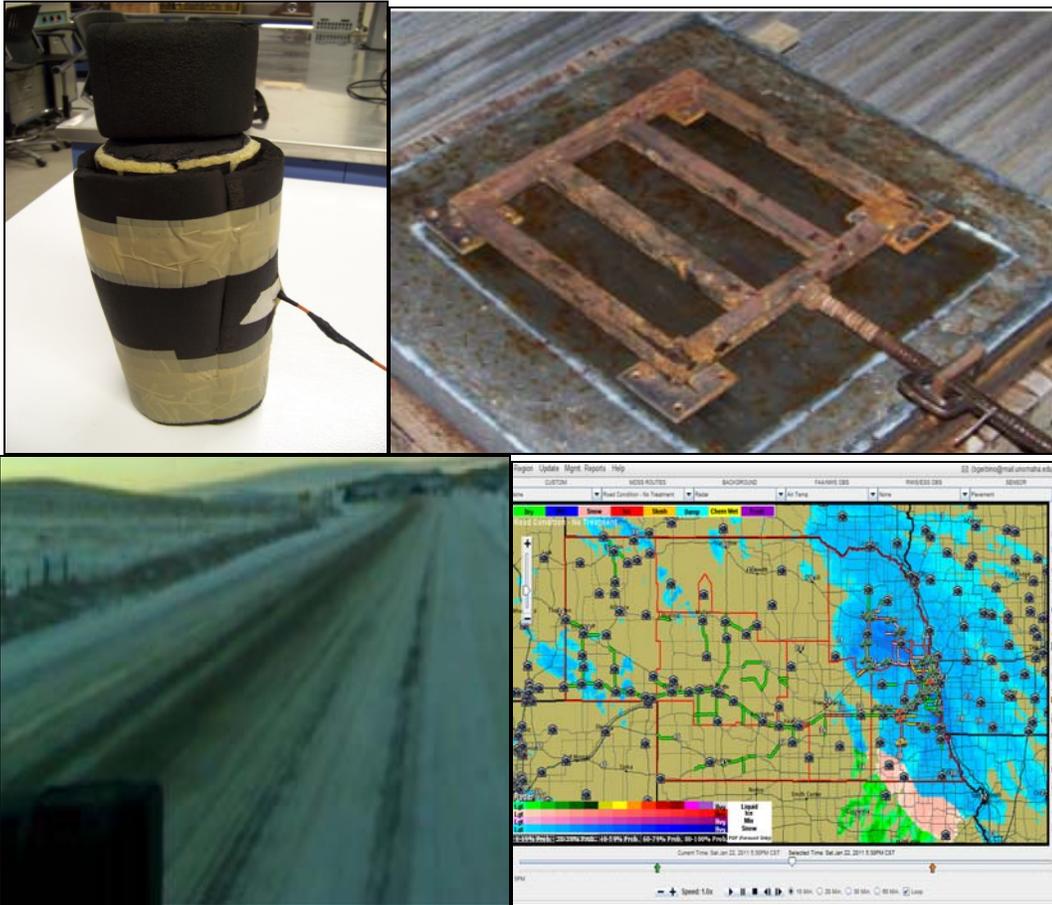


Performance Rating of De-icing Chemicals for Winter Operations

Nebraska Department of Roads

Project No. SPR-P1(10) P328



August 2011

Performance Rating of De-icing Chemicals for Winter Operations

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16. Abstract <p>The cost of deicing chemicals is a significant part of the Nebraska Department of Road's winter maintenance budget. Many products are available for use in highway and bridge deicing and new products are introduced each year. The objectives of this research are to develop a laboratory test to evaluate the performance of chemical deicers, to investigate national, state, and local standards, and to develop best maintenance practices to optimize the use of chemical deicers.</p> <p>Samples of sodium chloride, magnesium chloride, calcium chloride, potassium acetate, and beet juice based chemical deicers were selected for evaluation. The deicers were tested for ice melting performance, resulting pavement friction, the effect from direct sunlight, and the time to refreeze after application. Correlations between the laboratory test results with field data during winter storms were studied.</p> <p>The field data was collected by the Nebraska Department of Roads using Automatic Vehicle Location (AVL) systems installed on plow trucks in concert with the Maintenance Decision Support System (MDSS). The MDSS is a computerized system that collects weather data from area weather stations and gives maintenance crews recommended application rates for different weather events.</p> <p>The Shaker Test was developed to evaluate the ice melting capacities of chemical deicers. The test works well for assessing the ice melting capacities of liquid and solid deicers, but more research is needed for prewet solids. The beet juice based deicers were found to perform well at temperatures as low as 14°F when exposed to direct sunlight. A summary was compiled to outline the recommended standards of practice for anti-icing and de-icing operations using the selected deicing chemicals for particular types of winter storms.</p>			
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Chapter 1

Introduction

1.1 Background Information

The cost of deicing chemicals is a significant part of the Nebraska Department of Road's winter maintenance budget. The use of deicing chemicals is increasing every year to improve a Level of Service (LOS) and the price of the chemicals is also going up every year. The use of Maintenance Decision Support Systems (MDSS) allows users to be more precise in the selection of chemicals and the application rate for specified weather and pavement conditions.

Many products are available for use in highway and bridge deicing and new products are introduced each year. Data from the manufacturer provides theoretical performance under specified conditions. A test procedure for acceptance of new commercial deicing chemicals is needed to confirm the manufacturers' claims and to compare competing products under the same controlled conditions.

1.2 Research Objectives

The purpose of this project was to gather information regarding accepted test methods used to evaluate chemical deicer performance and to develop new test methods if necessary. The purpose of this project was also to research and generate a best practices summary for Nebraska Department of Roads. The results of this research will help the State of Nebraska to use deicing chemicals more effectively.

This research consists of a literature review and the documentation of the development of new testing procedures used to evaluate the performance of selected chemical deicers. After conducting a test standardized by the Strategic Highway Research Program, it was decided a new, simple and repeatable test needed to be developed to evaluate the performance of chemical deicers. The performance test developed by this project has been termed as the Shaker Test.

Other performance tests developed by this research include the Friction Test, the Sunlight Test, and the Refreeze Test. The purpose of the Friction Test was to confirm if a particular liquid deicer would cause roadways to become slick. The Sunlight Test was used to determine if darker colored chemical deicers have a significant advantage over lighter colored chemical deicers in direct sunlight. The purpose of the Refreeze Test is to determine when a deicing product will cease to function and the mixture with melted ice begins to refreeze on the roadway.

The field data used in this project was collected by the MDSS and plow trucks equipped with the automated vehicle locator (AVL). The MDSS collected real-time weather data including temperature, wind speed, and type and amount of precipitation. The field data collected by the AVL includes real time information of the vehicle location, type and amount of material being used per lane-mile, and pictures of the roadway conditions taken from the cab of the truck. The main purpose of collecting field data was to document the effect different chemical deicers had on the LOS of the roadway. The field data and observations were then compared against the data from the ice melting capacity tests conducted in the laboratory. Strong correlations between the field data and the laboratory test results would

validate the laboratory tests developed in this research. Further, the deicing performance of the different deicers will be ranked based on both the laboratory tests and the field data. The findings from this study can then be used to fine tune the current practices suggested by the MDSS.

1.3 Organization of the Report

There are 6 chapters in this report: Chapter 1 contains the introduction. Chapter 2 provides a summary of the literature review. Chapter 3 details the equipment required and the procedures for the tests conducted in this project. Chapter 4 presents the test results and an evaluation of each test. Chapter 5 summarizes field data from selected truck routes in a number of winter storms from the MDSS and a correlation with results from the Shaker Test was studied. Chapter 6 presents the findings and provides recommendations for the effective use of chemical deicers and further research needs.

Chapter 2

Literature Review

The objectives of the literature review were to survey accepted or standardized performance tests for chemical deicers and to research general standards of practice for chemical deicers. Several lab tests have been developed and published by the Strategic Highway Research Program (SHRP) in the Handbook of Test Methods for Evaluating Chemical Deicers (Chappelow et al., 1992). Many researchers used a number of these lab tests in their studies, but some also utilized different tests for various properties of chemical deicers.

2.1 Laboratory Tests

Each lab test used to quantify chemical deicer properties was evaluated to determine its effectiveness. Many tests were found to be useful, but some produced unreliable results or were found to be nonessential. This section will discuss some of the tests and their effectiveness in the evaluation of chemical deicers.

Performance properties of chemical deicers include: ice melting capacity, ice penetration, ice debonding, thermal properties, and the resulting friction coefficient of a de-iced roadway. Other deicer properties, such as viscosity and specific gravity, are more related to its applicability rather than performances.

2.1.1 Ice Melting Capacity

Two tests were found pertaining to ice melting capacity, one test for solid chemicals and the other test for liquid chemicals. These tests are in the SHRP Handbook (Chappelow et al., 1992). The designation for the solid chemical test is SHRP H-205.1 and the designation for the liquid chemical test is SHRP H-205.2.

The tests have a similar procedure and require a freezer or cold-room, some measuring equipment, and three square 11 in by 11 in Plexiglas dishes as seen in Figure 2.1.



Figure 2.1:
Ice Melting Capacity Dish

Ice is formed in the dish, deicer is applied, and the resulting brine is measured at intervals over a 60 minute period. This test can be utilized at different temperatures and will provide the total volume of melted ice and the melting rate.

At this time, there is no set standard for what volumes of ice should be melted to confirm an acceptable performance. This test is best used when doing a comparison with a

chemical deicer known to have acceptable field performance. The results of this test from other research will be discussed in chapter 4.

2.1.2 Ice Penetration

Two tests were found pertaining to ice penetration, one test for solid chemicals and the other test for liquid chemicals. These tests are also in the SHRP Handbook. The designation for the solid chemical test is SHRP H-205.3 and the designation for the liquid chemical test is SHRP H-205.4.

The tests have a similar procedure to the ice melting capacity tests and require a freezer or cold-room, some measuring equipment, and a rectangular 8in by 2in Plexiglas plate with 35mm depressions in the plate as seen in Figure 2.2.

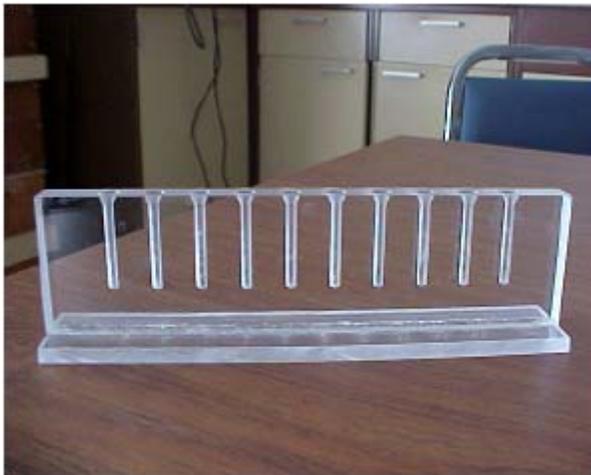


Figure 2.2:
Ice Penetration Test Apparatus (Nixon et al., 2007)

Ice is formed in the depressions, a few drops or grains of deicer are applied, and the resulting penetration is measured at intervals over a 60 minute period. This test can be utilized at different temperatures and will provide the total ice penetration and the rate of penetration.

The 60-minute test results from Nixon et al. (2007), Shi et al. (2009), and Akin and Shi (2010) are compared in Table 2.1. The results from different sources do not correlate, which suggests that this test produces inconsistent data and appears not repeatable. It is also not advisable to use solid deicing chemicals for this test because the grains would often become physically wedged in the narrow depression of the test apparatus.

Table 2.1: Comparison of Ice Penetration (mm) at 60 Minutes

Deicer	Nixon et al. (2007)			Shi et al. (2009)			Akin and Shi (2010)	
	30°F	10°F	0°F	30°F	10°F	0°F	30°F	15°F
NaCl (liquid)	3.5	1	1.5	--	--	--	9.5	1
NaCl (solid)	--	--	--	10	2.1	2	20	5.9
MgCl₂ (liquid)	5.6	3.5	0	30	18	3	10	2
MgCl₂ (solid)	--	--	--	--	--	--	8	3.4
CaCl₂ (liquid)	4.1	3	2.5	--	--	--	11	1.1
CaCl₂ (solid)	--	--	--	--	--	--	10.5	4.2
KAc	5.4	2	1	30	15	3	--	--

This test requires further development to produce more usable results. However, the depth at which a chemical deicer can penetrate may be of little importance. Many states do not put liquid deicing chemicals on accumulated ice as part of their standard of practice. Also, roadway traffic would help to fragment an ice sheet making the penetration ability of a chemical deicer less crucial.

2.1.3 Ice Debonding

Two tests were found pertaining to ice debonding or undercutting, one test for solid chemicals and the other test for liquid chemicals. These tests are also in the SHRP Handbook. The designation for the solid chemical test is SHRP H-205.5 and the designation for the liquid chemical test is SHRP H-205.6.

The tests have a similar procedure to the SHRP tests described above and require a freezer or cold-room, some measuring equipment, colored dye such as bromocresol green, a concrete substrate, a camera, and a dish or apparatus capable of molding 1/8-inch thick sheet of ice.

Large drops of dye are placed on the ice sheet, a drop or grain of deicer is placed in the middle of the dye, and pictures are taken at intervals over a 60 minute period. The pictures are used to determine the debonded area. Shi et al. (2009) used Adobe Photoshop to measure the debonded area, but other techniques could also have been used. When using liquid deicer, a hole through the ice to the substrate is needed to prevent the deicer from dispersing across the ice surface.

In Shi et al. (2009) and Akin and Shi (2010) this test produced unreliable and inconsistent results. The debonded area has an irregular shape and the dye tends to disperse on the ice surface, making the debonded area difficult to distinguish. The results from Shi et al. (2009) are shown in Figure 2.3.

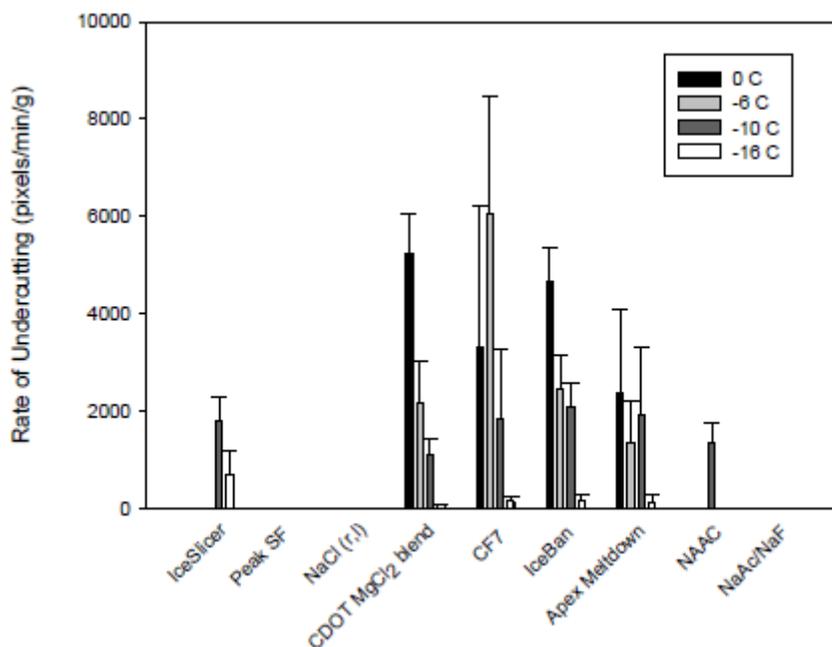


Figure 2.3:
Ice Debonding Test Results
(Shi et al., 2009)

This test requires further development to produce more usable results. However, the area a chemical deicer can debond an ice sheet from a substrate may be of little importance. This test cannot be used to compare solid and liquid deicers because they function differently in the field. And again, roadway traffic would help to fragment an ice sheet making the debonding ability of a chemical deicer less crucial.

Several different test methods have been developed (Chappelow et al., 1992; Cuelho et al., 2010) to measure the bond strength between snow and ice and the roadway surface, but no standardized method exists. The purpose of these tests is to determine when a deicer will break this interfacial bond at a particular temperature. The common variables for the different test methods are temperature, type of chemical deicer, and application rate for the chemical deicer. Snow or ice and chemical deicer is applied to a substrate and then scraped off. The tests measure the amount of force needed to remove the snow or ice at different temperatures and time intervals.

The differences between the test methods are the type of substrate, snow compaction methods, and scraping methods. The substrate is usually mortar, concrete, or asphalt mix, but some tests used aluminum with different surface treatments to increase the bond strength. Each test method uses a different technique or apparatus for scraping the surface of the substrate, but it usually consists of some type of blade that imitates a plow. The force needed for scraping was recorded by load cells.

Similar to the SHRP ice debonding tests, data obtained from these tests had very large scatter due to irregular debonding interface. All of these test methods require a cold room and expensive equipment for the testing. Measuring the force needed to break the interfacial bond seems to be an inefficient way to determine when the deicing chemicals have become effective.

2.1.4 Thermal Properties

Two tests were found pertaining to the thermal properties or, more specifically, the eutectic points of chemical deicers. There is no test in the SHRP Handbook pertaining to thermal properties.

The two tests have very different procedures, but both result in a heating-cycle thermogram for the tested deicing chemical. An example is shown in Figure 2.4. The chemicals must be in liquid form for the test. Solid chemicals are mixed with de-ionized water to form a saturated solution.

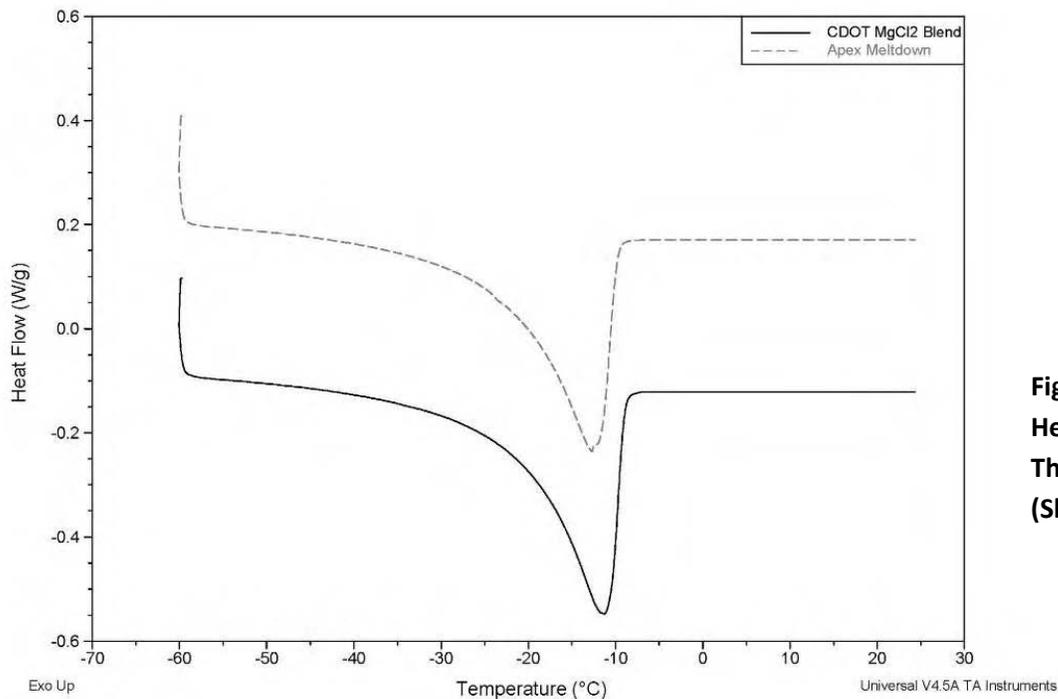


Figure 2.4:
Heating-Cycle
Thermogram Example
(Shi et al., 2009)

The test conducted by Shi et al. (2009) uses a differential scanning calorimeter (DSC) to create the thermograms. A sample of deicer at a chosen concentration is positioned in the DSC and is exposed to temperatures ranging from 77 to -76°F to determine its freezing point. The temperature at which the deicer begins to freeze is marked by a sharp peak on the thermogram. This peak strongly correlates to the temperature at which this particular concentration of deicer remains effective.

