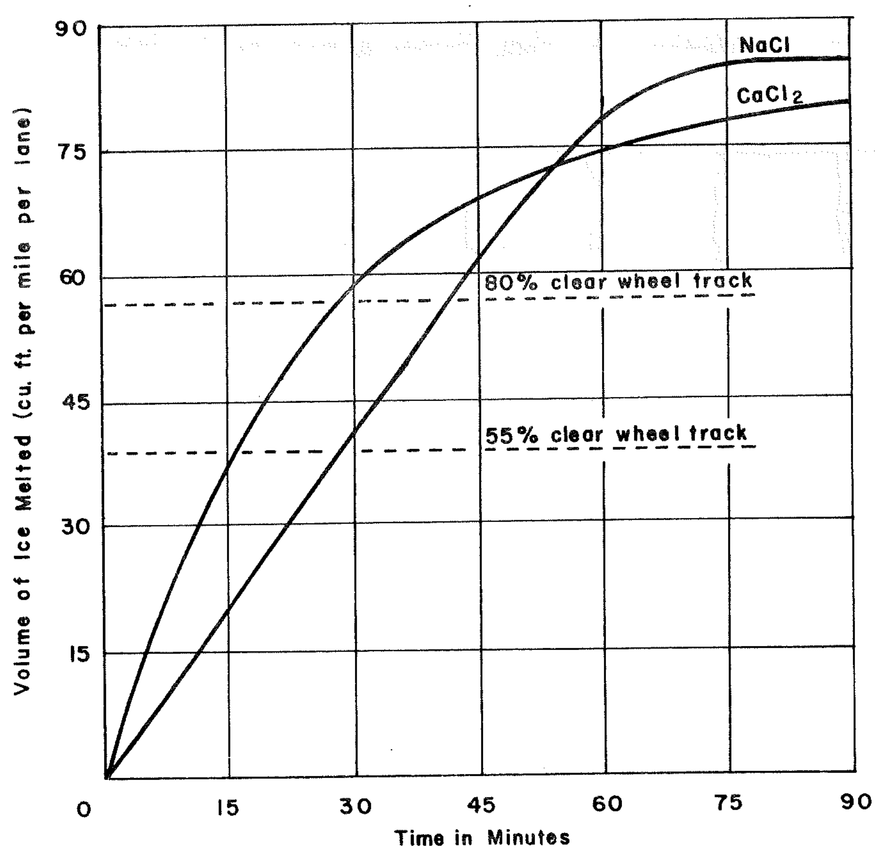

Fig. 15 Rate of Ice Removal by $CaCl_2$ Pellets & Rock Salt at 17° F.

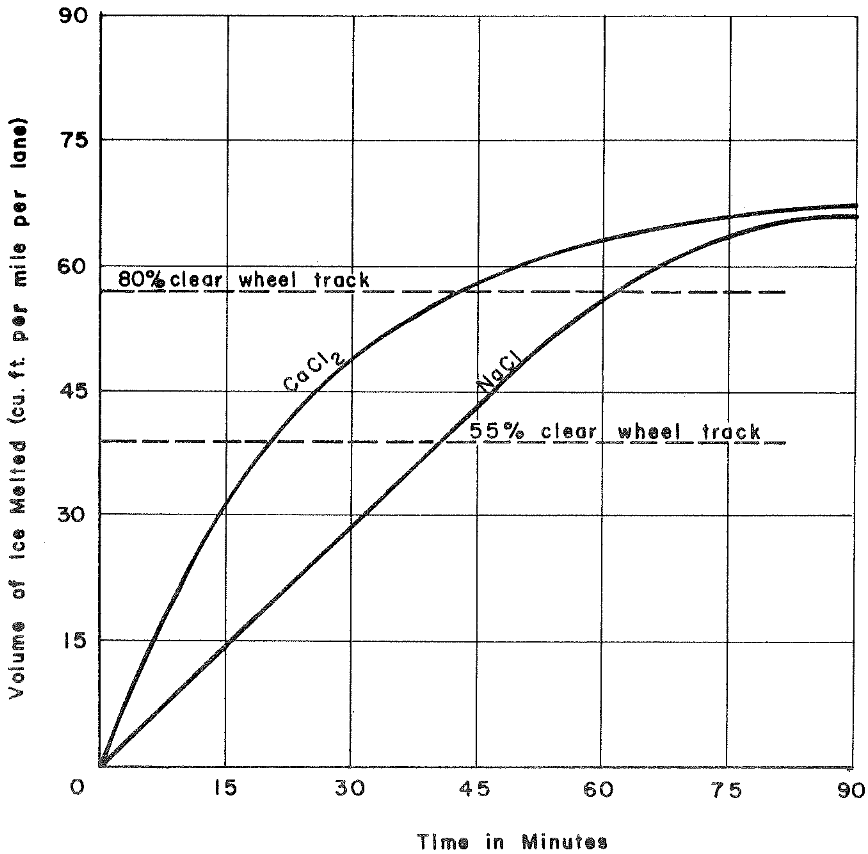

Fig. 16 Rate of Ice Removal by $CaCl_2$ Pellets & Rock Salt at 13 °F.

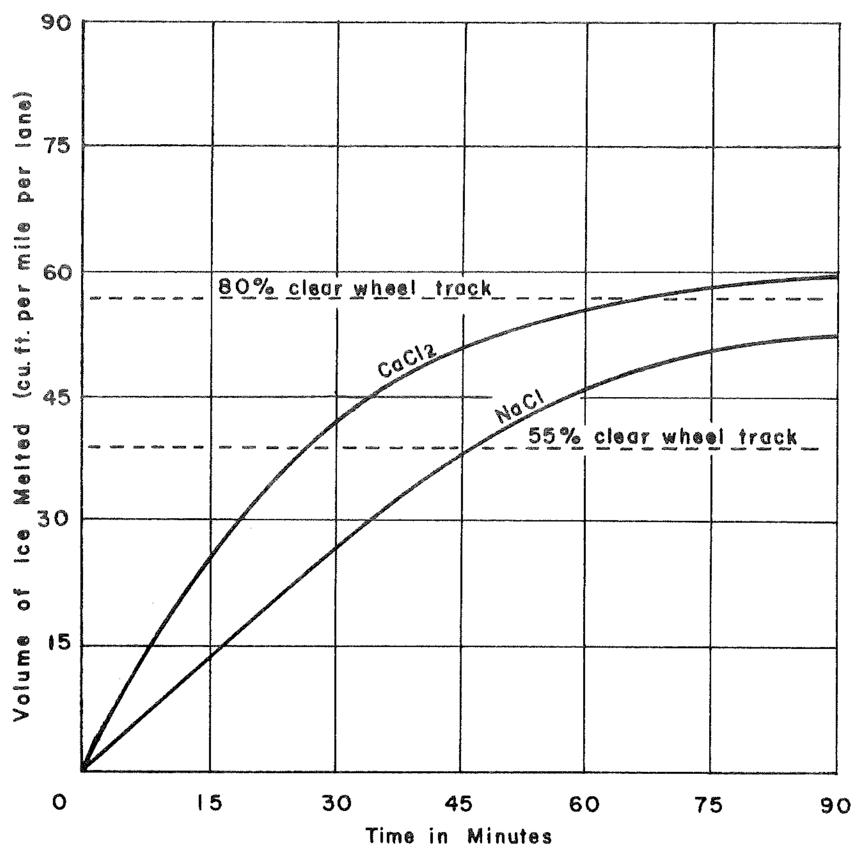

Fig. 17 Rate of Ice Removal by $CaCl_2$ Pellets & Rock Salt at 10° F.

Figures 18 and 19 are plots of the comparative ice removal rates of calcium chloride (pellets), sodium chloride (rock salt), and a 1/3 calcium chloride (pellet) - 2/3 sodium chloride (rock salt) mixture at 17 and 10°F respectively. The plots show that the chemical mixture removes ice at a rate closely resembling that of straight calcium chloride but still retaining most of the economical advantage of sodium chloride

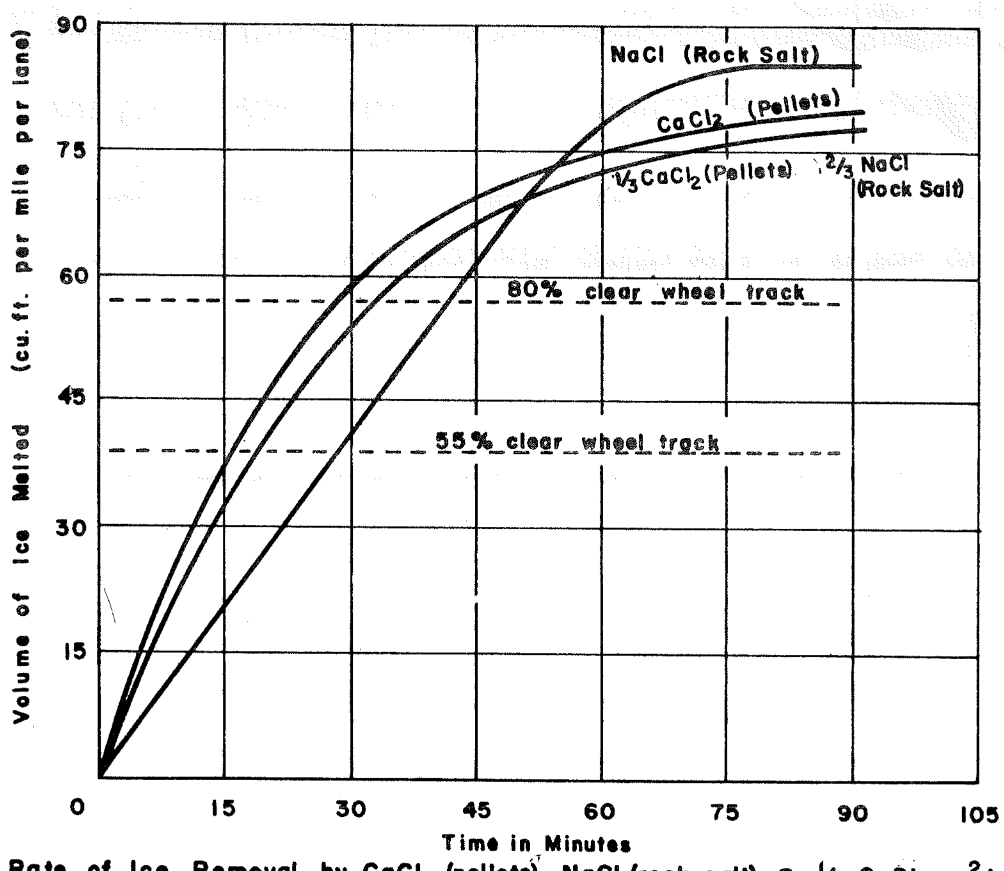

Fig. 18 Rate of Ice Removal by $CaCl_2$ (pellets), NaCl (rock salt), & 1/3 $CaCl_2$ - 2/3 NaCl at 17° F.