The test conducted by Nixon et al. (2007) uses a procedure to manually perform the same analysis as the DSC. It requires a cold room, an ethylene glycol bath capable of reaching -76°F, a thermistor, and some sort of stirring unit. A sample of deicer at a chosen concentration is positioned in the bath and is exposed to temperatures ranging from the temperature of the cold room to -76°F to determine its freezing point. The thermistor is used

during the test to record the temperature of the sample. The presence of forming ice crystals is determined visually and that particular temperature is recorded as the freezing point.

In Nixon et al. (2007), Shi et al. (2009), and Akin and Shi (2010) these tests produced very reliable data and can be used to determine if a deicing solution with a known freezing point has the correct chemical concentration. The results also show some correlation with the ice melting capacity test results.

The equipment needed for this test is relatively expensive and can be difficult to locate. Many existing differential scanning calorimeters cannot achieve temperatures below the room temperature. Also, it seems much of the data from this test can be determined more economically by using the ice melting capacity test and the specific gravity test, which will be discussed later.

2.1.5 Resulting Surface Friction Coefficient

Four different methods have been used to determine the resulting friction coefficient of a de-iced roadway. One of the tests has been standardized by the Pacific Northwest Snowfighters (PNS). Another test has been standardized by the SHRP under the designation SHRP H-205.10.

The test developed by the PNS (Specifications and Test Protocols, 2008) requires the friction analysis to be performed on a pavement surface within a controlled humidity chamber. The PNS is not specific as to what apparatus is used when determining the friction coefficient, just that it be calibrated and certified prior to the analysis. The PNS has used dragged sleds or tires for this test. A deicing chemical is applied to the pavement surface at

the recommended amount and the friction coefficient is measured while the humidity is raised and lowered over a period of time.

This test, if done properly, can generate a friction coefficient that is comparative to the “real life” friction coefficient between vehicle tires and pavement. This test may be helpful for areas with a high relative humidity because a deicing chemical will take longer to dry in higher humidity. But, this test does not take into account the effect of sunlight or wind on the drying time. A controlled humidity chamber may be difficult to obtain and one may question how significant humidity is to the friction coefficient when other important factors are ignored.

The test developed by the SHRP (Chappelow et al., 1992) uses a British Pendulum Tester as seen in Figure 2.5. A glass surface is used in the laboratory test. The pendulum is calibrated so the rubber end barely touches the glass surface as it swings. A deicing chemical is applied to the glass surface and the pendulum is allowed to swing. The pointer will indicate a British Pendulum Number (BPN). Greater friction between the glass and the rubber is indicated by a greater BPN.



Figure 2.5:
British Pendulum Tester

This test can also be done on concrete or asphalt surfaces. The testing apparatus is quite small and can be taken to perform testing on-site. Because this test does not yield an actual friction coefficient, it is best used by comparing the results to a known outcome. The findings from Lu and Steven (2006) suggest the results of this test do not correlate with the real-world friction between a tire and the roadway. The test apparatus is expensive and rather delicate. It would also be difficult and time consuming for a maintenance worker driving a snowplow to stop and perform a test.

An alternative to the British Pendulum Tester for collecting real-time, on-site surface friction data is a piece of equipment called a Friction Wheel, also known as a Mu-Meter or a SAAB friction tester. The Friction Wheel can be attached to a snowplow or other vehicle as a fifth wheel or removable trailer. It measures the roadway friction as the vehicle travels and outputs the data to a read-out or computer inside the vehicle. Figure 2.6 shows the results from SAAB friction tests by Alger et al. (1994).

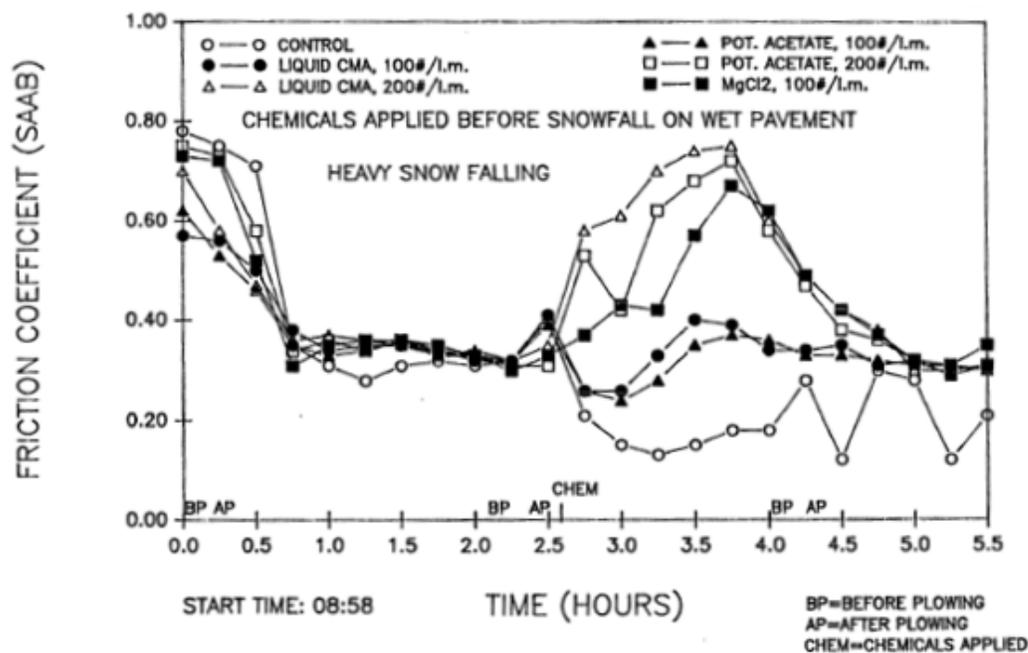


Figure 2.6: Results for SAAB Friction Tester (Alger et al., 1994)

Collecting data in this fashion is much more workable for the maintenance workers and can be used in concert with global positioning systems (GPS) to determine exact locations of problem areas. This equipment can be especially useful for locating “black ice” or other hard to see slippery areas. Although the Friction Wheel can yield invaluable information, the current cost for this equipment is too high to justify in a state budget. However, the costs of systems such as GPS and mixing tanks have been declining over the recent years. This may also be true for the Friction Wheel and other similar systems.

A tribometer was used by Shi et al. (2009) to test the resulting surface friction coefficient. The test apparatus is shown in Figure 2.7.

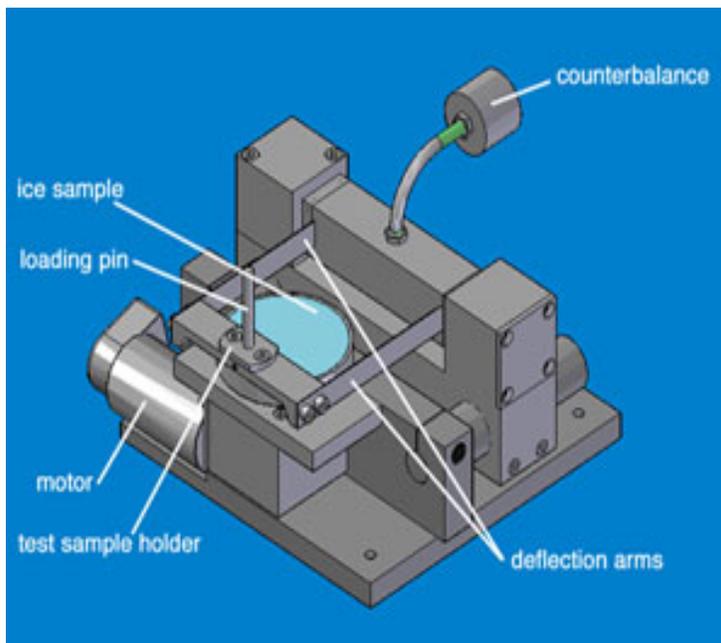


Figure 2.7: A Tribometer

A tribometer is a piece of laboratory equipment used to test friction or surface wear between two surfaces. Very often a single tribometer is designed to test specific surfaces. The test surfaces were rubber and ice frozen on a small concrete sample. A liquid deicer was applied to the ice surface and then the tribometer ran 100 cycles over 200 seconds.

The results from Shi et al. (2009) are shown in Figure 2.8. Shi et al. (2009) stated that the test was in need of modification. The results showed no clear differences between liquids, fragmented solids, or chemical bases. The test equipment is expensive and requires very specific surfaces to test. Since this apparatus was only designed for rubber and ice surfaces, it may not be useful for other surfaces.

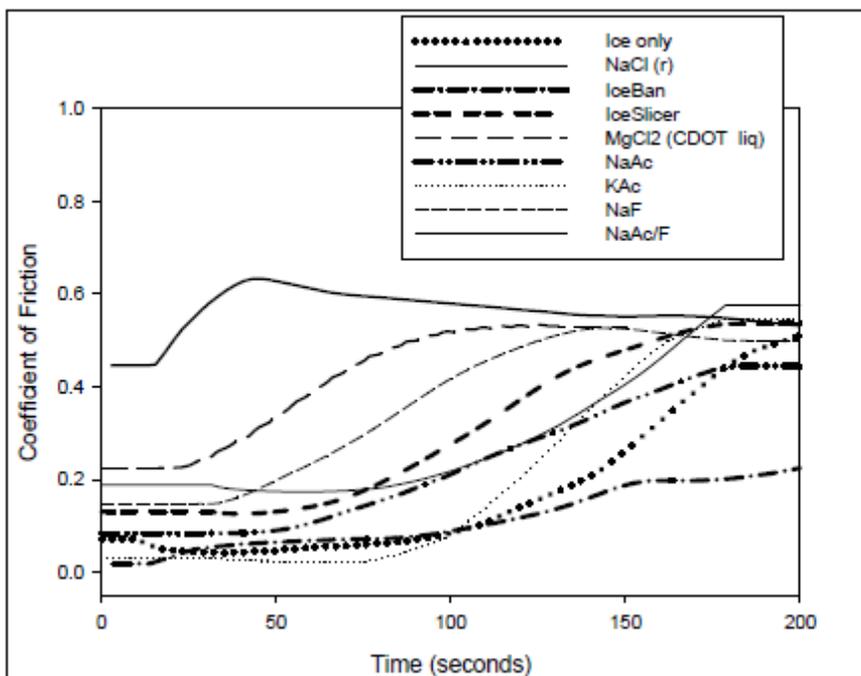


Figure 2.8:
Friction Test Results
(Shi et al., 2009)

2.1.6 Viscosity and Specific Gravity

Testing the viscosity and specific gravity of a liquid chemical deicer helps to determine the workability of the product. Both tests are relatively inexpensive and simple to perform. Determining the specific gravity of a liquid deicer with a hydrometer test is the best way to determine that product's quality. A deviation in specific gravity could indicate a manufacturing error or fermentation in some products.

Testing the viscosity of a liquid deicer can be done with a viscometer, a timed falling ball, or a timed rising bubble. A high viscosity liquid could lead to problems with clogging spray nozzles or failing pumps in the field. Any time spent unclogging or repairing equipment is time taken away from servicing the roadways.

2.2 Standards of Practice

Standards of practice concerning chemical deicers were researched to determine which techniques should be used under certain circumstances. Recommended application rates were also researched to determine how much should be used for certain types and amounts of precipitation.

Chemical deicers are typically not used when roadway temperatures are below 12°F due to a lack of performance (BlackBurn et al., 2004; Shi et al., 2004; Ketcham et al., 1996). Circumstances under which solid deicers, liquid deicers, prewet solids, and abrasives are best used are discussed in this section.

2.2.1 Solid Deicers

Solid deicers have been widely used in winter maintenance operations for several decades. In the studies by Blackburn et al. (2004) and Cuelho et al. (2010) solid deicers work the best for penetrating thick accumulations of snow or ice. Blackburn et al. (2004) also states the best time to apply solid deicers is early in a storm event. Applying at this time allows brine to form before the ice-pavement bond can strengthen.

One critical characteristic of solid deicers is the gradation of the particles. Blackburn et al. (2004) states finer gradations can work faster, but do not last as long as more coarse

gradations of deicers. The study also states finer gradations should not be used for large amounts of precipitation because they are quickly diluted and washed away. CTC & Associates LLC. (2009) recommends the use of coarse grained deicers for precipitation rates greater than 0.5 inches per hour because they will not dilute as quickly.

The most significant problem with solid deicers is the amount of chlorides and acetates needed to achieve the desired level of service. The residue from the deicers damages the roadway infrastructure and has a negative impact on the environment. As a result of the cumulative effect of chlorides being released into the environment, some bodies of surface water and groundwater have become undrinkable (Canada, Parks and Outdoor Recreation, 2010).

2.2.2 Liquid Deicers

Liquid deicers are used in winter maintenance operations because smaller amounts of chlorides or acetates can be used to achieve the desired level of service (Peterson et al., 2010). Blackburn et al. (2004) and Peterson et al. (2010) state liquid deicers work very well in temperatures above 28°F, but have a high potential to refreeze in temperatures below 20°F. They recommend that the area be retreated every 1-1/2 hours to prevent refreezing, if liquids are used in lower temperatures. Blackburn et al., (2004) also state that liquids are not readily able to penetrate ice or compacted snow layers. Liquids work well for treating the thin layers of snow or ice that remain after plowing (Alger et al., 1994).

Anti-icing is a relatively new technique that agencies have begun to use over the past 10 years. Anti-icing is a proactive deicing technique used to prevent the ice-pavement bond

from forming. Liquids are the best choice for anti-icing operations (Alger et al., 1994). A liquid deicer is placed on the roadway 24 hours before a storm. The liquids evaporate leaving a stratum of crystallized chlorides or acetates on the roadway. The most significant obstacles for the use of anti-icing are the up-front costs of new equipment, training, and reliable weather forecasts. A survey done by Shi et al. (2005) found the anti-icing practice can lead to significant long-term savings.

Cuelho et al. (2010) estimate that 5 times the amount of energy is needed to break the ice-pavement bond when anti-icing is not used. Shi et al. (2005) state that anti-icing can lead to less use of abrasives and the Colorado, Kansas, Oregon, and Washington Departments of Transportation reported significant savings in material and labor when using the anti-icing technique.

The best time to perform anti-icing operations recommended by Blackburn et al. (2004) and the CTC & Associates LLC. (2009) is to treat for frost and black ice, and before a snow event in temperatures above 20°F. Lower temperatures could cause the deicer to freeze. Anti-icing should not be used before rain or freezing rain events because the material will be washed off from the road. Wind speeds above 15mph could also inhibit anti-icing operations (Blackburn et al., 2004; CTC & Associates LLC., 2009; Ketcham et al., 1996).

Calcium chloride and magnesium chloride are both hygroscopic materials, meaning they absorb water from the air. Because of this trait, those materials do not require prewet for high moisture storms, but they can cause slick roadways under certain conditions. Shi et al. (2004) found calcium chloride and magnesium chloride residues can attract more moisture than sodium chloride, causing slippery conditions. CTC & Associates LLC. (2009) found

calcium chloride and magnesium chloride can cause slick roads when used in temperatures above 28°F and with humidity greater than 40%. Kuhl et al. (1999) found liquid magnesium chloride can cause slick conditions if applied to snowpack greater than 1/4-inch thick. Donahey and Burkheimer (1996) found calcium chloride can leave a roadway wet for several days after use while sodium chloride will dry a few hours after the end of a storm.

2.2.3 Prewet Solid Deicers

Prewetting solid deicers is also a relatively new technique that agencies have begun to use over the past 10 years. Prewet is most often used to help solid deicers adhere to the roadway. Shi and O'Keefe (2005) found that prewet road salt had a 96% material retention on a roadway while dry road salt had a 70% material retention. Donahey and Burkheimer (1996) also found that after 100 vehicles passed through the roadway, 30% of prewet material remained on the roadway while only 5% of dry material remained on the roadway. This can result in significant material savings. Blackburn et al. (2004) state a prewet of 10-12 gallons per ton is sufficient to minimize bounce and scatter of the solids.

Roosevelt (1997) and Donahey and Burkheimer (1996) state the prewet helps the salt go into solution faster, or work faster. Many agencies prewet the stockpile to prevent freezing or caking of the solids. The Michigan State Department of Transportation found small quantities of solid calcium chloride can be mixed into the stockpile to keep it from freezing (Public Sector Consultants, 1993).

Shi et al. (2005) cautioned that prewet material is typically discouraged for use on unpaved roadways because it may cause the roads to thaw and become unstable. Prewet is

not needed if snow events are preceded by rain or for use on wet snow at about 32°F (Roosevelt, 1997). Use of prewet results in additional cleaning of the application equipment, but the amount of cleaning can be reduced if the prewet is performed at the spinner just before landing on the roadway.

2.2.4 Abrasives

Abrasives or sand are used at low temperatures, typically below 12°F (Shi et al., 2004 and Blackburn et al., 2004), to create traction on a roadway covered in snow or ice. Shi et al. (2005) and Fuller (2011) discovered dry sand does not stick to the roadway and can be swept off by as few as 50 passing vehicles. This problem can be minimized by prewetting the sand with salt brine or by mixing in a small amount of a solid hygroscopic material like calcium chloride. The salt brine helps the sand take root to the snow or ice on the roadway, keeping it on the road and creating more traction (Shi and O'Keefe, 2005).

The gradation of the sand can affect the friction performance of the sand. Al-Qadi et al. (2002) found coarse graded sands worked best at temperatures below 14°F and fine graded sands worked best above 27°F. Sands with gradation between 0.04 and 0.08 inches worked well at all temperatures.