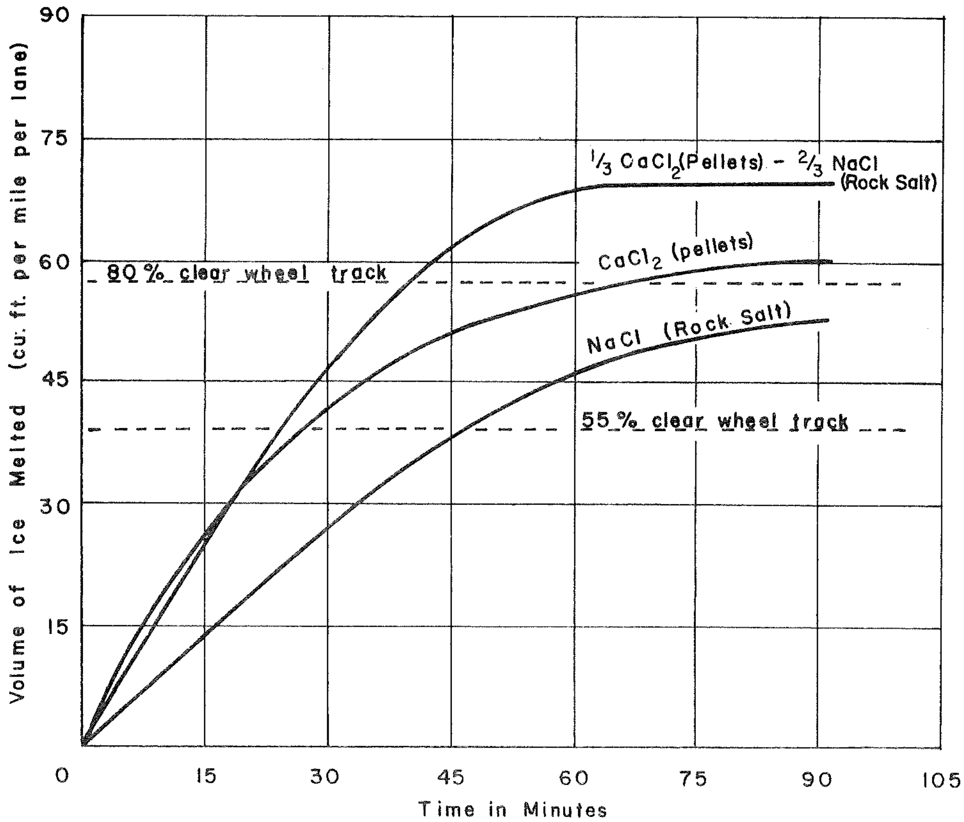

Fig. 19 Rate of Ice Removal by $CaCl_2$ (pellets), NaCl (rock salt), & $\frac{1}{3}$ $CaCl_2$ - $\frac{2}{3}$ NaCl at 10° F.

The comparative ice removal rates of sodium chloride (evaporated salt) and the 1/3 $CaCl_2$-2/3 NaCl mixture at 17 and 10°F are shown in Figures 20 and 21 respectively. The plots show that initially the rate of ice removal by the evaporated salt is somewhat greater than the pellet-rock salt mixture; however, the evaporated salt is overtaken by the mixture within 30 to 40 minutes.

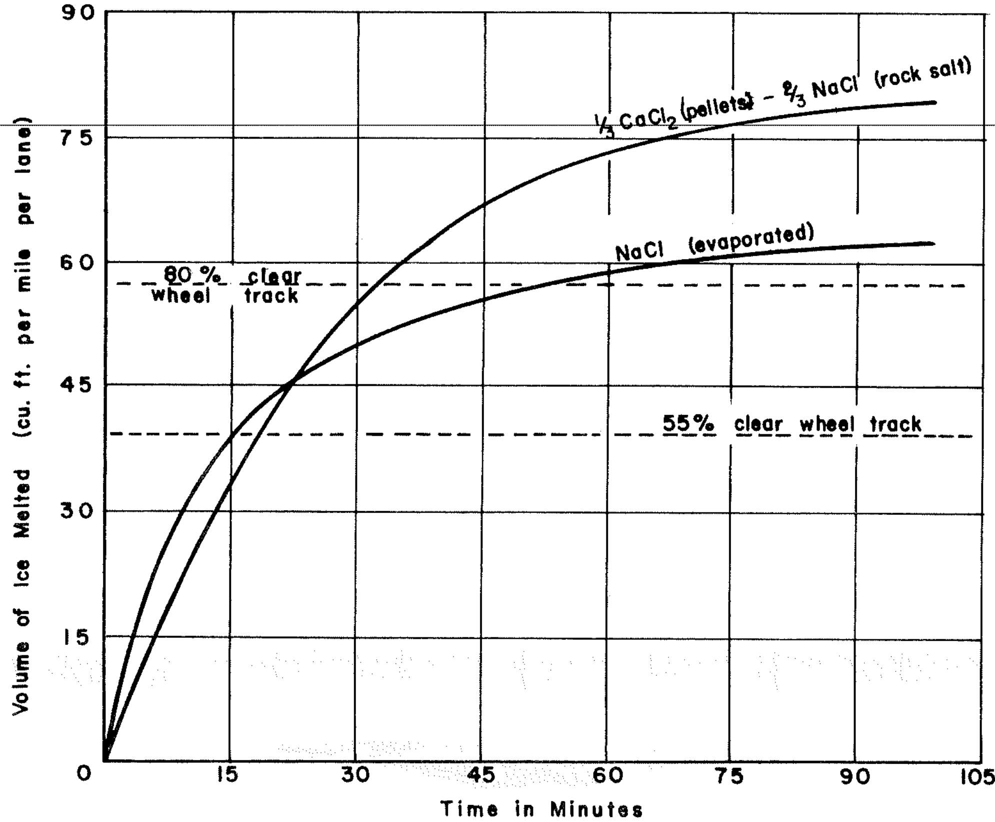

Fig. 20 Rate of Ice Removal by NaCl (evaporated), & $\frac{1}{3}CaCl_2$ (pellets) - $\frac{2}{3}$ NaCl (rock salt) at 17°F.