Vaa (2004) found that sand prewet with water heated to a temperature of 194-203°F helped the sand stay on the roadway after as many as 2000 passing vehicles. The sand is prewet with hot water at the chute or spinner leaving a film of hot water on the sand. The water has a brief melting effect and then the sand/water mix freezes to the roadways in small lumps. Figure 2.9 shows an example of the end product of this practice.



Figure 2.9: Sand Prewet with Hot Water on a Roadway (Transportation Research Circular, 2004)

The amount of water needed to achieve this kind of effect is 30% by weight of the sand. This practice requires a sand gradation of 0.08 inches or smaller with an application rate of 2600 pounds per lane-mile. The geographical areas that would benefit most from this practice are places with large amounts of snowfall with steep roads, like mountain ranges. For the most part, the State of Nebraska probably would not benefit from this practice.

2.2.5 Application Rates

A method to estimate the deicer application rate for particular situations was developed by Blackburn et al. (2004). The method accounts for several variables including precipitation rate, type of precipitation, traffic, cycle times, and type of deicing chemical. This method is complicated and requires the use of 6 different tables. Defining the precipitation rate is the most significant source of difficulty with this procedure because the rate is defined visually as light, moderate, heavy, and unknown. The technology exists to determine the real-time rate of precipitation. One way to improve the effectiveness of this procedure would be to replace the light, medium, and heavy precipitation rates with actual numbers.

The Federal Highway Administration (Ketcham et al., 1996) also has recommendations and suggestions for chemical application rates for liquids, solids, and prewet solids. The document addresses what should be used before and after light snow storms, light snow with periods and moderate to heavy snow, moderate to heavy snow storms, frost or black ice, freezing rain, and sleet.

CTC & Associates LLC. (2009) compiled the standards of practice for application rates, anti-icing, and other winter maintenance considerations from 12 different states. Most standards of practice are the same from state to state, but differences emerge about application rates.

Peterson et al. (2010) presents a simple estimation table, shown in Table 2.2, utilized by the Iowa Department of Transportation. In this method, application rates are based on temperature, cycle times, storm type, and precipitation rates. Some of the current practices adopted by many agencies referenced in the Ketcham et al. (1996), CTC & Associates LLC. (2009), Peterson et al. (2010), and Blackburn et al. (2004) are summarized in Table 2.3.

Table 2.2: Method for Estimating Application Rates (Peterson et al., 2010)

Example During-Storm Direct Application Rates for Salt Brine (NaCl) ^{2,5} Illustration Only (adjust based on local factors and experience) Gallons Per Lane Mile (gplm) <i>Pounds Per Lane Mile (ppm) shown in parentheses</i>				
Event Type	Pavement Temperature			
	32-30°F	29-27°F	26-24°F	23-21°F
For 2-Hour (or less) Cycle Times				
Light Snow (less than 0.5"/hour)	20 (45)	35 (80)	40 (91)	55 (125)
Medium Snow ¹ (0.5"/hour to 1.0"/hour)	35 (80)	45 (102)	55 (125)	NR
For 3-Hour Cycle Time³				
Light Snow (less than 0.5"/hour)	35 (80)	50 (114)	65 (148)	80 (182)
Medium Snow ¹ (0.5"/hour to 1.0"/hour)	50 (114)	65 (148)	80 (182)	NR
Notes:				
<ol style="list-style-type: none"> 1. Only consider using DLA for medium snow events based on your experience, and when other factors are highly favorable such as pavement temperature and moisture content. 2. It is suggested to generally supplement the DLA application with a light direct pre-wet granular application (70 ppm) when possible (especially as dilution-refreeze potential increases). 3. For cycle times greater than 2 hours, supplementing DLA with direct granular is strongly suggested (see Note 2). 4. NR = Not recommended 5. For enhanced chemicals and blends, work with vendors. Verify that these rates are reasonable or where they should be adjusted. 				

DLA = Direct Liquid Application

Table 2.3: Standard of Practice Summary

	Temperature Range, °F			
Weather/Road Conditions	Above 32	32-20	20-12	Below 12
Rain	Use little to no treatment unless the temperature is expected to drop. In that case pre-treat with road salt less than 100 lbs/lane-mile.	Pre-treat with road salt prewet with 8-10 gal/ton NaCl at less than 100 lbs/lane-mile. During event, prewet is not necessary.	Not Applicable	<p>Use abrasives prewet with 8-10 gal/ton of NaCl to help “root” the abrasives.</p> <p>Using MgCl₂ or CaCl₂ could cause slippery conditions.</p>
Freezing Rain			Use Road Salt prewet with 8-10gal/ton NaCl.	
Sleet			Using MgCl ₂ or CaCl ₂ could cause slippery conditions. If liquids must be used, retreat every 1.5-2hrs to prevent refreeze	
Ice	If not preceded by any of the above, pre-treat with liquid NaCl 20-50 gal/lane-mile. Post-treat with road salt prewet with 8-10gal/ton NaCl.			
Light Snow (less than 0.5 in/hr)	If not preceded by rain, freezing rain, or sleet liquid NaCl can be used for pre and post-treatment and during the event.	Use Road Salt prewet with 8-10 gal/ton. Use MgCl ₂ or CaCl ₂ if humidity is low.		
Moderate to Heavy Snow (greater than 0.5 in/hr)	Pre-treat with liquid NaCl 20-50 gal/lane-mile. Use road salt during and after the event. Prewet is not necessary during the event.	If liquids must be used, patrol every 1.5-2hrs to prevent refreeze		
Compacted Snow	Use Road Salt if Necessary	Use Road Salt prewet with 8-10 gal/ton NaCl	Use Road Salt prewet with 8-10 gal/ton. Use MgCl ₂ or CaCl ₂ if humidity is low.	
Winds Greater than 15mph	Treatment may cause blowing snow to stick to roadway.			No Treatment

Chapter 3

Deicing Chemicals Performance Tests

This chapter describes the purpose and procedures of the five performance tests for chemical deicers that were studied or developed as a result of this project. The five tests are: SHRP Ice Melting Capacity Test (Chappelow et al., 1992), Shaker Test, Friction Test, Sunlight Test, and Refreeze Test.

The SHRP Ice Melting Capacity Test has been used by several state departments of transportation including the Iowa and Colorado DOTs. It has also been used in several research studies by Nixon et al. (2007), Shi et al. (2009), and Akin and Shi (2010). It is a frequently cited test, but its results do not necessarily correlate with what has been observed in the field and the test is known not repeatable between laboratories. This test was conducted in this research as a starting point.

The Shaker Test was developed by this research as a performance test for chemical deicers. Its purpose was to determine the ice melting capacity of a deicer while simulating the stirring effect of traffic. Current data shows consistent results and the test is repeatable.

The Friction Test is used to determine if a liquid deicer will have a detrimental effect on roadway friction. It is possible for a deicer to have a high ice melting capacity but cause slippery roadways. Many tests have been developed to test roadway friction. The test used in this research uses a weighted sled with rubber contact points. This test most closely resembles the friction test used by the Pacific Northwest Snowfighters (2008).

The Sunlight Test was developed to determine if a dark color is an advantage to a chemical deicer when exposed to direct sunlight. The decision was made to develop this test after processing some data from both the SHRP Ice Melting Capacity Test and the Shaker Test. A very dark colored chemical deicer that is known to do well in the field did poorly in both performance tests. The results of the sunlight test helped to understand how certain chemical deicers work in the field.

The Refreeze Test was developed to determine when roadway that has been treated with a chemical deicer will begin to refreeze. This test was also used to evaluate the effect of particle size on the refreeze time for solid chemical deicers.

3.1 SHRP Ice Melting Capacity Test

This test was developed by the Strategic Highway Research Program (Chappelow et al., 1992) and is used to analyze the ice melting capacity of both liquid and solid chemical deicers. The current research suggests this test is not repeatable between different laboratories.

The tests were conducted using the SHRP H205.1 and H205.2 test methods (Chappelow et al., 1992). Testing was performed at 20°, 10°, and 0° F. The samples of deicers consisted of 3 grams of road salt that passed through a #4 sieve, and are prewetted with 1mL of liquid deicer. The variables in these tests were the environmental temperature and the prewetting liquid. The prewetting liquid deicers used are given in Table 3.1.

Table 3.1: Liquid Deicers used in SHRP Ice Melting Capacity Test

Deicer	Composition
Salt Brine	23% NaCl
Mg-A	29% MgCl ₂
Mg-B	30% MgCl ₂
K Ace	50% Potassium Acetate
Beet Juice-A	Carbohydrate Byproduct

Because Salt Brine is much less expensive than all other liquid deicers, in the field it is often mixed with other liquid deicers to help lower the cost of roadway treatment.

Different Salt Brine/liquid deicer ratios were used in the SHRP Ice Melting Capacity Test to study the effect mixing ratios has on the end product. The ratios used were 100% of liquid deicer, 50/50 Salt Brine/liquid deicer, 60/40 Salt Brine/liquid deicer, and 85/15 Salt Brine/liquid deicer. These ratios are commonly used in the field.

3.1.1 Equipment

The following equipment is required for the SHRP Ice Melting Capacity Test:

- a. 19.7 ft³ Chest Freezer with Temperature Controls
- b. 3 Circular Plexiglas Test Dishes, 9 inches in Diameter and ¾ inches Deep
- c. 3 Thermocouple Wires
- d. A Scale Capable of Measuring to the Nearest 0.0001 Gram
- e. A #4 Sieve
- f. Other Equipment: Timer, Syringes, Graduated Cylinders, and Containers

The use of a 19.7 ft³ chest freezer was a deviation from SHRP, which recommended the test be performed in a walk-in freezer or a modified upright freezer. The chest freezer was chosen as a less expensive alternative. The obvious problem with using a chest freezer is fluctuations in temperature in the chest due to opening the door. Hence, thermocouple wires

were embedded in the ice strata to monitor the ice temperature. The test setup is shown in Figure 3.1.

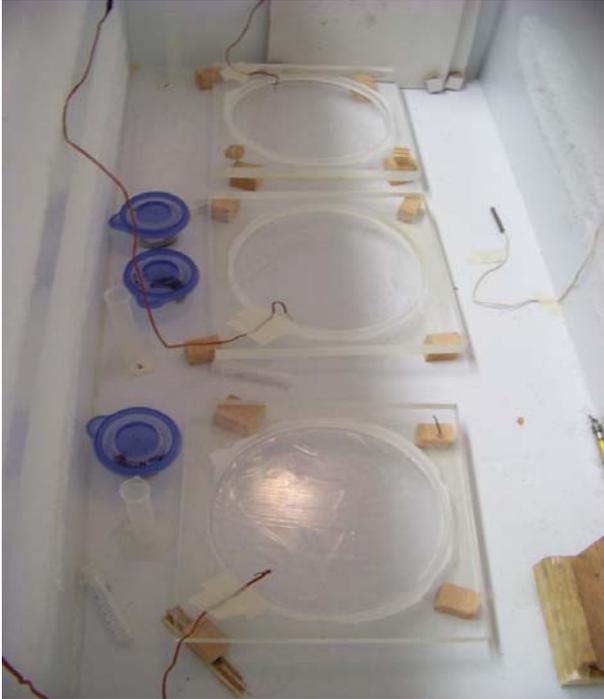


Figure 3.1:
SHRP Ice Melting Capacity Test Setup inside Freezer

3.1.2 Procedure:

Each test is conducted in triplicate.

3.1.2.1 Preparation of Test Samples

1. Pass the solid deicer through a #4 sieve. The passing solids are used for testing.
2. Dry the solid deicer in an oven for 24 hours and then store it in a desiccator.
3. Weigh and record the empty container.
4. Place 3 grams of solid deicer in the small container with a lid.
5. Use a syringe to dribble 1mL of liquid deicer or liquid deicer/salt brine mix onto the 3 grams of solid deicer.
6. Place the lid on the container to prevent any losses or water vapor absorption.

7. Weigh and record the container and deicer sample. Subtract the weight of the empty container to get the weight of the deicer sample.
8. Place the container in the freezer set at the desired temperature. Allow the deicer sample to cool and equilibrate for 5-6 hours.

3.1.2.2 Testing Procedure

1. Place the three test dishes within the freezer set at the desired temperature and allow to cool overnight. The dishes should rest on spacers to insure airflow underneath the dishes and to assist the leveling process.
2. Place 130mL of distilled water in each test dish. This amount of water will create a 1/8 inch thick ice sheet in the dish.
3. Place thermocouple wires in the water within the test dish.
4. Give the water at least 5-6 hours to freeze.
5. Take a temperature reading of the ice surfaces using the thermocouple reader.
6. Take the deicer samples from the containers and apply to the ice sheets. The deicer should be as evenly distributed as possible. Inevitably, some liquid deicer will remain in the containers.
7. Record the surface temperatures after application.
8. Temperature readings of the ice surfaces should be taken before and after each brine measurement. The temperature should not be allowed to deviate more than 3 degrees.
9. Allow the deicer samples to melt the ice. Brine measurement should be done one dish at a time. As shown in Figure 3.2, at a specific time interval the test dish is tipped so the brine can collect at one end and be decanted using a syringe. The brine is weighed using a scale and returned to the test dish. The weight is recorded to the nearest

0.0001 gram. The actual removal, weighing, and return of the brine should be done in less than 2 minutes.



Figure 3.2: Collecting Brine

10. Step 9 should be performed at 10, 20, 30, 45, and 60 minutes from the time of application. Different time intervals can be used if needed or preferred.
11. The test is complete after 60 minutes unless specified otherwise. The test dishes can be removed from the freezer, rinsed clean with distilled water, towel dried as much as possible, and placed back in the freezer.

3.1.3 Data Processing:

There are two ways to present the data from this test. The data can be presented as melting rates for the different chemical deicers or as melting totals for a particular time interval, usually 60 minutes. The melting capacity is commonly presented as the amount of ice melted per amount of deicer. In the case of this research the measured amounts are divided by approximately 4 grams. The number is a little different for each liquid chemical deicer.

3.2 Shaker Test

Due to the inaccuracies of the SHRP Ice Melting Capacity Test, there is a need to develop a simple and repeatable test that can be used to accurately determine the ice melting capacity of a deicer. It can be used to test liquid and solid deicers, but more modifications may be needed for testing prewetted solids. The idea behind this test was to use a modified martini shaker to simulate the effect of traffic on the roadway while evaluating the ice melting capacity of a deicer. This research utilized four modified martini shakers. The four shakers are made from similar materials and are of similar construction. The four shakers also produced very similar test results.

The primary advantage of the Shaker Test is the ability to perform the test without a large freezer. Current data also suggests this test yields consistent results between laboratories. The test can be performed inside a small freezer in which the shaker can set in an upright position. The shaker has enough insulation to maintain its internal temperature when taken out of the freezer. When the lid is taken off, it will maintain its temperature for several seconds. With the lid on it will maintain its temperature for about 2 ½ minutes. The retention of steady temperature allows the shaking to be done outside the freezer.

Testing was performed at 20°, 10°, and 0° F. Deicer samples consisted of 7 mL of liquid deicer, 5 grams of dry solid deicer, or 5grams of solid deicer soaked in a liquid deicer to simulate prewetting at a stockpile. The liquid deicers evaluated are listed in Table 3.2. As was done in the SHRP Ice Melting Capacity Test, pure deicing chemicals and different deicer/brine ratios were evaluated using the shaker test. The most commonly used

brine/deicer ratios were 85/15 and 50/50, though one of the chemicals was extensively evaluated for various ratios.

Table 3.2: Liquid Deicers used in Shaker Test

Deicer	Composition
Salt Brine	23% NaCl
Mg-A	29% MgCl ₂
Mg-B	30% MgCl ₂
K Ace	50% Potassium Acetate
Beet Juice-A	Carbohydrate Byproduct
Mg-C	Carbohydrate Byproduct and 26.9% MgCl ₂
Mg-D	Carbohydrate Byproduct and 25% MgCl ₂
Beet Juice-B	Carbohydrate Byproduct
Calcium Chloride	Carbohydrate Byproduct and 30% CaCl ₂

3.2.1 Equipment:

a. Modified Martini Shaker

As shown in Figure 3.3(a), plastic martini shakers were used for this research because many chemical deicers will quickly corrode steel, even stainless steel. The type of insulation material used on the shakers is commonly used to insulate copper water pipes and can be obtained at a hardware store, as shown in Figure 3.3(b).

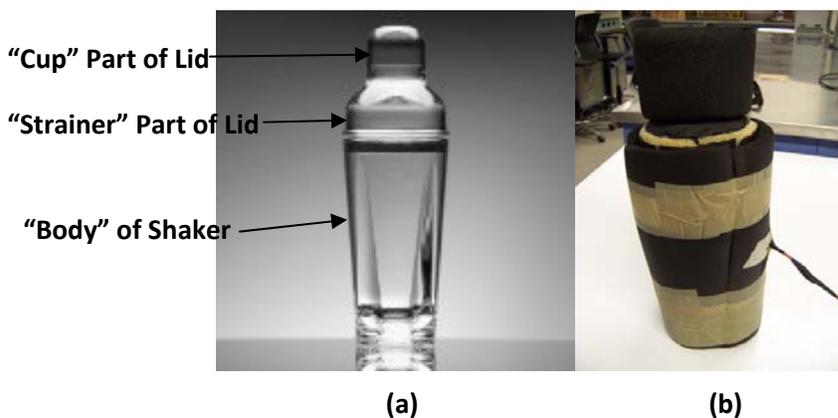


Figure 3.3:
(a) Martini Shaker
(b) with Insulation

b. Freezer

The freezer attached to an upright refrigerator is large enough for testing. A thermostat may be needed to set the temperature in the freezer.

c. Thermocouple Reader and 4 ft-Long Wires (Optional)

A thermocouple reader and wires are used to monitor the temperature inside the shaker without having to open the shaker. The wire is installed by drilling a small hole into the side of the shaker located at mid-height. The hole should be just large enough to fit the wire. The hole is then sealed with glue or rubber cement, as shown in Figure 3.4.

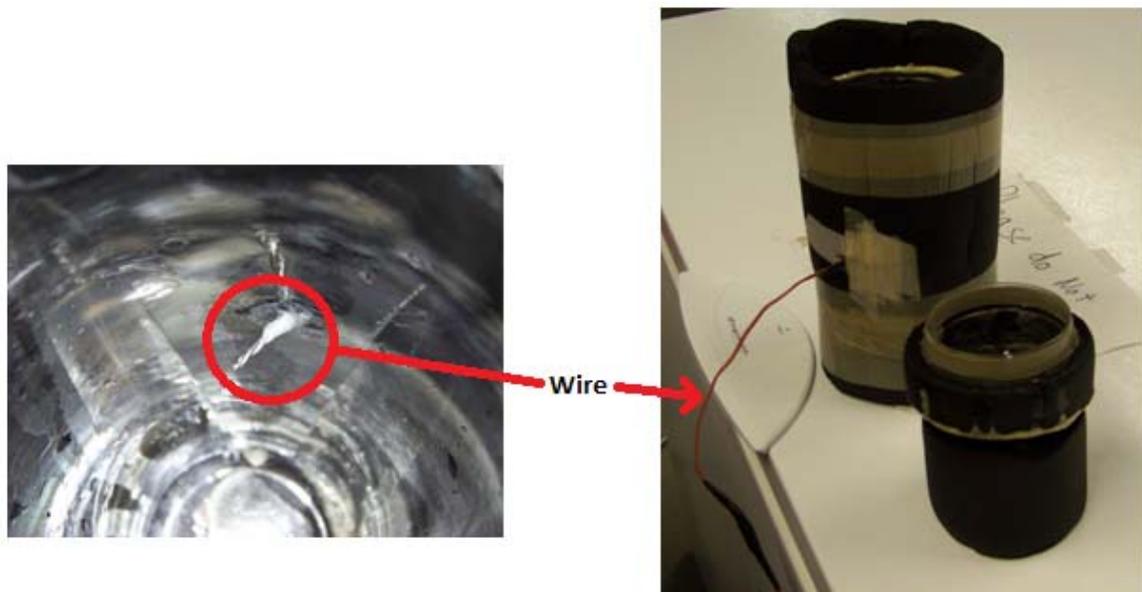


Figure 3.4: Thermocouple Wire

- d. Mini Ice Cube Tray, Producing 1 cm³ Ice Cubes**
- e. Scale Measuring to the Nearest 0.01 Gram**
- f. Clock with Second Reading**
- g. #4 Sieve for Solid Screening**
- h. Other Equipment: Spoon, Measuring Syringes, 2 Small Bowls**

3.2.2 Procedure:

Each test is conducted in triplicate.

1. Prepare Ice Cubes. Use a syringe to measure 1 mL of distilled water into each aperture of the ice cube tray.
2. Prepare Deicer Sample. If using a pure sample of liquid chemical deicer, use a syringe to measure 7 mL and discharge into the shaker. If using a liquid deicer/brine mix, measure the needed amounts of deicer and brine and discharge separately into the shaker. The liquids will mix together in the shaker.

If using solid deicer, pass the deicer through a #4 sieve. The solid that remains on the sieve is used for testing. This gradation size is used because smaller gradations tend to stick to the sides of the shaker, disrupting the test. Weigh 5.00 ± 0.03 grams of the solid and place the sample in the shaker.

3. Weigh and record the weight of small bowl #1.
4. Place the shaker with the chemical deicer sample, the shaker lid, the filled ice cube tray, and small bowl #1 in the freezer set at the desired temperature. The shaker lid is placed next to the shaker, not on the shaker.
5. Let the ice freeze. Once frozen, remove 10 ice cubes from the tray and place them in small bowl #1.
6. Weigh and record the weight of small bowl #1 with the ice cubes. Put the bowl with the ice cubes back in the freezer. Once the ice cubes have been weighed they must be used within 2 days. Otherwise, the ice cubes will evaporate.
7. Let the shaker and the ice acclimate in the freezer for 5-6 hours or overnight. Plug in the thermocouple wire to monitor the internal temperature of the shaker.

8. Take a temperature reading immediately before testing.
9. Open the freezer door and dump the 10 ice cubes from small bowl #1 into the shaker. Place the lid on the shaker. This step must be done quickly as to maintain the internal temperature of the shaker.
10. Begin Shaking. Shaking must be done at 2 cycles a second for liquids and 3 cycles a second for solids and prewet solids. The shaker must be held at an upward angle of about 30°, as shown in Figure 3.5. Holding the shaker at this angle will prevent separation of the liquids from the solids.



Figure 3.5: Shaking Angle

11. Shake for 5 minutes while setting the shaker down after every minute to quickly take a temperature reading.
12. After 5 minutes, turn the shaker upside-down and return it to the freezer in that position. Keep the plug-in end of the thermocouple wire outside the freezer. The liquids will drain into the cap portion of the lid while the remaining ice stays in the strainer portion of the lid. The ice will stop melting.
13. Let the shaker set in the inverted position inside the freezer for 5 minutes. Take a temperature reading every minute.
14. Weigh and record small bowl #2 with the spoon setting in the bowl.
15. Remove the shaker from the freezer while keeping it in an inverted position.

16. Remove the body of the shaker from the lid. Most of the remaining ice will be in the accessible portion of the lid, as shown in Figure 3.6.

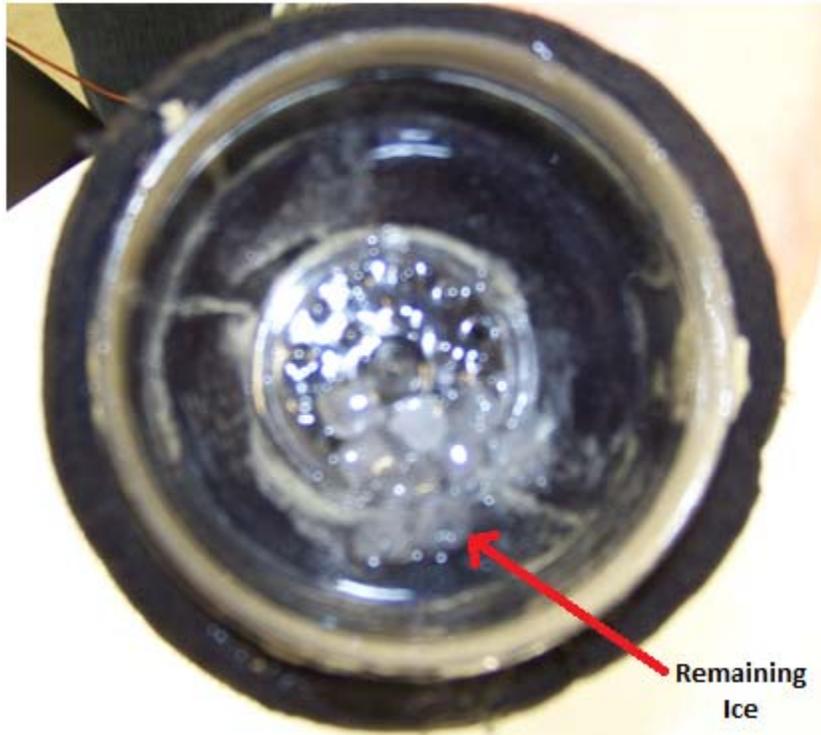


Figure 3.6:
Remaining Ice in Strainer
Section of Lid

17. Quickly use the spoon to move the remaining ice from the lid to small bowl #2. Once in the bowl the ice is allowed to melt.
18. Move any remaining ice from the body of the shaker to small bowl #2, if any.
19. Weigh and record small bowl #2 with the spoon and the remaining ice.

3.2.3 Data Processing:

The total amount of melted ice is determined using the following equation:

$$\frac{(\text{Weight of Bowl \#1 and 10 Ice Cubes} - \text{Weight of Bowl \#1}) - (\text{Weight of Bowl \#2 and Spoon and Remaining Ice} - \text{Weight of Bowl \#2 and Spoon})}{\text{Weight of Deicer}}$$
(1)

Ice melting capacities data from the Shaker Tests are presented as the amount of melted ice per amount of deicer. For liquids, data is presented as grams of melted ice per milliliter of

deicer. For solids and prewet solids, data is presented as grams of ice melted per gram of deicer. The standard deviation and variance are calculated for each data point.

3.3 Friction Test

The purpose of this test was to determine if liquid chemical deicers could cause slippery conditions when applied to an ice covered roadway. It is important to test if a liquid deicer will create a slippery roadway because the deicer may have an acceptable ice melting capacity, but still have a negative effect on the level of service of the roadway. Many liquid chemical deicers, especially those with organic components, have been known to ferment and cause slippery roadways. Many tests can be used to determine whether fermentation has occurred, the easiest is to smell the liquid for fermentation odor. The test described in this section measures the actual friction coefficients of a surface during and after a chemical deicer has been used to remove a given amount of ice. This test closely represents one tire of a small car whose brakes has locked and is sliding across a concrete surface covered by a thin layer of ice at about 20°F. These conditions are described in detail as follows.

This test was meant to emulate reality as much as possible, but the surface of a roadway is not uniform. A roadway surface will probably not have the same friction coefficients at different locations. The best ways to utilize this test are to compare the performances of different liquid deicers to each other and to have a baseline performance for comparison. The baseline performance used in this test was a concrete surface saturated with water. When the data from this test is processed in this manner, the composition of the roadway becomes a much less significant variable.

These tests were done in a walk-in freezer at $20 \pm 4^{\circ}\text{F}$. Only liquid deicers were used because the varying shape, size, and hardness of solid deicers would have caused considerable variance in the results. The liquid deicers evaluated by the Friction Test are given in Table 3.3.

Table 3.3: Liquid Deicers used in Friction Test

Deicer	Composition
Salt Brine	23% NaCl
Mg-A	29% MgCl ₂
Mg-B	30% MgCl ₂
K Ace	50% Potassium Acetate
Beet Juice-A	Carbohydrate Byproduct
Mg-C	Carbohydrate Byproduct and 26.9% MgCl ₂
Mg-D	Carbohydrate Byproduct and 25% MgCl ₂
Calcium Chloride	Carbohydrate Byproduct and 30% CaCl ₂

This test used a weighted sled with rubber contact points pulled across a concrete surface to determine the static and kinetic friction coefficients while a chemical deicer was being used to remove a thin ice layer from that surface. The total surface area of the rubber contact points is 9in^2 and the total weight of the sled is 270 lbs. The values of surface area and total weight were chosen to accommodate the laboratory's existing resources. The weight creates 30 psi of pressure on the roadway, similar to the pressure of a small car. A load cell and data acquisition system was also used in this test to continuously sample the force needed to pull the weighted sled. This test was intended to simulate the sudden braking of a vehicle.

The ice layer was created by spraying a fine mist of 25 mL of distilled water on a 2.5ft^2 area of the concrete slab. The water instantly freezes on contact with the slab creating an uneven ice layer. This technique produces an ice layer similar to the way light sleet would form on a roadway surface.

Many State Departments of Transportation make it a policy not to use liquid deicers on ice layers due to runoff. During this test, the problem was rectified by limiting the flow of the liquids using acrylic based sealant. This caused the liquid deicer and melted ice to pool in the location and the path of the rubber contact points on the sled, as shown in Figure 3.7. The depth of the pooling was not consistent, but could be as much as 1/8-inch.

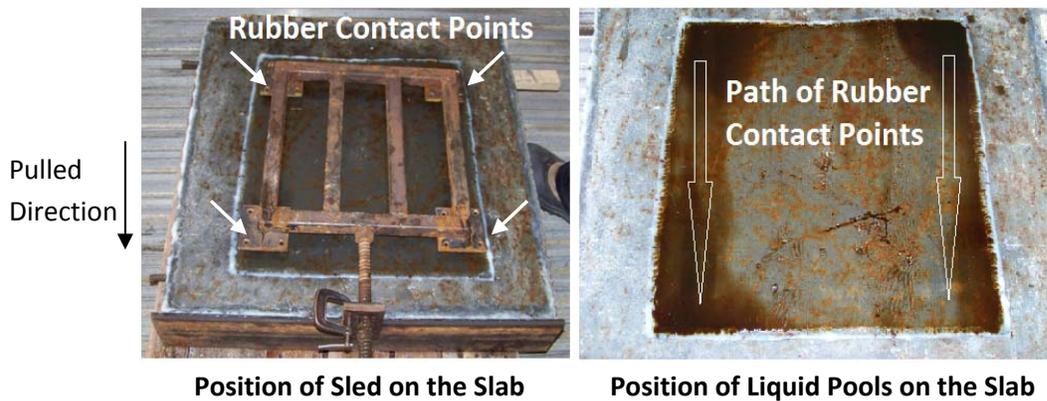


Figure 3.7: Details of Liquid Pooling Issue

3.3.1 Equipment:

- a. Walk-in Freezer with Temperature Controls
- b. Steel Sled with Rubber Contact Points

As shown in Figure 3.8, the sled is made of 1-inch steel tubing and four 3-inch square steel plates welded together to produce a stiff frame. The stiff frame helps to insure evenly distributed load. The purpose of the steel plates is to transfer load to the rubber contact points as evenly as possible. The rubber contact points are cut from the tread of a tire and are oriented symmetrically to mimic the common position of a tire on a roadway, with the tread parallel to the roadway. The rubber contact points were glued to the steel plates. The shape of the sled was dictated by the shape of the available weights.



Rubber Contact Points on Sled

Rubber Contact Points Cut from Center of Tread

Figure 3.8: Rubber Contact Points

c. Weights

The sled was built to accommodate 1-ft square weights. The total weight of the sled needed to be 270 lbs. Several weights were used to approach the target weight of 270 lbs. A bucket of sand was used to attain the exact weight of 270 lbs.

d. Small Load Cell and Data Acquisition System

e. Spray Bottle Capable of Producing a Fine Mist

f. Graduated Cylinder

g. Squeegee

The squeegee is used to spread the liquid deicer and to clean the concrete surface after testing.

h. 1-inch Diameter Threaded Bar, 2 Nuts, 1 washer, ¼ inch thick Modified Steel Angle, and Grease

The threaded bar, nuts and washer, and steel angle are used to pull the sled. The Friction Test details and setup are shown in Figure 3.9. One nut is welded to the sled and is used to secure the threaded bar to the sled. When the other

nut is tightened, the sled is dragged forward. The load cell records the amount of force used to pull the sled. The threaded bar and all contact points must be very well greased.

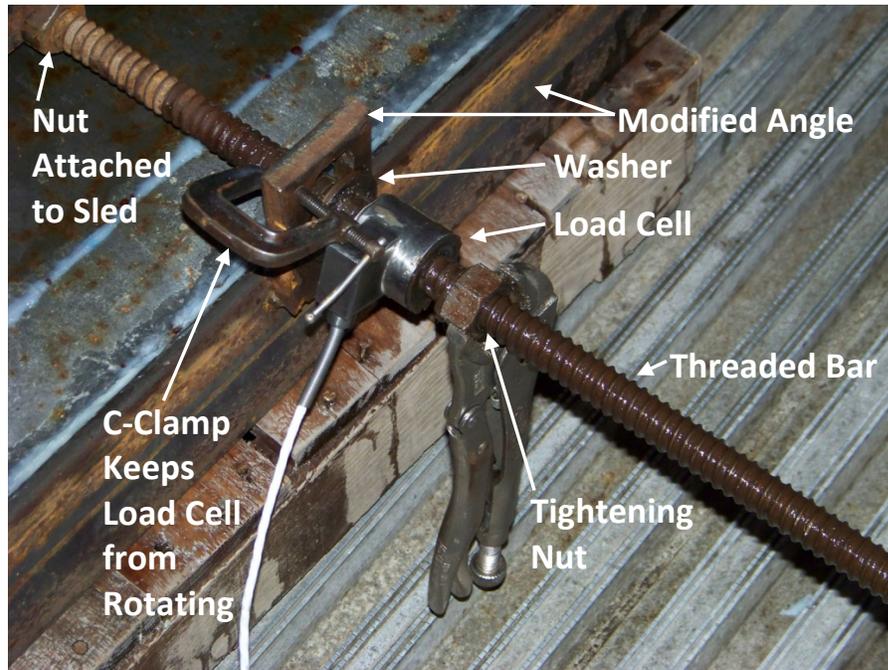


Figure 3.9: Equipment and Setup to Drag Sled

3.3.2 Procedure:

Tests are repeated at least twice for each chemical.

3.3.2.1 Preparation of the Steel Angle

The purpose of the steel angle is to provide a stiff segment to place the load cell against when the sled is being dragged across the slab. Ideally, when one side of the steel angle is placed under the slab, the other side will fit around the side of the slab and stick up over the surface of the slab. A hole was drilled in one leg of the steel angle sticking up over the surface of the slab so the threaded rod attached to the sled could fit through the hole without touching the sides of the hole.

3.3.2.2 Preparation of the Concrete Slab

1. Make a 2-foot square, 2-in thick concrete slab. There is no specified composition of the concrete to be used for this test, but it is recommended to use a mix common to the local area. There is no required concrete thickness to be used for the test, but a thinner slab will cool more quickly.
2. Let the concrete slab set for 7 days before testing.
3. Clean the concrete slab surface thoroughly with distilled water and remove all stray granules.
4. Move the slab to the walk-in freezer and place the modified steel angle. This allows the sled to brace against the slab when the sled is pulled.
5. Level the concrete slab as much as possible.
6. If needed, place the acrylic based sealant on the concrete surface. The best way to do this is to place the sled on the slab in the location needed for testing and trace around it with the sealant, as depicted in Figure 3.10.



Figure 3.10:
Applying Acrylic Sealant on
Concrete Slab

3.3.2.3 Testing Procedure

1. Activate the walk-in freezer set at the desired temperature.
2. Allow the slab, sled, weights, and other mechanical equipment to equilibrate for 5-6 hours inside the freezer.
3. Put 25 mL of distilled water in the spray bottle and spray the concrete surface area within the sealant. Spray the water as evenly as possible, as shown in Figure 3.11.

The water will freeze almost instantly.

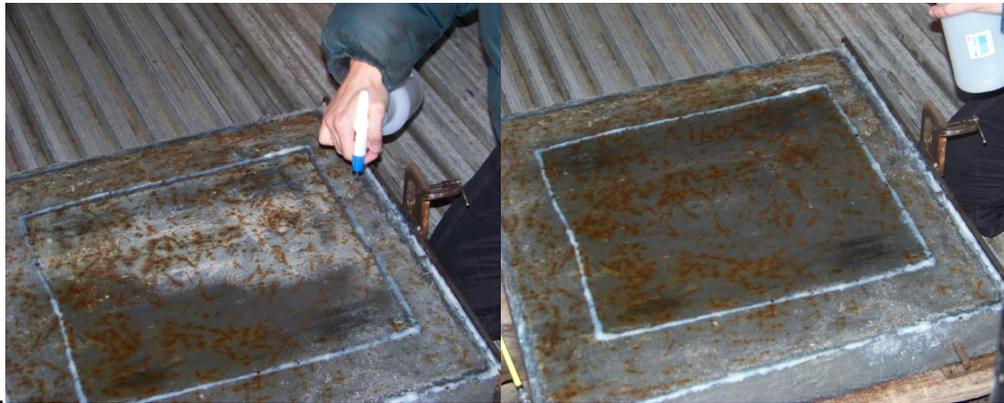


Figure 3.11: Making Ice Layer

The following steps (steps 4-9) must be done in 5 to 6 minutes:

4. Put 25 mL of liquid deicer in a graduated cylinder and deposit the deicer within the frozen area on the slab. Use the squeegee to spread the deicer across the ice. The deicer should be moved to cover the ice with the majority of the deicer remaining in the center to distribute naturally.
5. Place the sled and weights on the frozen area and place the load cell as seen in Figure 3.12.