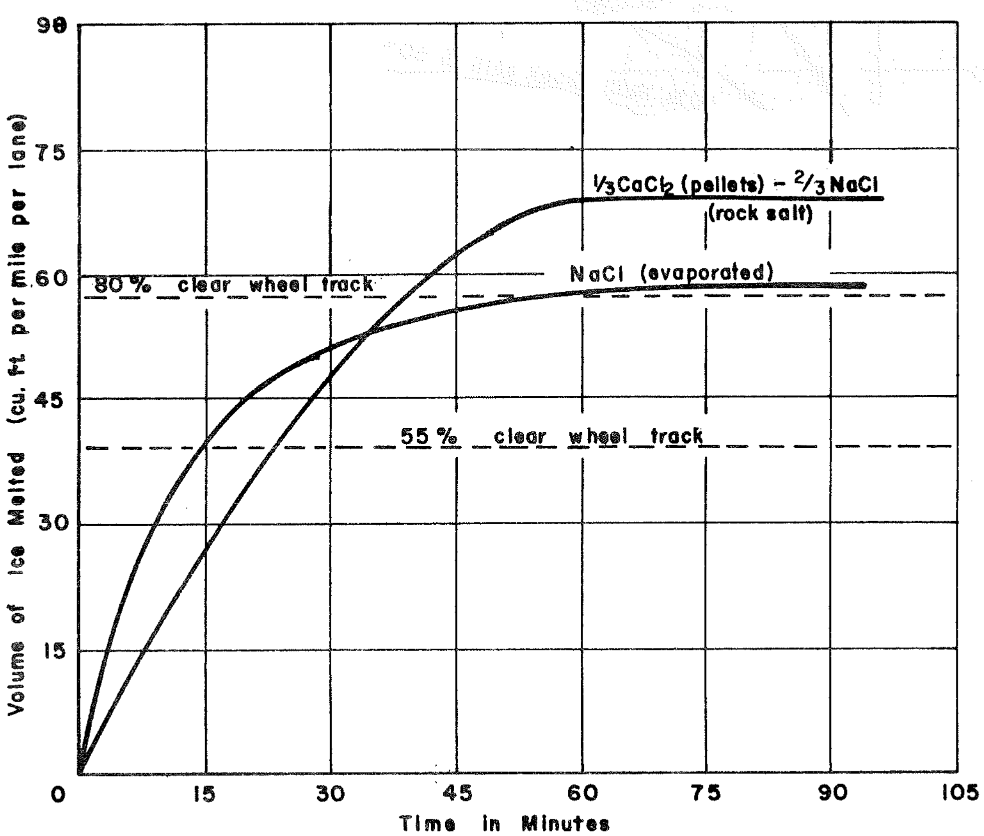

Fig. 21 Rate of Ice Removal by NaCl (evaporated) & $1/3$ $CaCl_2$(pellets)- $2/3$ NaCl (rock salt) at 10°F.

Figures 22 and 23 are plots of the comparative ice removal rates of abrasive-chloride mixtures and a 1/3 $CaCl_2$-2/3 NaCl mixture. As indicated by the curves the abrasive-chloride mixtures are relatively ineffective for ice removal from pavements particularly at temperatures.

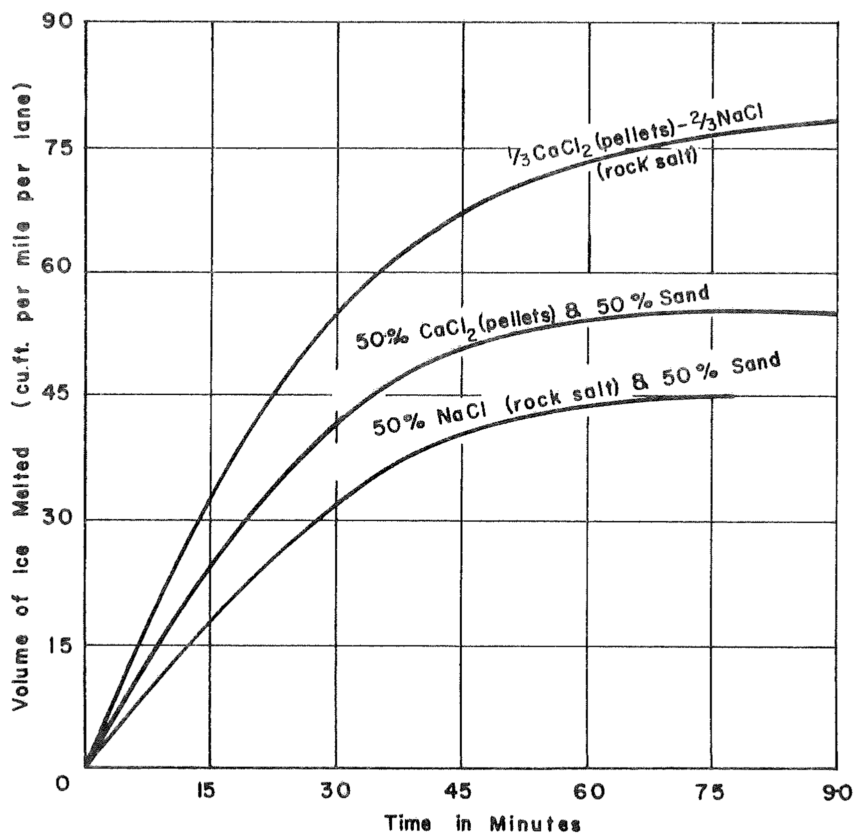

Fig. 22 Rate of Ice Removal by Abrasive - Chloride Mixtures & $CaCl_2$ - NaCl Mixture at 17° F.

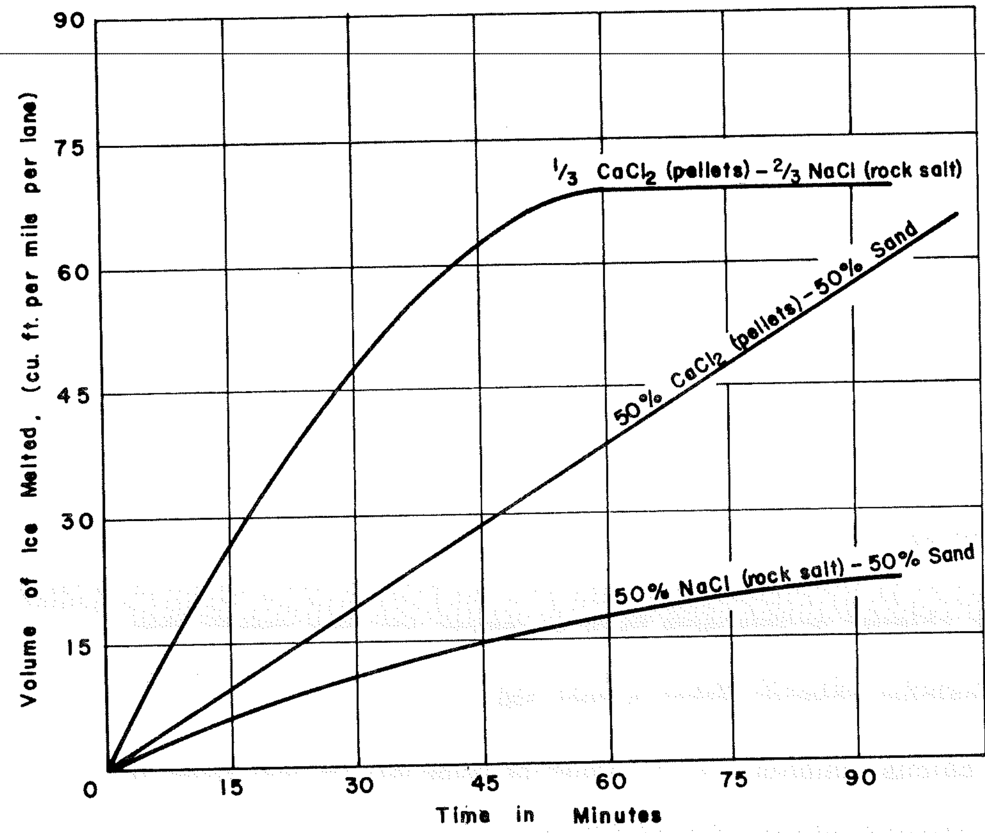

Fig. 23 Rate of Ice Removal by Abrasive-Chloride Mixtures & $CaCl_2$- NaCl Mixture at 10° F.

Ice Removal Conclusions

On the basis of the limited test data for this study, the following general conclusions are indicated:

1. The amount of melt by sodium chloride (rock salt) is primarily dependent on the average of the ice and air temperatures.
2. The amount of melt by calcium chloride within a given temperature range is proportionate to the amount of chemical applied.
3. The rate of ice removal for both calcium chloride and sodium chloride is similar above 15°F.

4. Below $15^{\circ}F.$, calcium chloride was found to be more effective than sodium chloride.

5. Below $10^{\circ}F.$, sodium chloride was found to be relatively ineffective in clearing a wheel path within a reasonable period of time of 60 minutes.

6. The rate of application of sodium chloride should be varied inversely with the temperature.

7. The rate at which both calcium chloride and sodium chloride removes ice is inversely proportional to the ice thickness.

8. Calcium chloride pellets were found to remove ice more rapidly than either calcium chloride flakes or rock salt.

9. A 1/3 calcium chloride - 2/3 sodium chloride mixture was found to be the only one which provided clear wheel paths with any consistency. The mixture removed ice at a rate closely resembling that of straight calcium chloride.

10. Sodium chloride (evaporated salt) was found to have a high rate of ice removal in the first 20 minutes after application but fell off rapidly after that time.

11. Mixtures of sodium chloride with abrasive and calcium chloride with abrasive were found to be relatively ineffective for ice removal from pavements particularly at temperatures below about $15^{\circ}F.$

OUTDOOR STORAGE OF CHLORIDE SALTS

The primary concern of this portion of the study was the determination of the storage characteristics of bulk sodium chloride, calcium chloride and mixtures of the two. The decision to include packaged material in the study was based on the problem of salt caking in some types of paper bags. Packaged calcium chloride was not included in the study since no problem was evident in this respect.