Figure 3.12: Friction Test Setup

6. Begin data sampling with the computer and load cell. The data acquisition system should be set to sample 3 times a second.
7. Set the load cell in place so the threaded bar is not in contact with the washer.
8. Tighten the nut using a slow, smooth motion. When the load cell is bearing against the washer, force is exerted on the load cell and the sled is moving forward. Continue motion for several seconds.
9. Loosen the nut. Halt sampling on the computer and save the data. Reset the computer for the next sampling.
10. Look at the data and determine the magnitude of the force needed to move the sled.
11. Remove the weights from the sled and move it back to its original position.
12. Repeat steps 5-11 every 5 to 10 minutes until 3 consecutive tests yield similar magnitudes of force. The target time intervals are 5, 10, 15, 20, 25, and 30 minutes from the time the deicer is placed on the slab.

13. When testing is complete, rinse off the rubber contact points on the sled and flush the concrete surface with warm water. Use the squeegee to remove excess liquid from the surface of the slab.
14. Rinse the squeegee.

3.3.3 Data Processing:

The data from testing consists of a time series of the magnitudes of force being exerted on the sled at 1/3 second interval.

No force is applied when the load cell is initially activated. This occurs just before tightening and just after loosening the nut. The applied force will increase as tightening begins. The peak magnitude force occurs when static friction has been reached and the sled has begun to move. The peak force is the value used to calculate the static friction coefficient. The forces gradually decrease after the peak force as the sled is moving. The average of these values is used to calculate the kinetic friction coefficient. The following equations are used to calculate the static and kinetic friction coefficients:

$$\text{Static Friction Coefficient} = \frac{\text{Peak Force on Graph}}{\text{Weight of Cart}} \quad (2)$$

$$\text{Kinetic Friction Coefficient} = \frac{\text{Average of Lesser Forces on Graph}}{\text{Weight of Cart}} \quad (3)$$

The static and kinetic friction coefficients are calculated for every time interval. This test should be run at least twice for each liquid deicer to obtain an average performance.

3.4 Sunlight Test

The purpose of this test is to determine if darker colored chemical deicers have a significant advantage over lighter colored chemical deicers in direct sunlight. The prewet and application rates used in this test are much higher than those used in practice. The results of this test are presented by photos to show how the different samples of deicers compare to each other in direct sunlight and in shaded areas.

Samples of solid chemical deicers are prewet with a liquid chemical deicer with the intention of darkening the color of the solids. The same amount of liquid and solid is used for each sample and the solids all have a similar gradation. The chemical deicers used in this test are given in Table 3.4. The samples are applied to separate plots of ice that are 1/8 inches thick. Pictures are taken of the plots at the same time intervals. The performance of the deicers is evaluated visually.

Deicer	Composition
Salt Brine	Liquid-23% NaCl
50/50 Mix of Beet Juice-A/Salt Brine	Liquid-Carbohydrate Byproduct/ 23% NaCl
15/85 Mix of Beet Juice-A/Salt Brine	Liquid-Carbohydrate Byproduct/ 23% NaCl
Road Salt	Solid-NaCl
Pink Salt	Solid-Complex Chloride NaCl, MgCl ₂ , KCl

3.4.1 Equipment:

- a. Sample Containers with Lids
- b. Measuring Syringes
- c. #4 and #8 Sieves
- d. Camera
- e. Thermometer

- f. Scale Measuring to the Nearest 0.01 Gram
- g. Acrylic Based Sealant
- h. Test Plots

Any substrate can be used for this test. As shown in Figure 3.13, the test plots used in this research were constructed of an 18-inch by 13-inch concrete slab divided into 8 plots using acrylic based sealant.



Figure 3.13: Sunlight Test Surface

3.4.2 Procedure:

3.4.2.1 Sample Preparation

1. Pass the solid deicers through a #4 and #8 sieve. The solids caught on the #8 sieve are used for testing.
2. Measure 2.0 ± 0.03 grams of solid and place in sample container with lid. Tip the sample container to one side so all the sample is in the same area of the container.
3. Measure $\frac{1}{2}$ mL of liquid deicer using a syringe. The deicer can be a pure sample or a sample mixed with salt brine.
4. Dribble the $\frac{1}{2}$ mL of liquid deicer on the sample of solid deicer in the sample container.

5. Steps 2-4 must be done twice for each solid/liquid deicer combination so a test can be done in a sunlit area and a shaded area. Figure 3.14 shows some deicer samples.



Figure 3.14: Sunlight Test Sample Preparation

6. Place the lids on the sample containers to prevent any losses.

3.4.2.2 Testing Procedure

1. Take deicer samples and test plots outside and let them acclimate overnight.
2. Select a day for testing. The weather must be clear and sunny with air temperature less than or equal to 20°F. The testing must also be done in an area with little to no wind.
3. Place the test plots on a shaded, level area. Fill the test plots with distilled water to create a 1/8-inch thick ice sheet on each plot. Each plot may require a different amount of water.
4. Let the water freeze for 3-4 hours.
5. Use the thermometer to determine the air temperature in the shaded and sunlit areas.
6. Spread the deicer samples on separate test plots. Distribute the deicers as evenly as possible. Place the test plots in the sunlight with the appropriate plots remaining in the shade. Take pictures of the test plots immediately before and after application, as shown in Figure 3.15.



Figure 3.15:
Deicing Samples in Shaded and Sunlit
Areas

7. Take pictures every 3 to 5 minutes for 60 minutes.
8. When the test is complete, thoroughly rinse the test plots with warm water. Dry the test plots as much as possible. Leave the test plots outside for future tests.

3.4.3 Data Processing:

The pictures taken during the test are visually evaluated to determine if a particular solid/liquid deicer combination shows a clear advantage over other combinations. The pictures taken during the test can be used to reveal certain deicers having better deicing performance under sunlight. The picture taken at 60 minutes or the final picture is used to make the comparison. The area affected by the deicer in the separate plots can be determined by using a grid of areas, but obvious visual differences are preferred.

3.5 Refreeze Test

The purpose of the refreeze test is to determine when a deicing product will cease to function and the mixture with melted ice begins to refreeze on the roadway. Estimating when a treated roadway will begin to refreeze helps to determine when trucks should be sent out to treat the roadway again. This test can be used for liquid deicers and solid deicers. Prewet solid deicers were used for testing, but did not yield useful results. The chemical deicers used for this test are given in Table 3.5.

Deicer	Composition
Liquids	
Salt Brine	23% NaCl
Mg-A	29% MgCl ₂
Mg-B	30% MgCl ₂
K Ace	50% Potassium Acetate
Beet Juice-A	Carbohydrate Byproduct
Mg-C	Carbohydrate Byproduct and 26.9% MgCl ₂
Mg-D	Carbohydrate Byproduct and 25% MgCl ₂
Beet Juice-B	Carbohydrate Byproduct
Calcium Chloride	Carbohydrate Byproduct and 30% CaCl ₂
Solids	
Road Salt	Solid-NaCl
Pink Salt	Solid-Complex Chloride: NaCl, MgCl ₂ , KCl

This test is based the SHRP Ice Melting Capacity Test. It consists of placing a sample of deicer on an ice sheet and measuring the amount of liquid that can be removed from the ice surface at particular time intervals over several hours. As time elapses, the amounts of liquid that can be removed will increase as melting occurs and then decrease as the liquid begins to refreeze. The thickness of the ice sheet for these tests was 1/8-inch, but a particular thickness is not required as long as the same is used for all the tests.

The amount of deicer used for this test depended partially on what is used in the field. For liquid deicers, an amount corresponding to 109 gallons per lane-mile was used for testing because it was the smallest amount that could be measured with reasonable accuracy. For solid deicers, an amount corresponding to 910 pounds per lane-mile was used for testing because smaller amounts would not produce measurable results. These are considered large application rates in the state of Nebraska but are not uncommon.

The tests were performed in a walk-in freezer, but it could be adapted for use in a smaller freezer. The temperature during the tests was $14\pm 2^{\circ}\text{F}$. As was done for the SHRP Ice Melting Capacity Test and the Shaker Test, pure deicing chemicals and different deicer/brine ratios were evaluated using the Refreeze Test. The deicer/NaCl ratios evaluated were 15/85 and 50/50. The solid deicers were used specifically to study the effect of the particle gradation on the refreeze time. The solids were passed through #4, #8, #20, and #40 sieves. The solids retained on the #8, #20, and #40 sieves were used separately for testing.

3.5.1 Equipment:

- a. Containers, with and without Lids
- b. Syringes Capable of Measuring to the Nearest 0.1 mL
- c. Graduated Cylinder
- d. Walk-in Freezer with Temperature Controls
- e. Scale Measuring to the Nearest 0.01 Gram
- f. #4, #8, #20, and #40 sieves

3.5.2 Procedure:

Each test is conducted in triplicate.

1. Pass solid deicers through #4, #8, #20, and #40 sieves. The solids retained on the #8, #20, and #40 sieves are used separately for testing.
2. If needed, pre-mix the liquid deicers at the desired ratios. Place several milliliters of the liquid deicers in containers and place the lids. The deicers are now pre-mixed for all needed testing.
3. Place containers, syringes, and all chemical deicers in the freezer.
4. Set the freezer to the desired temperature.
5. Use the graduated cylinder to place 25 mL of distilled water in each container. This will create a 1/8-inch thick ice sheet in the containers.
6. Let the temperature of the ice, equipment, and deicers equilibrate for 4-5 hours.
7. Apply a sample of deicer to the ice sheet. For liquids, use ½ mL. For solids, use 0.5 ± 0.03 grams.
8. Use a syringe to remove and measure the liquid from the ice surface, as shown in Figure 3.16. Take measurements at 1-hour intervals for 5 hours.



Figure 3.16: Refreeze Test Liquid Measurement

9. Clean the containers with the leftover ice by thoroughly rinsing with distilled water.
10. Clean the syringes with distilled water.
11. All equipment and deicers may be left in the freezer for later testing.

3.5.3 Data Processing:

The refreeze time was determined for the deicers based on the data over a 5-hour test period. The results from the three tests for each deicer are presented in the next chapter.

Chapter 4

Test Results and Evaluation

4.1 SHRP Ice Melting Capacity Test

This test was developed by the Strategic Highway Research Program and can be found in the Handbook of Test Methods for Evaluating Chemical Deicers (Chappelow et al., 1992). It served as the starting point for test development in this project. Testing was performed at 20°, 10°, and 0° F. The test samples consisted of 3 grams of road salt with 1mL of liquid prewet. Different liquid deicer/sodium chloride ratios were used as a prewet to study the effect mixing ratios has on the end product. The ratios used were 100% of liquid deicer, 50/50 liquid deicer/ sodium chloride, 40/60 liquid deicer/sodium chloride, and 25/75 liquid deicer/sodium chloride.

4.1.1 Test Results

The results of the SHRP Ice Melting Capacity Test can be presented as melting rates for the different chemical deicers or as melting totals for a particular time interval, usually 60 minutes. The 60 minute totals for 0°F and 10°F are shown in Figures 4.1 and 4.2, respectively. The colored bars represent the different deicer/NaCl ratios. The percentages stand for the percent of the specified deicer used in the prewet. For example, the red colored bar represents 25%. This means a mix of 25% deicer and 75% of sodium chloride was used to prewet the road salt, or, the prewet consisted of a 25/75 mix of deicer/NaCl. The performance of 100% salt brine is used as the reference for comparison. The performance of 100% Beet Juice-A is not shown because the high viscosity of this product disrupted the test.

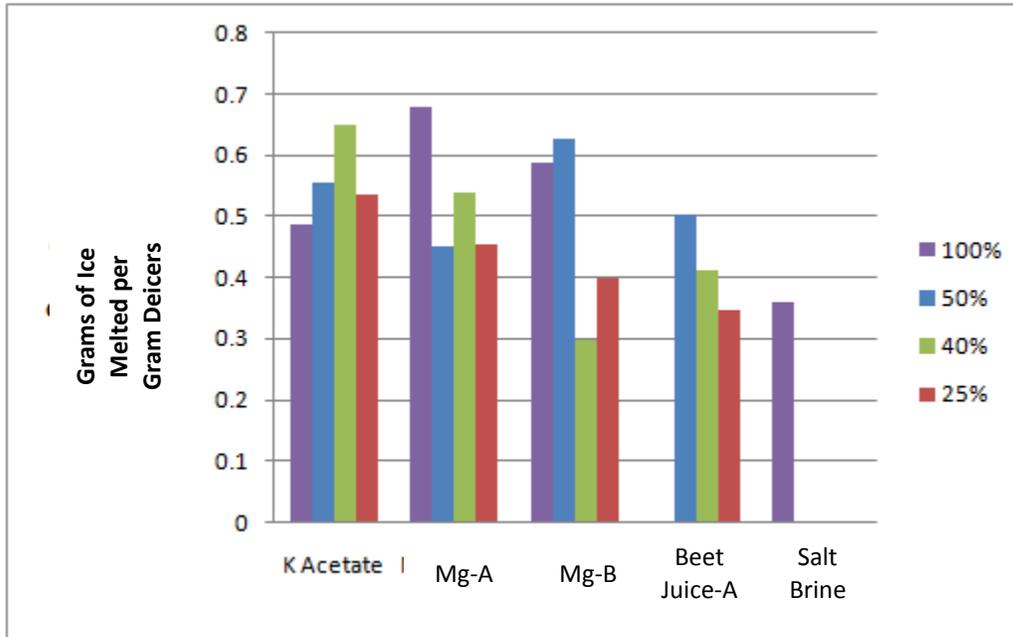


Figure 4.1: SHRP Ice Melting Capacity Test Results at 0°F for 60 Minutes

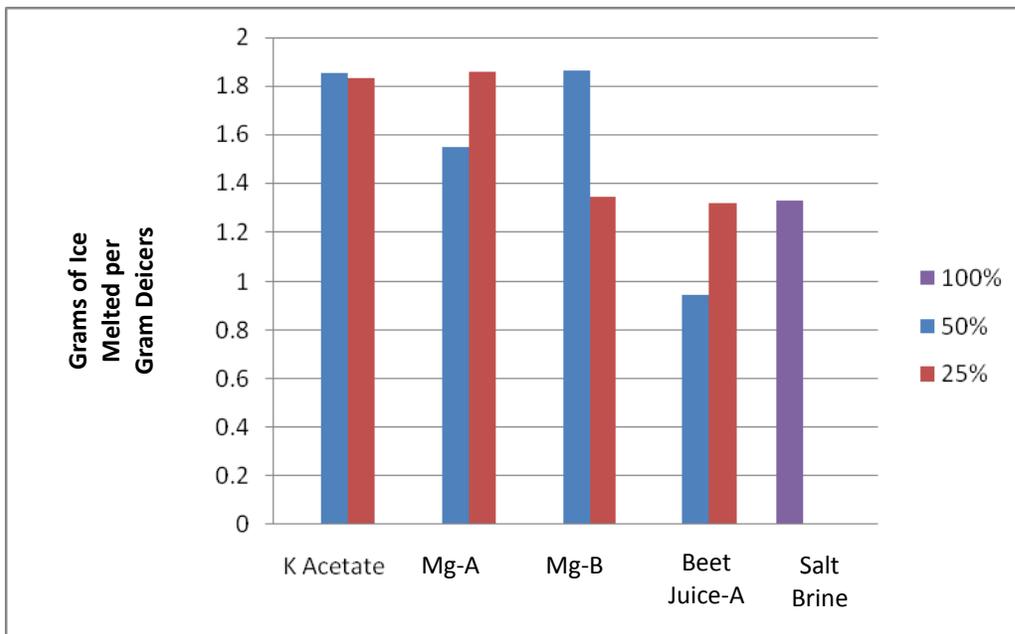


Figure 4.2: SHRP Ice Melting Capacity Test Results at 10°F for 60 Minutes

The 60-minute totals suggest the Beet Juice-A mixes do not perform as well as the other mixes. It can be seen from these figures that there is a lack of consistency. SHRP Ice

Melting Capacity Tests were not performed at 20°F because it was decided the test was too inconsistent to continue. Figures 4.3-4.9 depict the melting rates for each temperature and mix ratio.

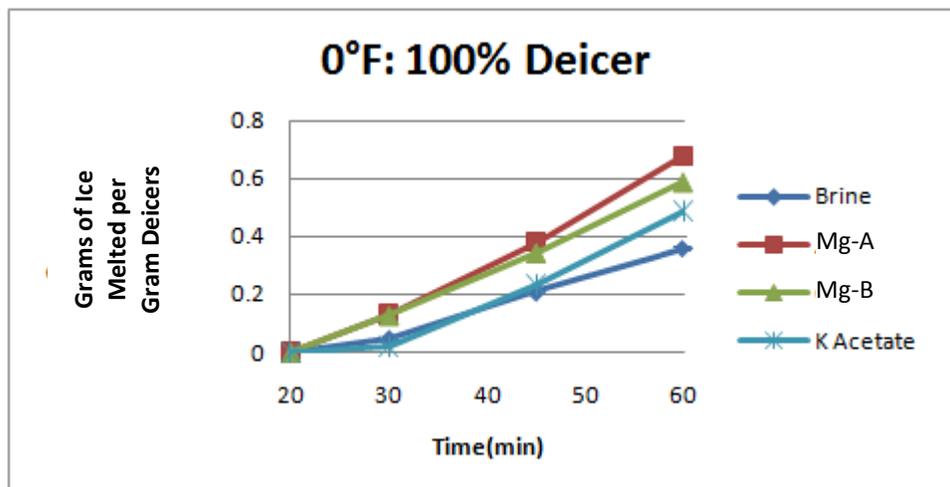


Figure 4.3:
SHRP Ice Melting Capacity
Test Rates at 0°F for 100%
of Indicated Deicer

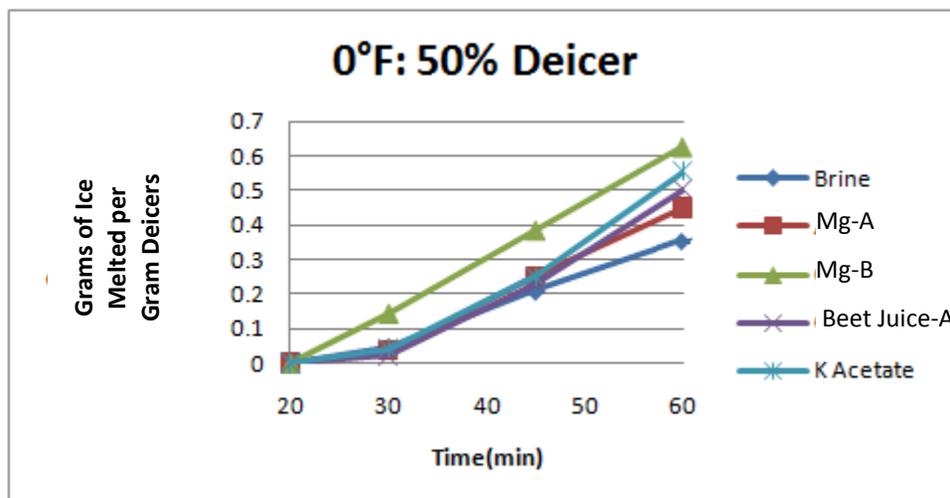


Figure 4.4:
SHRP Ice Melting Capacity
Test Rates at 0°F for 50/50
Mixes of Indicated Deicer
and Sodium Chloride

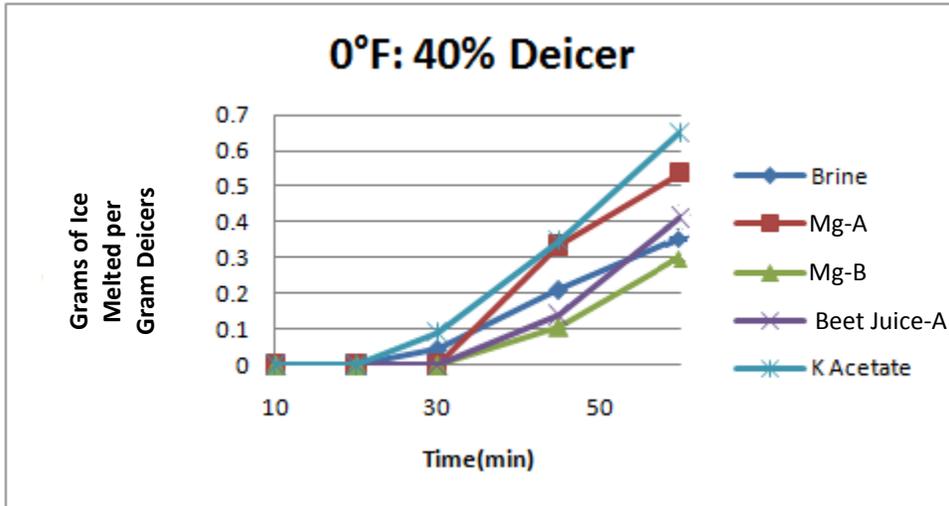


Figure 4.5:
SHRP Ice Melting Capacity Test Rates at 0°F for 40/60 Mixes of Indicated Deicer and Sodium Chloride

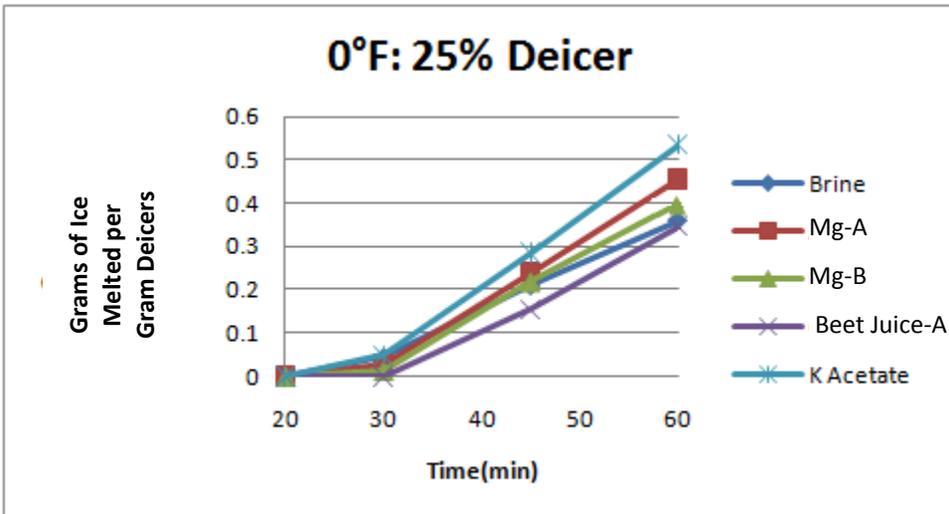


Figure 4.6:
SHRP Ice Melting Capacity Test Rates at 0°F for 25/75 Mixes of Indicated Deicer and Sodium Chloride

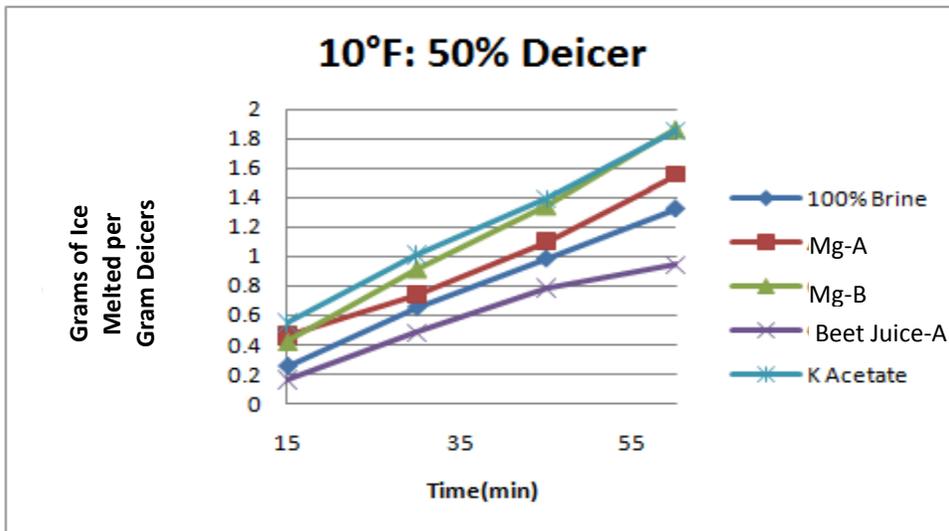


Figure 4.7:
SHRP Ice Melting Capacity Test Rates at 10°F for 50/50 Mixes of Indicated Deicer and Sodium Chloride

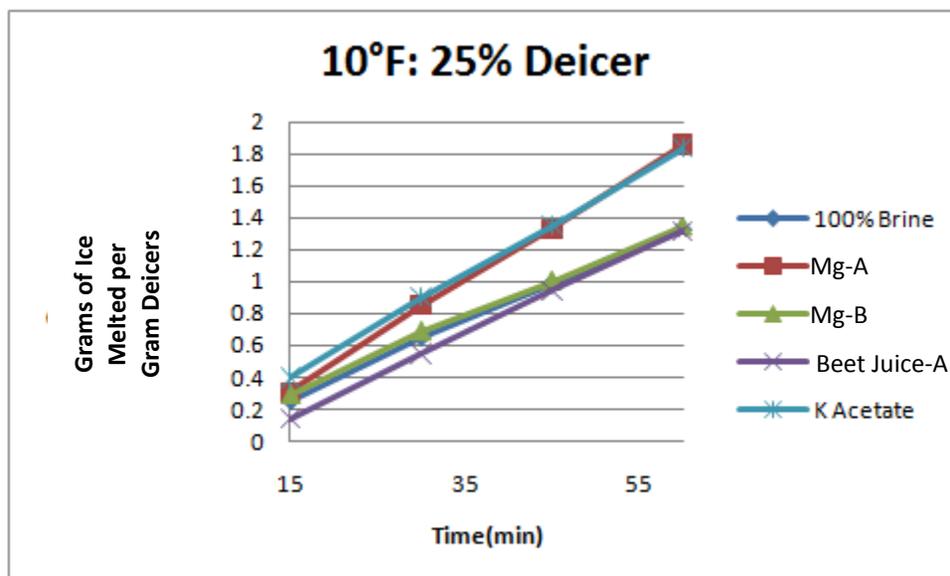


Figure 4.8:
SHRP Ice Melting Capacity
Test Rates at 10°F for 25/75
Mixes of Indicated Deicer
and Sodium Chloride

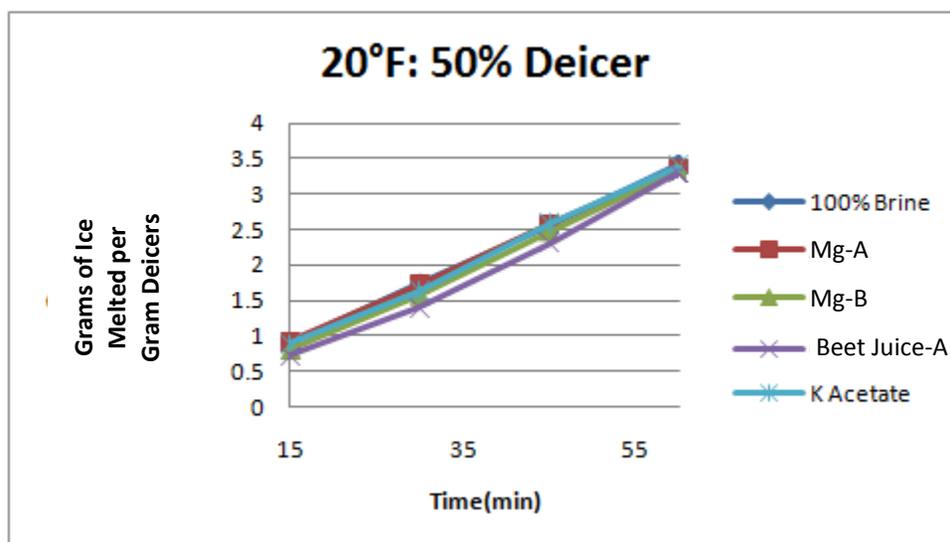


Figure 4.9:
SHRP Ice Melting Capacity
Test Rates at 20°F for 50/50
Mixes of Indicated Deicer
and Sodium Chloride

The melting rates are fairly close for the various deicers. At 0°F, it takes at least 30 minutes for the deicers to start melting the ice. At 10°F, the deicers do not start working until after 15 minutes of exposure. Potassium acetate and Mg-A consistently perform better than sodium chloride. The results for the Mg-B do not show any consistency. Beet Juice-A consistently performs the same as or worse than sodium chloride. However, the data in Figure 4.4 shows a 50/50 mix of Beet Juice-A/NaCl performs better than sodium chloride

alone at 0°F which correlates with what has been reported by roadway maintenance personnel in the State of Nebraska.

At 20°F, all the deicers are producing identical results suggesting a 50/50 ratio of deicer/NaCl will perform the same as sodium chloride alone. The accuracy of these results is questionable because they do not correlate with the observations that sodium chloride becomes much less effective than other deicers below about 20°F. This data also does not correlate with field reports in the State of Nebraska.

4.1.2 Sources of Error

Many sources of error exist in this test. The variances for these tests at 45 and 60 minutes vary from 5% to 25%. About half of these variances are greater than 10%. Prevalent sources of error include the use of a chest freezer for testing and the testing of prewet solids. Others sources include liquid retention from cavities formed in the melting ice and problems that come from mixing deicers.

Opening the door of the chest freezer caused the temperature to increase during testing. The temperature of the ice did not increase by more than 3°F, but the air temperature could increase by as much as 10°F. This could result in less consistent ice melting capacities.

Road salt is a much less homogeneous material than the liquid deicers because road salt contains small amounts of gravel. This physical attribute could cause significant error in test results if some samples contain more gravel than others. The granules also created cavities in the ice sheet that retained some liquid even when the test dish is tipped. A research project (Goyal et al., 1989) using the SHRP Ice Melting Capacity Test tried using different types of blotter paper to absorb all the liquids. This method resulted in needing many more

tests to determine ice melting capacities of a deicer in 60 minutes because the liquids could not be adequately returned to the test dish.

Problems with mixing the liquid deicers are believed to cause the most inconsistency in the results between different mix ratios. The problem comes from mixing the liquids in separate graduated cylinders. Any deicer/NaCl mixes with deicer amounts greater than 40% produce a solid precipitate. This did not occur with the Beet Juice-A or Beet Juice-B mixes. As seen in Figure 4.10, this precipitate quickly settles and sticks to the inside of the graduated cylinder. There was always residue left in the graduated cylinder after the liquids had been poured for use as a prewet. The precipitate is most likely solid chlorides and/or acetates that can become separated from the prewet liquid, thus reducing the liquid's ice melting capacity. The precipitate has also been reported to clog deicer distribution systems on trucks in the State of Nebraska.

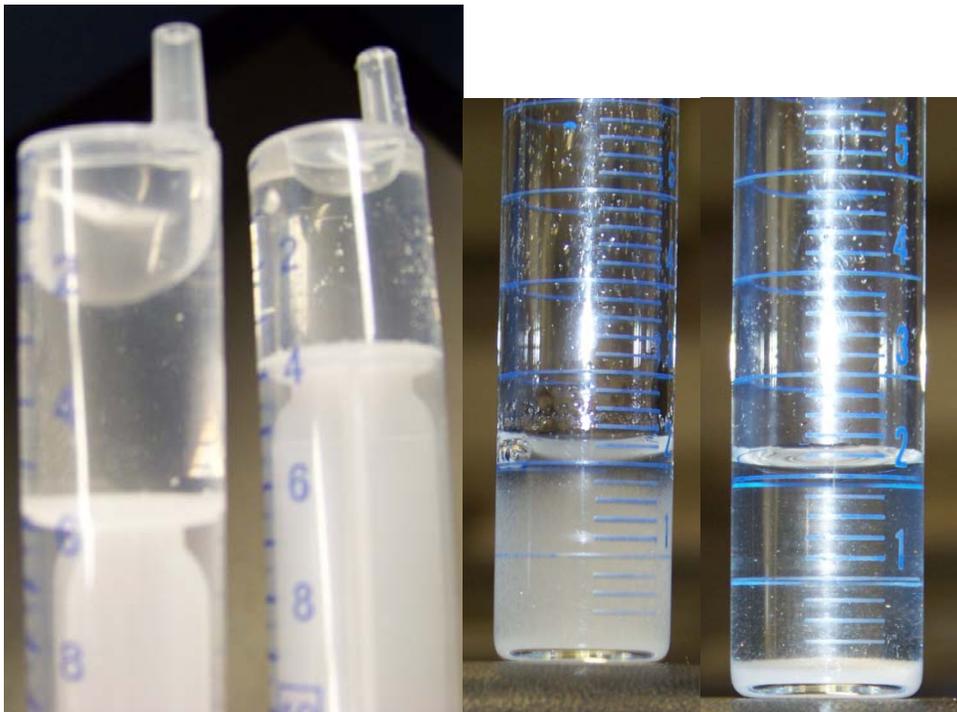


Figure 4.10: (Left) Clear Deicers in Separate Syringes, (Middle) Precipitate Formed After Mixing Deicers, (Right) Settled Precipitate

4.1.3 Test Evaluation

The results of this test were found to be too inconsistent to justify the expense of its use. Some research papers (Akin and Shi, 2010; Shi et al., 2009; Nixon et al., 2007; Alger and Haase, 2006) have produced more consistent results, but those projects conducted the SHRP Ice Melting Capacity Tests in a walk-in freezer. Each of these research projects used a slightly different procedure from the SHRP Ice Melting Capacity Test, usually having to do with the size of the ice sheet or deicer sample. The results from Akin and Shi (2010), Shi et al. (2009), and Nixon et al. (2007) cannot be compared with the SHRP test results from this study because those studies did not use prewet solids. However, the results from Alger and Haase (2006) are compared with the results from this study in Table 4.1.

Some of the SHRP Ice Melting Capacity test results from Alger and Haase (2006) are shown in Figure 4.11. This research tested samples of prewet road salt. The purpose of their research was to determine how the prewetting rate, at 6, 8, or 10 gal/ton, would improve the ice melting capacity.

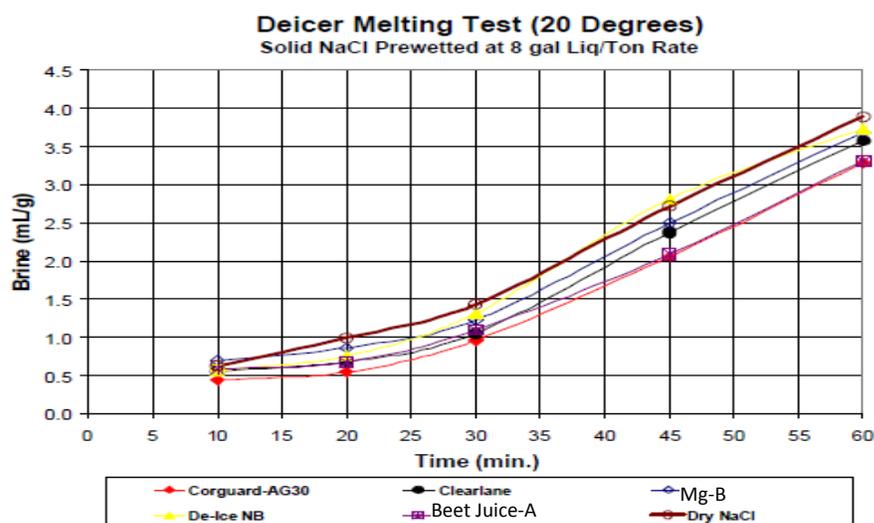


Figure 4.11:
SHRP Ice Melting Capacity Test
Results (Alger and Haase,
2006)

Their results did not clearly show different performances between the type and the amount of prewet. There were also several instances where “Dry NaCl” outperformed several other products, which is not consistent with observations from the field. The results from Figure 4.11 correlate well with those in Figure 4.9; however, the units do not exactly match. One milliliter of brine will typically weigh between 1.0 and 1.18 grams. The specific gravity of brine measured at 60 minutes was probably closer to 1.0 gram in Figure 4.9, because of the large volume of water in the brine. The results from Figures 4.9 and 4.11 are compared in Table 4.1.

Deicer	Alger and Haase (2006)	This Research
Mg-B	3.7	3.34
29% MgCl₂	3.6	3.36
Beet Juice-A	3.3	3.30

The 60-minute results from Akin and Shi (2010) for the SHRP Ice Melting Capacity Tests at 15°F and 30°F are shown in Figure 4.12 and Figure 4.13, respectively. This project used different amounts of ice and chemical deicer. The modifications resulted in an application rate of 2270 lbs/lane-mile and 245 gal/lane-mile rather than the 1320 lbs/lane-mile and 144 gal/lane-mile as specified in the original SHRP test. The multiple columns for each chemical represent tests that were done on different days.

The test results are consistent between Figures 4.12 and 4.13 and between tests done on different days. Test results for 0°F were not shown because the liquid measurements were very low. Aside from the results at 0°F, the variances from the results at different temperatures and time periods are quite low. The variances range from 0 to 20% with over half less than 10%.

One notable inconsistency between the data in Figure 4.12 and known outcomes from the field is the performance of the solid sodium chloride at 15°F. Figure 4.12 shows the solid sodium chloride to have better performance at 15°F than calcium chloride and magnesium chloride, but reports from the field show sodium chloride to have lesser performance at this temperature than the other two chemical deicers. Akin and Shi (2010) commented that the test results for the solids at 15°F after 20 minutes of exposure correlated much better with results from the field than the results at 60 minutes of exposure.