The Test Site

The test site selected for this portion of the study was within the storage grounds of a highway maintenance depot. The tests were conducted on a bituminous surfaced storage base 10 feet wide and 60 feet long. The base had a slope in only one direction of 1/2 inch per foot across the 10 foot width. The site and materials under test were protected from accidental disturbance by a 4-foot high wood slat snow fence. An overall view of the test site is shown in Figure 24.

Figure 24 The test site for outdoor storage of chloride salt.

Test Materials

The bulk materials included in the tests are given in Table 5. Assuming the sodium chloride (rock salt) to have a purity of 100%, the weights of calcium chloride were computed based on their purity as advertized by the manufacturer.

Where mixtures were included they were prepared by hand using square nosed shovels to blend the materials together.

TABLE 5

POUNDS OF BULK MATERIALS USED

Identification	Sodium-Chloride Rock Salt	Calcium Chloride Flakes Type I	Calcium Chloride Pellets
A	1,000		
B		1,282	
C			1,053
D	750		263
E	500		526
F	500	641	
G	1,000 *		

* Covered with a 4 inch layer of sand instead of polyethylene sheeting.

The packaged material consisted of 40 bags of sodium chloride (rock salt) in several types of paper bags as follows:

"U" Untreated paper bags with three layers of untreated paper - 15 bags.

"B" Bituminous treated bags with three layers of paper, two of which were treated with bituminous - 10 bags.

"Bo" Bituminous treated bags similar to "B" above except they were in previous storage for about nine months - 5 bags.

"P" Plastic cemented bags having three layers of paper, two of which were glued together with a plastic cement - 10 bags.

The packaged material was placed on planks in five stacks of eight bags per stack. Since there were five stacks, an arrangement was worked out so that no more than two similar bags would be represented in each layer. The arrangement of stacking is shown in Figure 25.

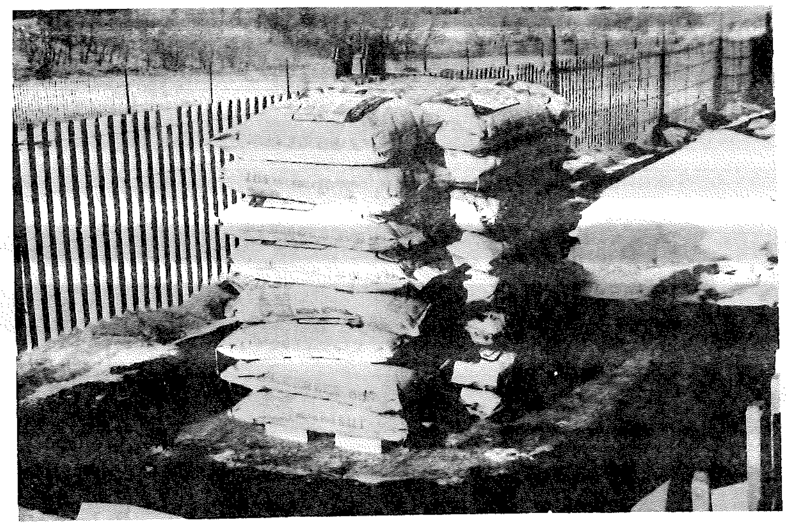

Figure 25 General arrangement of packaged NaCl.

All materials included in the study were placed in test between November 7 and 10, 1960, except Test Material "G" (100% sodium chloride with a sand cover) which was placed May 3, 1961.

<u>Protective Covering Material</u>

The protective covering material used in this study was a nominal 5 mil white polyethylene sheeting similar to that used for curing concrete. It was anchored with sand-filled burlap bags placed at the base of each storage pile. No polyethylene sheeting material was used to cover Test Material "G" since this test was introduced to study the effectiveness of a light sand cover.

Collection of Data

Observations of the bulk test materials were made once a month and those for the packaged material once every two months. Observations included moisture determinations, amounts of caking and crusting and whether or not each material was free flowing.

Duplicate moisture samples of the bulk materials were taken about midway between the base and apex of each conical storage pile. They were taken either at a depth of two to three inches below the surface or one sample was taken at the surface and the other about five to six inches into the pile. The moisture determinations for the bulk materials are given in Table 6. It is noted that the figures given are averages of the separate tests.

Single moisture samples were taken of the bagged material by cutting a small opening near the center of the bag, as shown in Figure 26, removing about 300 grams of salt, and then taping the opening closed.

Figure 26 Method of taking moisture sample from packaged NaCl

TABLE 6

MOISTURE DATA FOR BULK MATERIALS

Average Moisture - Percent of Dry Weight

Test Material	12-6-60	1-3-61	2-3-61	3-1-61	4-7-61	5-3-61	6-1-61	7-6-61	8-7-61	9-6-61	10-4-61	12-7-61
A	0.6	0.5	0.7	0.9	0.6	0.2	0.9	2.2	1.1	0.9	2.5	-
B	11.7	11.9	11.1	11.9	10.3	11.9	15.6	16.0	16.9	22.8	23.6	-
C	0.6	0.4	0.4	0.6	0.1	0.4	0.8	0.8	0.6	1.3	1.7	-
D	0.6	0.6	0.5	1.1	0.6	0.4	0.6	1.1	1.3	1.5	5.8	-
E	0.4	0.5	0.3	0.5	0.3	0.4	0.4	0.9	0.6	1.7	6.4	-
F	6.7	8.0	6.7	7.2	6.2	8.3	10.7	14.2	12.6	14.5	21.5	-
G	-	-	-	-	-	0.2	0.5	2.6	0.6	0.5	1.0	1.0

and almost half were sampled three times or more. The moisture data and data of moisture test are given in Table 7.