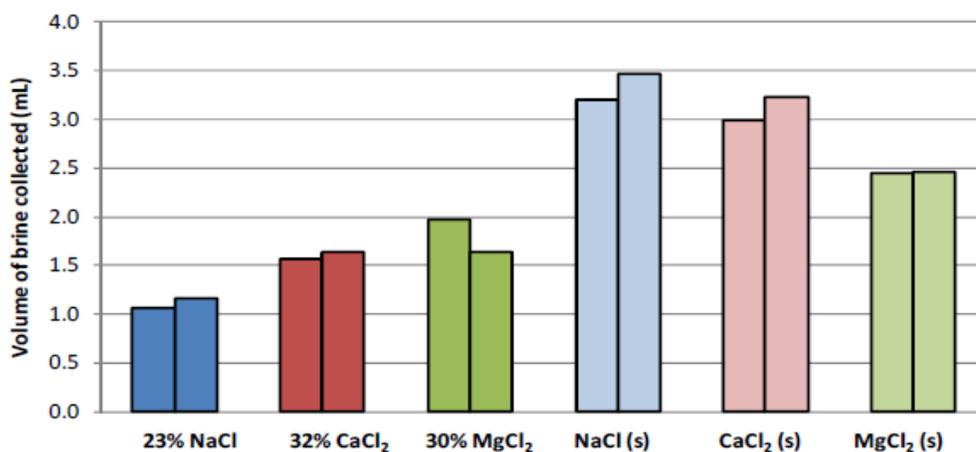


Figure 4.12: Modified SHRP Ice Melting Capacity 60-Minute Test Results at 15°F (Akin and Shi, 2010)

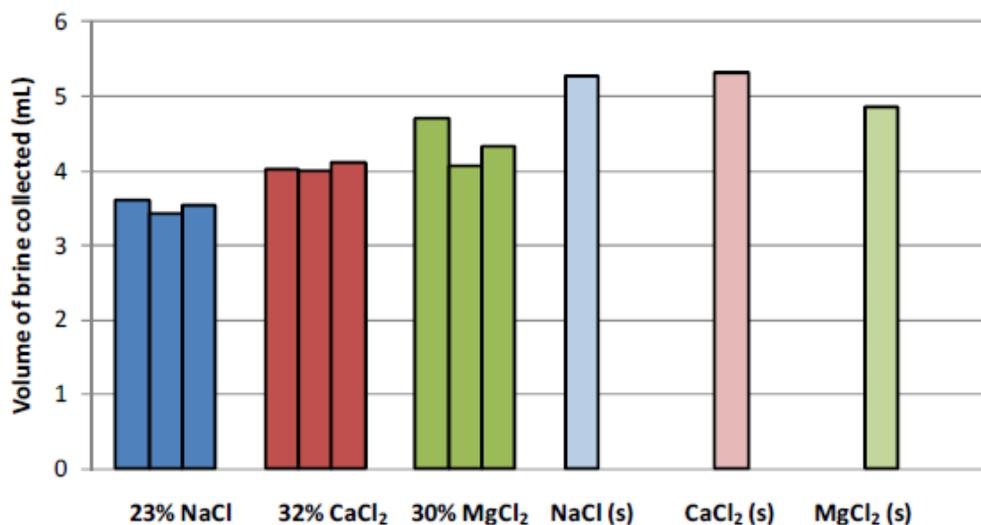


Figure 4.13: Modified SHRP Ice Melting Capacity 60-Minute Test Results at 30°F (Akin and Shi, 2010)

The 60-minute results from Shi et al. (2009) for the SHRP Ice Melting Capacity Tests are shown in Figure 4.14. The sodium acetate (NAAC), Peak SF (sodium formate), Pink Salt, and sodium chloride are all solid deicers. The magnesium chloride and IceBan are liquids. These tests were performed in the same manner as the tests from Akin and Shi (2010).

The error bars show the variances to be reasonable for most of these tests. Figure 4.14 compares the ice melting capacities of solid sodium based products with liquid magnesium chloride mixes. However, liquid and solid deicers should not be compared to each other in a laboratory setting as they work differently in the field.

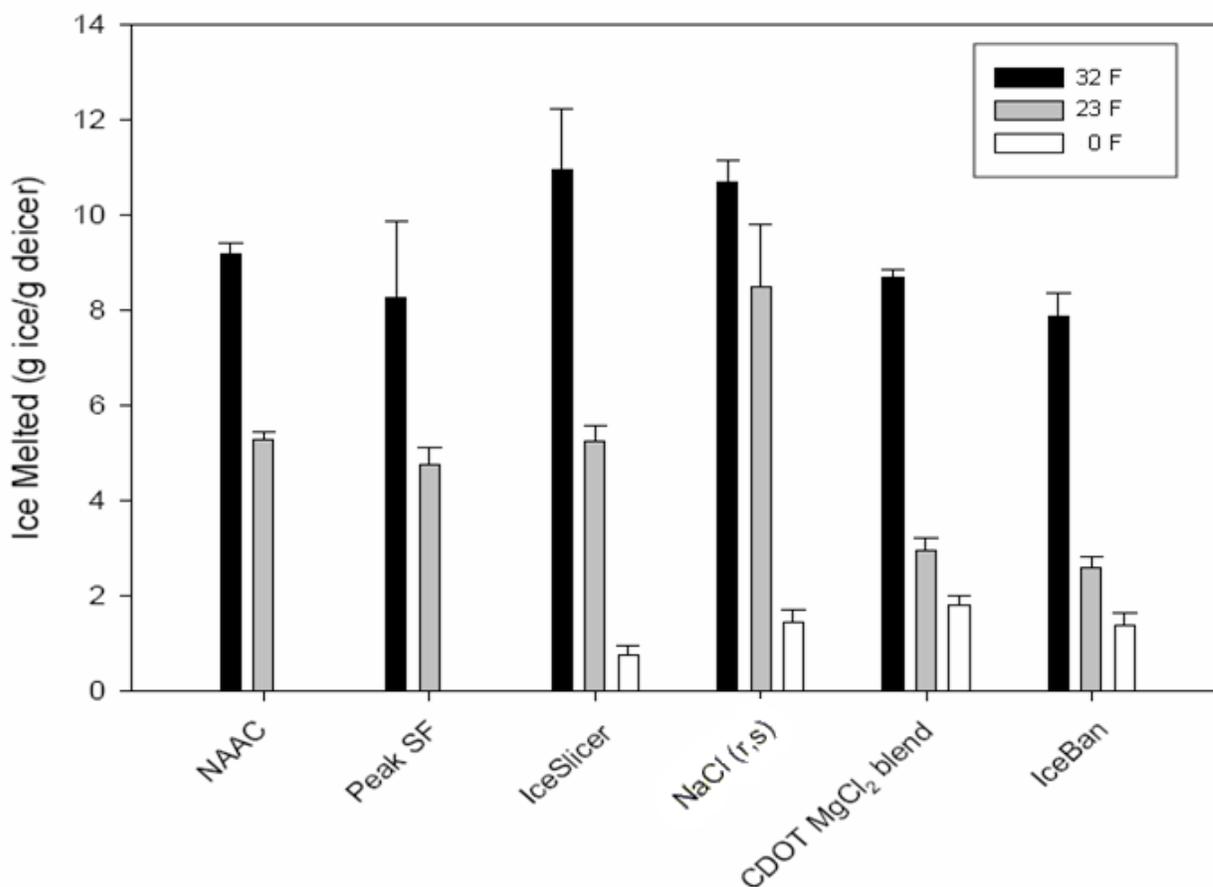


Figure 4.14: Modified SHRP Ice Melting Capacity Test Results at 60 Minutes (Shi et al., 2009)

The 60-minute results from Nixon et al. (2007) for the SHRP Ice Melting Capacity Tests are shown in Figure 4.15, where several liquid deicers' performances are compared. "MB" represents mineral brine, a mix of different chloride bases. "IBU" represents IceBan Ultra, a 25% magnesium chloride mix. They used 80mL of distilled water to form the ice sheet and 5mL of liquid deicer per test, but the size of the Plexiglas test dish was not reported.

One inconsistency shown in the data is that the performance at 0°F was better than that at 10°F. In the field, sodium chloride is expected to become ineffective at 0°F and no deicers are expected to perform better at lower temperatures. Another inconsistency is the performance of the IceBan Ultra. The IceBan and the Mg-B have similar magnesium chloride concentrations, but data showed they performed quite differently. Since IceBan is bio-degradable, it is possible that the sample used for testing could have been a bad batch.

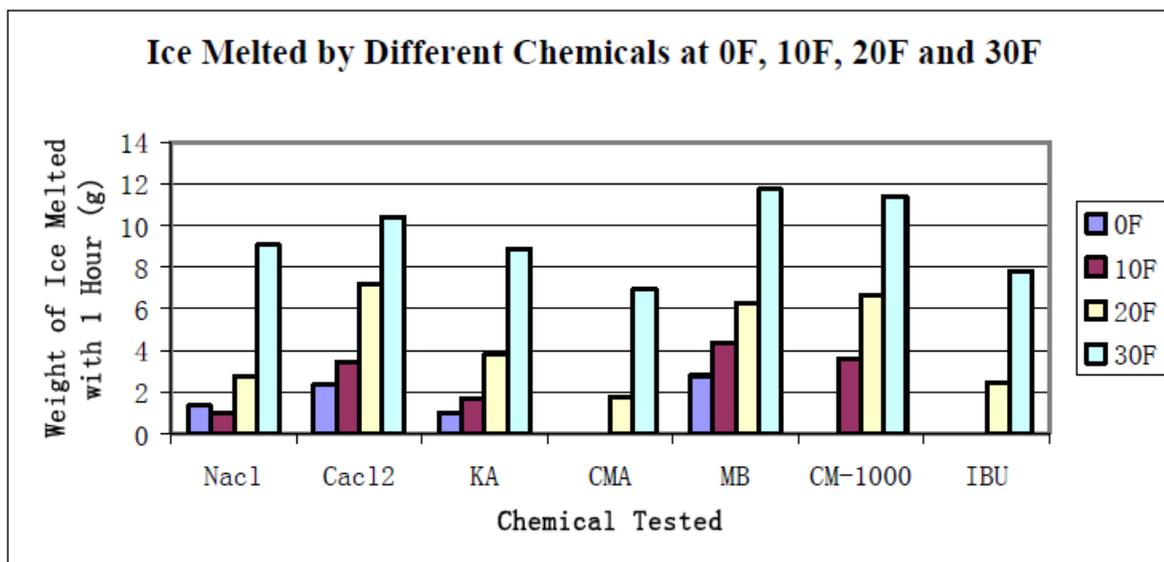


Figure 4.15: SHRP Ice Melting Capacity Test Results at 60 Minutes (Nixon et al., 2007)

Due to the many sources of error, it is evident that the SHRP Ice Melting Capacity Test is not repeatable between different laboratories. Furthermore, the results from this test often do not correlate with field observations.

4.2 Shaker Test

The Shaker Test has several advantages over the SHRP Ice Melting Capacity Test. One advantage is that the test results are not affected by the size of the freezer. The freezer in an upright refrigerator is large enough for testing. Another advantage is the Shaker Test is able to produce repeatable results between laboratories. The use of this test by other researchers will further confirm this observation. Also, the error caused by mixing liquid deicers in the SHRP Test does not exist in the Shaker Test, as the deicers mix inside the shaker and none of the precipitate is lost. Lastly, the procedure for the Shaker Test is simpler and more flexible than that of the SHRP Ice Melting Capacity Test. The Shaker Test takes 10 minutes whereas the SHRP Ice Melting Capacity Test takes at least 20 minutes to produce results. Many elements in a SHRP Ice Melting Capacity Test can be easily mishandled and disrupt the results.

As part of the evaluation, several actions were taken during the procedure in an attempt to disrupt the Shaker Test. These actions included: dropping the shaker and having the lid fall off, shaking at different frequencies throughout the procedure, having the shaker in different positions while shaking, and using different amounts of ice between tests. If the lid is replaced quickly after its removal, it will not affect the results. The shaking frequency does not have to be exact as long as it is close to the recommended frequency. The shaking position does not seem to have an effect as long as the liquids do not become separated from

the solids. Always use the recommended number of ice cubes, however, the results will not be significantly affected if the amounts of ice differ by less than 1 gram.

The test results for liquid deicers, solid deicers, and prewet road salt are presented separately herein.

4.2.1 Test Results

One observation that pertained to all the tests was how the temperature inside the shaker changed during the procedure. As shown in Figure 4.16, the temperature in the shaker drops sharply while shaking and then rebounds to its original temperature. The temperature drop is due to the ice melting reaction which absorbs the heat energy in the shaker. When the ice stops melting, the temperature gradually returns to its original state.

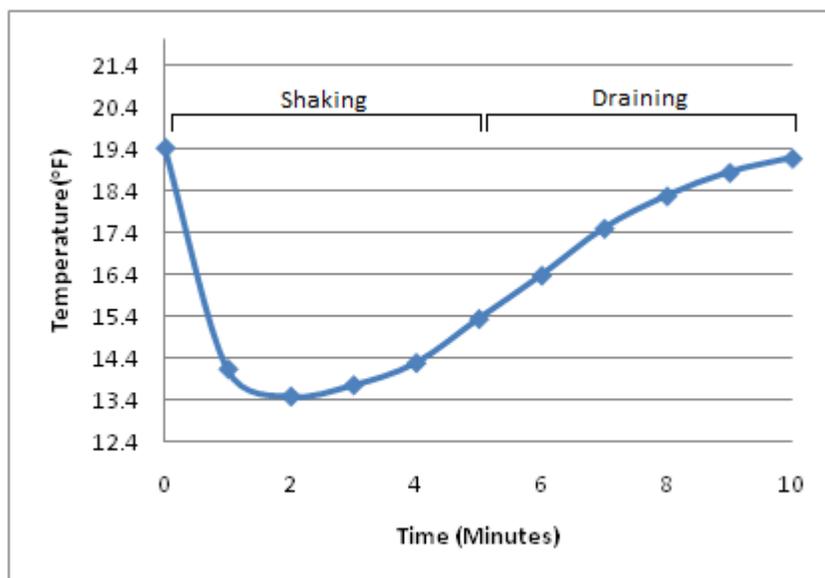


Figure 4.16:
Temperature Change inside the Shaker during the Shaker Test

4.2.1.1 Liquid Test Results

Nine different liquid deicers were evaluated at 20°F, 10°F, and 0°F. The effect of mixing liquid deicers with salt brine was also evaluated for deicer/brine ratios of 15/85 and

50/50, although the effect of ratio was extensively evaluated for Beet Juice-A. The chemical bases of the liquid deicers tested are sodium chloride, magnesium chloride, calcium chloride, potassium acetate, and carbohydrate or “beet juice” mixes.

The results for liquid deicers are shown in Figures 4.17, 4.18, and 4.19. The percentages at the top of each column represent the ratio of the indicated chemical deicer in that particular mix. The standard deviation and variance are presented as a range on top of each bar.