Some slight caking was found to exist in only a few of the bags of rock salt within the ten month storage period. However, the cake was easily broken by hand and no difficulty would have been experienced in using the material.

On the other hand, considerable caking and crusting did occur in some of the bulk storage piles which would create difficulty in their use. The observations of crusting and caking are summarized in Table No. 8 along with the average moisture content of each material.

TABLE 7

MOISTURE DATA FOR PACKAGED NaCl

Bag Position[a]	Moisture - Percent of Dry Weight 2-3-61	4-7-61	6-2-61	8-7-61	10-4-61	11-8-61
1 NB		0.2				0.4
1 EB			0.3			0.3
1 SU			0.9			0.4
1 WU		0.4				0.5
1 CP		0.1				0.4
2 NP			0.4			0.2
2 EP			0.5			0.3
2 SB			0.6			0.2
2 WU			0.4			0.4
2 CU		0.3				0.4
3 NU			0.5			0.6
3 EU			0.5			0.2
3 SP			0.5			0.3
3 WB			0.3			0.2
3 CB		0.3				0.2
4 NB$_o$			0.4			0.1
4 EB			0.3			0.2
4 SU			0.4			0.1
4 WP			0.3			0.3
4 CP		0.1		0.2		0.2
5 NP	0.3			0.1		0.2
5 EB$_o$	0.3			0.3		0.2
5 SB	0.3			0.2		0.2
5 WU	0.4			0.1		0.4
5 CU	0.4			0.4		0.3
6 NU	0.6					0.6
6 EU			0.4			0.4
6 SP		0.2		0.3		0.3
6 WB			0.3			0.3
6 CB	0.3			0.1		0.2
7 NB$_o$		0.1			0.3	0.3
7 EB		0.1			0.1	0.5
7 SU		0.6			0.2	0.4
7 WU			0.3		0.4	0.4
7 CP	0.3			0.1	0.2	0.3
8 NP	0.4			0.3	0.3	0.5
8 EB$_o$	0.3			0.4	0.1	0.2
8 SB	0.4			0.2	0.3	0.2
8 WU	0.4			0.6	0.6	0.8
8 CU		0.4			0.9	1.2

(a) The number indicates the layer within the stack.
The first letter refers to the compass position of the stack - North, East, South, West or Center.
The second letter refers to the type of paper bag (see text).

TABLE NO. 8

Summary of Bulk Storage Pile Conditions

Test Material	After Two Months Storage		After Ten[1] Months Storage	
	Physical Condition	Moisture (Aug.-%)	Physical Condition	Moisture (Aug.-%)
A	2-3 in. hard base crust. Slight crust on outer surface — easily broken.	0.6	Entire pile caked in a solid mass. Can be broken with some difficulty.	0.9
B	1-1½ in. base crust. No surface crust — free flowing.	11.9	Slight outer surface crust - easily broken and free flowing beneath.	22.8
C	½-1½ in. base crust. No surface crust — free flowing.	0.4	1-1½ in. base crust. 0-½ in. surface crust — free flowing beneath.	1.3
D	0-1 in. base crust. No outer surface crust — free flowing.	0.6	1 in. base crust. Slight crusting at outer surface — free flowing beneath.	1.5
E	1 in. base crust. No surface crust — free flowing.	0.5	1 in. base crust. Slight crusting in outer surface — free flowing beneath.	1.7
F	1-1½ in. base crust. No outer surface crust — free flowing.	8.0	2 in. base crust. No crusting at outer surface — free flowing.	15.0
G	Fairly hard cake developing especially on outside - softer within.	2.6	2-3 in. very hard surface crust. Inner portion caked but not too hard.	1.0

(1) All except Test Material "G" which was seven months.

Analysis of the Data and Discussion

As shown by the data, 100% sodium chloride - rock salt (Test Material "A") crusted within a two-month storage period. And, it was completely caked within ten months although the moisture content remained quite low (0.6 to 0.9%).

100% calcium chloride, Type 1 flakes, (Test Material "B") developed a base crust of 1 - 1½ in. within a two month storage period while no surface crusting was evident even though the moisture content was quite high (11.9%). At ten months, a slight outer surface crust developed which was easily broken. The chemical remained free flowing in spite of the fact that the moisture content almost doubled in an eight month period. It is believed the base crust formation in this and other stockpiles in the test, as shown in Figures 27 and 28, is related to the amount of surface water on the storage base that is available to the stockpile. This points up the need for a well constructed, free draining storage base.

Figure 27 Base crust formation in rock salt.

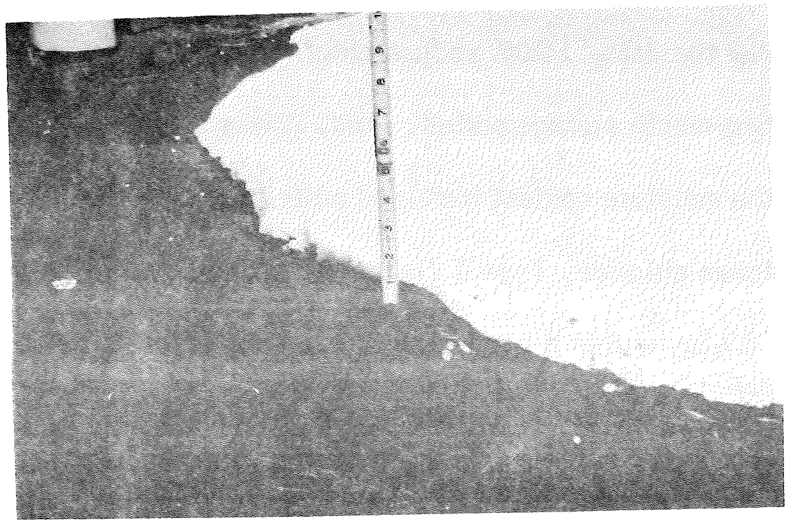

Figure 28 Base crust formation in calcium chloride

100% calcium chloride pellets (Test Material "C") developed a base crust of ½ to 1½ in. within a two month storage period but no surface crusting occurred. At ten months, no increase in base crust was noted although a crust varying from 0 to ½ in. developed on the surface. The moisture content remained low (1.3%) and the chemical was free flowing.

Mixtures of sodium chloride and calcium chloride all developed a base crust of 0 to 1½ in. within a two month storage period with no surface crusting at all. At ten months the base crust varied from 1 to 2 in. with only slight surface crusting. All chemical mixtures remained in a free flowing condition throughout the test period. The moisture contents remained below 2% except in Test Material "F" (50% sodium chloride and 50% calcium chloride flakes) which had a gradual increase up to 15% at the end of ten months. In all cases of the mixtures it was noted that after a short period of storage only particles of rock salt were left on the surface. These particles then fused together to form this light crust.

Sodium chloride with a 4 in. sand cover, (Test Material "G") developed into a fairly hard cake with a two-month period and at the end of seven months became very hard on the surface. The material was not free flowing and this method of storage cannot be considered desirable.

Packaged rock salt stored well. The moisture content generally remained under one percent during the ten-month storage period with no detrimental amount of hardening or caking occurring. Only in a few cases where the moisture content approached or exceeded 1% was any caking noticed and in these cases the cake was easily broken by hand. A marked difference in moisture is noted between the types of paper bags. The moisture of the salt in the unlined bags was as much as double that in the treated bags. The polyethylene sheeting used in this study as a cover over the bags provided a very effective moisture barrier. In fact the barrier was so effective, it prevented the natural escape of moisture during dry periods. The moisture then collected on the outside of the bags as shown in Figure 29 and, in some cases, deteriorated the bags to the point of breaking.

Figure 29 Collection of moisture on bags.

Outdoor Storage Conclusions

1. Calcium chloride (pellets or flakes), and mixtures of sodium chloride with at least 25% calcium chloride, can be stored outdoors in bulk with a light polyethylene sheet cover for at least 10 months without appreciable hardening.

2. Sodium chloride (rock salt) can be stored outside up to two months in bulk when covered with a light polyethylene sheeting. Bulk storage of sodium chloride beyond 3 months appears to be unsatisfactory.

3. Packaged sodium choloride (100 lb. bags) may be stored outdoors with a light polyethylene sheet cover for at least 10 months with no appreciable hardening.

RECOMMENDATIONS

Ice Removal

Table 9 gives a recommended range of application rate for eight ice removal materials. These rates are based on an ice thickness of about 1/16 inch and on clearing a wheel path 1½ - 3 feet in width. It should be pointed out however, that additional material may be required for complete removal of ice from the roadway.

TABLE 9

Recommended Application Rates of Chemicals and Chemical-Abrasives for Ice Removal

Ice Removal Material	Suggested Width of Spread (ft)	Application Rates (lb per lane mile[a]) for 1/16 in. Ice		
		Below 10°F.	10-20°F	20-32°F
$CaCl_2$ (pellets)	2-4	300-375	250-300	(175-250)[c]
$CaCl_2$ (flakes)	2-4	350-450	275-350	(200-275)[c]
NaCl (rock salt)	3-4	(400-550)[b]	250-400	200-250
NaCl (evaporated)	3	(325-500)[b]	200-325	150-200
1/3 $CaCl_2$ (pellets) - 2/3 NaCl (rock salt)	2-4	300-475	250-300	175-250
1/3 $CaCl_2$ (flakes) - 2/3 NaCl (rock salt)	2-4	350-500	275-350	200-275
50% $CaCl_2$ (pellets) - 50% Sand	4	(excess of 500)[b]	(300-500)[b]	200-300
50% NaCl (rock salt) - 50% Sand	4	(excess of 600)[b]	(325-600)[b]	225-325

[a] Quantities given shall be doubled for 2-lane roadways
[b] Not recommended because of the low rate of ice removal. Quantities given are suggested if no other material is available.
[c] Not recommended because a greasy condition often results. Quantities given are suggested if no other material is available.

Since the application rates recommended above are based on a limited number of tests, they may require modification after being used by the maintenance crews for a suitable period of time. Suggested modifications are therefore invited.

Outdoor Storage of Chloride Salts

Bulk sodium chloride intended for outdoor storage longer than two months should be mixed with at least 25% calcium chloride - preferably pellets. A mixture of ~~1/3~~ 2/3 sodium chloride (rock salt) - ~~2/3~~ 1/3 calcium chloride (pellets) appears to be the best all-round mixture when considering storage, ice removal action and economy.

FURTHER RESEARCH

Additional testing of the more promising materials is recommended to be conducted under field conditions. It is suggested that the roadway be iced in a manner similar to that used in this study. However, more thought should be given to the elimination or greater control of some of the variables. For example the chemicals and chemical mixtures might be applied at a better controlled rate using a fertilizer spreader, also a better method for evaluating the amount of ice removal might be found.

Other governmental bodies and agencies are encouraged to conduct field tests similar to Minnesota's to validate or disprove the results and conclusions presented herein.