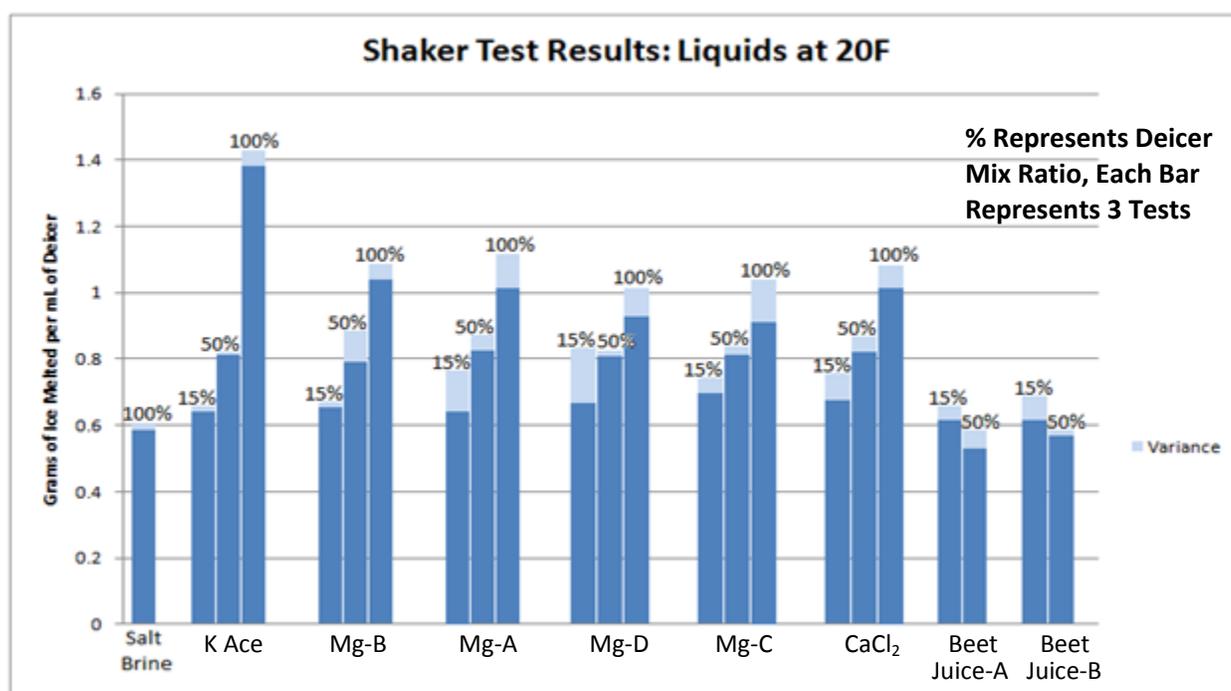


Figure 4.17: Shaker Test Liquid Results at 20°F

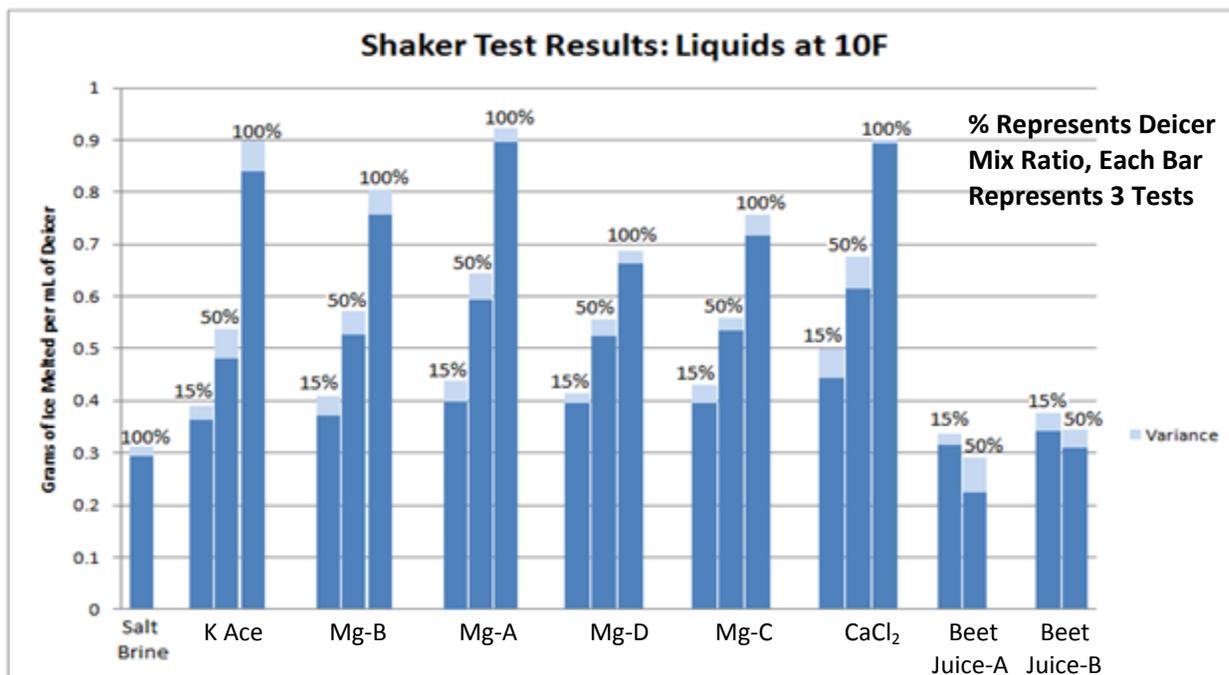


Figure 4.18: Shaker Test Liquid Results at 10°F

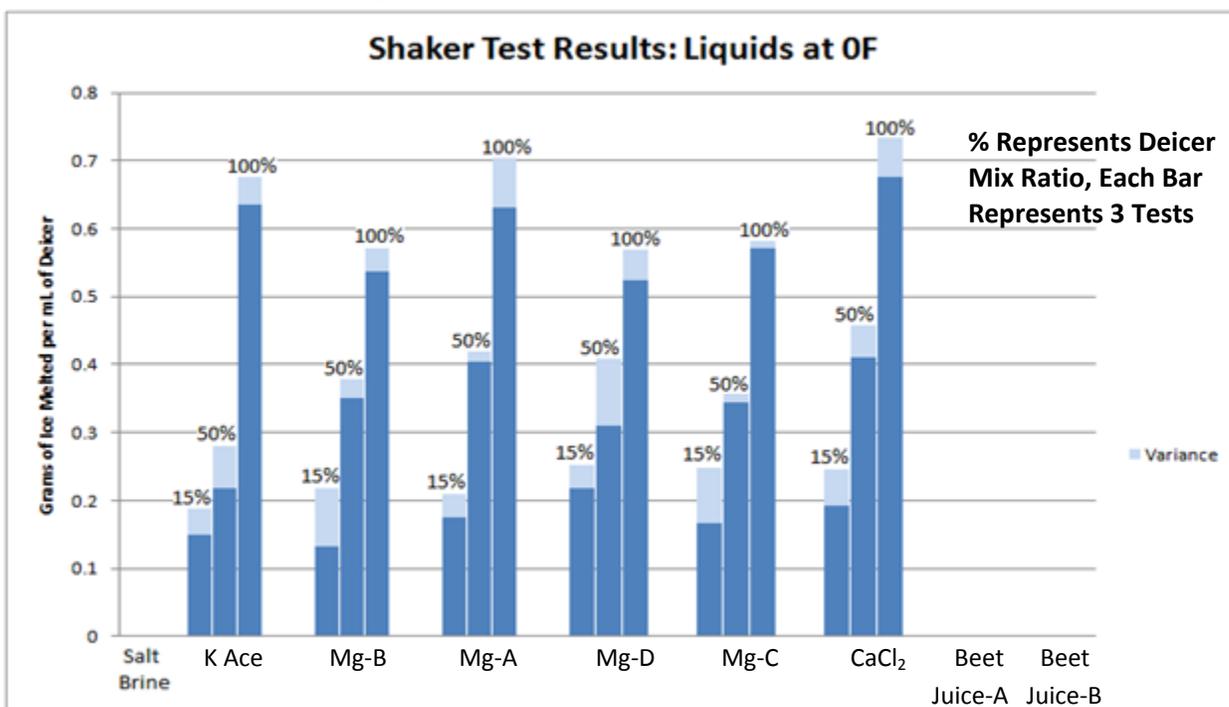


Figure 4.19: Shaker Test Liquid Results at 0°F

The Salt Brine, Beet Juice-A, and Beet Juice-B were ineffective in melting ice at 0°F.

The results for liquid deicers show consistent trends with respect to mix ratios and temperatures. Some of the essential findings are:

- Potassium acetate (K Ace), Mg-A, calcium chloride consistently perform the best at each temperature with potassium acetate performing very well at 20°F.
- Sodium chloride consistently performs the worst except for the 50/50 mixes of Beet Juice-A/NaCl and Beet Juice-B/NaCl.
- Mg-C and Mg-D are very similar products with similar concentrations of magnesium chloride, and the two produced almost identical results.
- Beet Juice-A and Beet Juice-B are also similar products, and the two mixes produced almost identical results.
- The Mg-C and Mg-D have slightly lower chloride concentrations than Mg-A, calcium chloride, and Mg-B. The Mg-C and Mg-D do not perform as well as these other products.
- The 50/50 and 15/85 mixes of potassium acetate/NaCl do not perform as well as other deicer/NaCl mixes at any temperature.
- Mg-A has been reported to perform better than the Beet Juice-A mixes. This field data supports the Shaker Test results.

The variances from the 64 liquid test results are presented in Table 4.2. These variances show the test can produce consistent results for liquids, even at 0°F.

Table 4.2: Variances in Shaker Test Liquid Results (%)

Deicer	20°F	10°F	0°F
Sodium Chloride	1.77	3.27	NA
15/85 K Acetate/NaCl	1.15	3.75	11.21
50/50 K Acetate/NaCl	0.37	5.75	12.60
Potassium Acetate	1.56	3.40	3.19
15/85 Mg-B/NaCl	1.41	4.97	24.34
50/50 Mg-B/NaCl	5.67	4.29	3.88
Mg-B	2.09	3.17	3.11
15/85 Mg-A/NaCl	8.78	4.93	8.86
50/50 Mg-A/NaCl	2.79	4.07	1.93
Mg-A	4.86	1.41	5.56
15/85 Beet Juice-A/NaCl	3.38	3.28	NA
50/50 Beet Juice-A/NaCl	4.75	13.28	NA
15/85 Mg-D/NaCl	11.11	2.47	7.04
50/50 Mg-D/NaCl	1.09	2.91	13.78
Mg-D	4.46	1.71	4.17
15/85 Mg-C/NaCl	3.22	4.15	19.78
50/50 Mg-C/NaCl	1.47	2.11	1.70
Mg-C	6.62	2.62	0.99
15/85 CaCl₂/NaCl	5.63	5.73	12.10
50/50 CaCl₂/NaCl	2.63	4.88	5.29
Calcium Chloride	3.10	0.46	4.06
15/85 Beet Juice-B/NaCl	5.41	4.86	NA
50/50 Beet Juice-B/NaCl	1.37	5.38	NA

NA = Not Applicable

4.2.1.2 Solid Test Results

Only two solid chemical deicers, road salt and Pink Salt, were tested. Road salt is solid sodium chloride and Pink Salt is an orange colored, finely graded solid made up mostly of sodium chloride with small amounts of magnesium chloride, calcium chloride, and other chemicals. Of the samples used for testing, the road salt had a gradation greater than 4.75 mm (#4 sieve) and the Pink Salt had a gradation smaller than 4.75 mm (#4 sieve). The results are shown in Figure 4.20. Field observations have shown that Pink Salt performs better than road salt. Both solids were passed through sieves so they have similar gradations before testing.

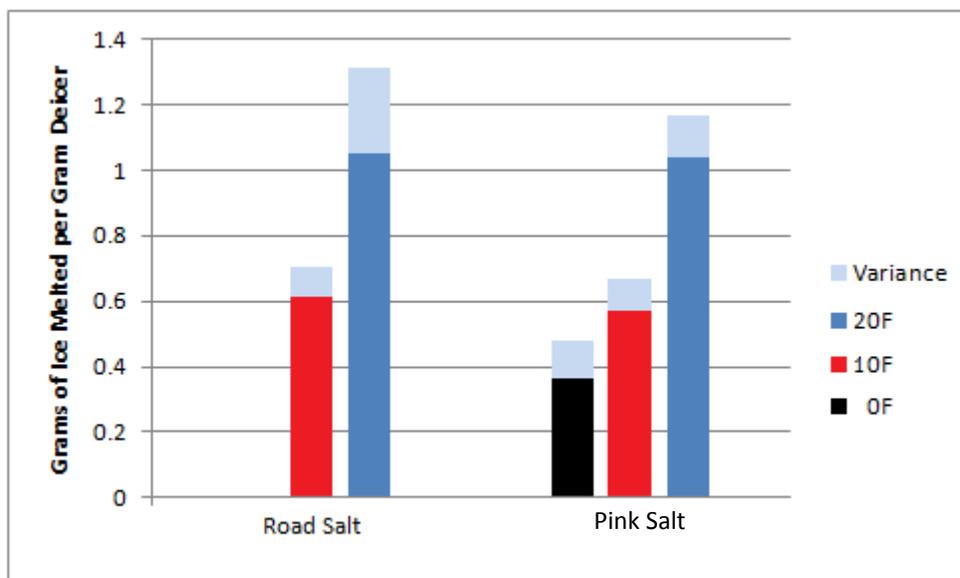


Figure 4.20: Shaker Test Solid Results

Results from the Shaker Test showed the rock salt and the Pink Salt to have almost identical ice melting capacities at 20°F and 10°F. The rock salt did not melt ice at 0°F, but the Pink Salt did. It is unclear if this contrast at 0°F is a result of the different chemical compositions or of the gradation of the Pink Salt. Similar gradations were used for both chemicals, but while larger granules of road salt tend to be solid pieces, the larger granules of Pink Salt tend to be smaller granules pressed together. These granules break apart during the Shaker Test and finer particles make it more effective to melt ice at 0°F.

The results suggest smaller gradations melted ice more quickly than larger gradations. Samples measuring 4 grams with a gradation of 2.38mm (#8 sieve) melted about 0.10 grams of ice more than samples measuring 5 grams with a gradation of 4.75 mm (#4 sieve).

The variances from the solid test results are given in Table 4.3. These variances are higher than those from the liquid results because of the variability of the solid materials.

Deicer	20°F	10°F	0°F
Road Salt	11.06	6.72	NA
Pink Salt	5.97	7.80	14.0

4.2.1.3 Prewet Road Salt Test Results

The results for the prewet road salt are not as consistent as the results for liquids or dry solids. These inconsistencies are most likely caused by the preparation of the deicer samples. For serviceability reasons, the samples of road salt were prewetted by placing them in containers filled with a liquid deicer. The road salt could have stayed soaking in these containers for several days. When the road salt was moved from the prewetting liquid to the shaker, care was taken to leave as much liquid as possible in the container. This resulted in road salt samples coated with an amount of liquid deicer that can be estimated, but cannot be measured with certainty.

A better way to prepare the samples is to take a larger amount of road salt and prewet with the equivalent of 8 gal/ton to mimic wetting at the stockpile. Once prewetting is complete, smaller samples can be used for testing. This was not done because the amount of road salt required was not available.

The results for prewet road salt are shown in Figures 4.21, and 4.22. The standard deviation and variance are presented as a range on top of each bar. The potassium acetate (K Ace) results are not shown in Figure 4.22 because a problem occurred during the prewet process. The potassium acetate reacted with the road salt forming a pudding-like substance shown in Figure 4.23.

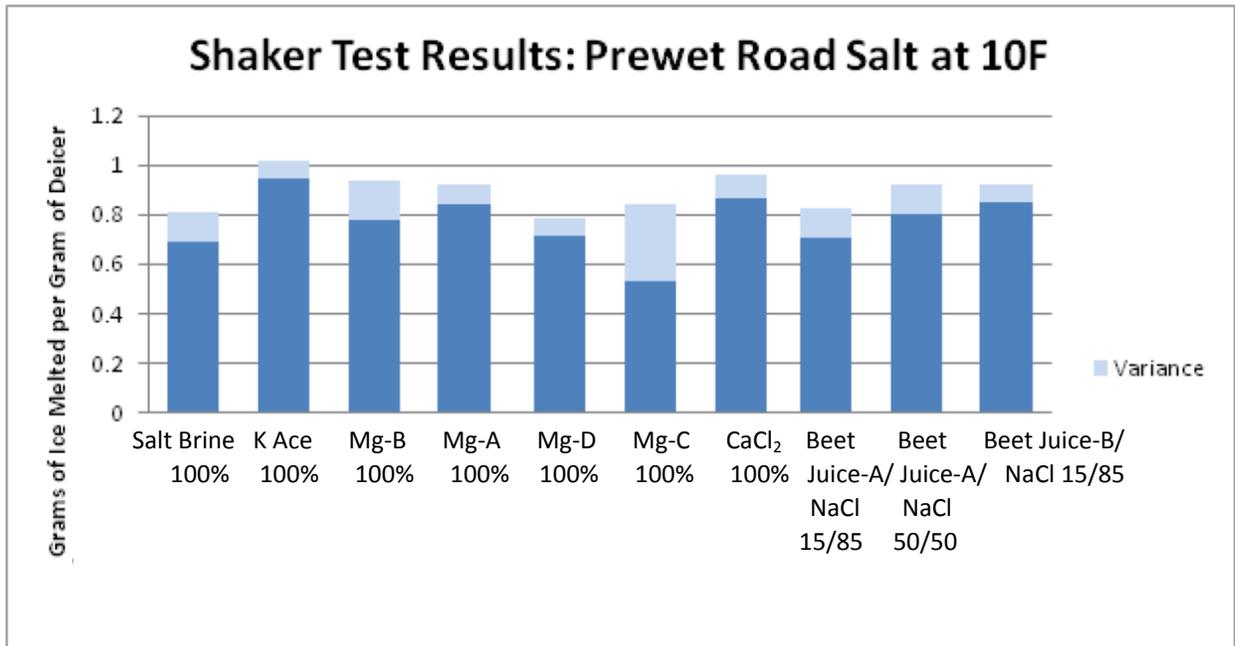


Figure 4.21: Shaker Test Results for Prewet Road Salt at 10°F; each Bar Represents 3 Tests

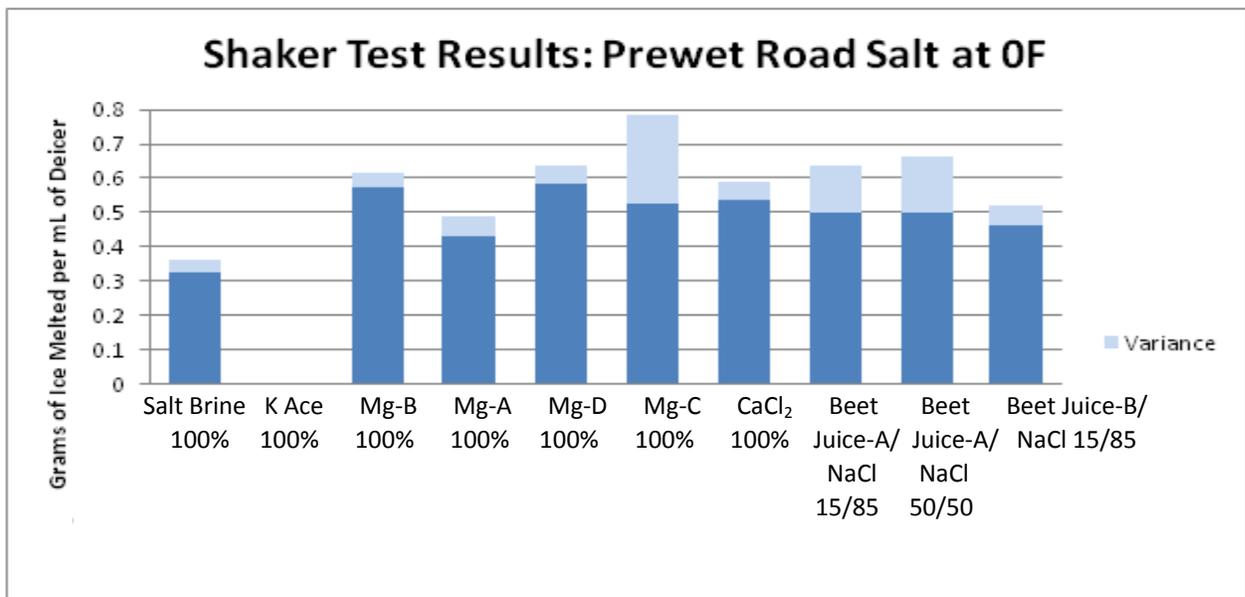


Figure 4.22: Shaker Test Results for Prewet Road Salt at 0°F; each Bar Represents 3 Tests

Beet Juice-A and Beet Juice-B mixes showed different ice melting performance between the prewet results and the liquid results. The data shows those mixes work much better as a prewet than as a straight liquid deicer. The performance of the Beet Juice-A as a

prewet correlates with reports from the field in the State of Nebraska. Specifically, the prewet results for the 50/50 mix of Beet Juice-A/NaCl outperforming the results for the 15/85 mix correlates well with field reports. The performance of Beet Juice-A as a liquid mix does not correlate with field reports, but it does correlate with data collected from the MDSS in the State of Nebraska.

The prewet results at 10°F correlate well with the liquid results except for the Beet Juice-A and Beet Juice-B mixes. The prewet results at 0°F do not correlate well with the liquid results. Specifically, that the Mg-B performed better than the Mg-A is contrary to the liquid results. Mg-C and Mg-D performed better than the Mg-A and the Mg-B, also being contrary to the liquid results.



Figure 4.23:
Potassium Acetate Reacted with Road Salt

The variances from the 19 prewet test results are given in Table 4.4. These variances and test results show the test can produce consistent results for prewet road salt at 10°F, however, further development is needed to improve the results at 0°F.

Table 4.4: Variances in Shaker Test Prewet Results (%)

Deicer	10°F	0°F
Sodium Chloride	7.84	4.71
Potassium Acetate	3.68	NA
Mg-B	9.07	3.36
Mg-A	4.60	6.52
15/85 Beet Juice-A/NaCl	7.63	12.39
50/50 Beet Juice-A/NaCl	6.98	13.89
Mg-D	4.76	4.44
Mg-C	22.55	19.77
Calcium Chloride	5.15	4.44
15/85 Beet Juice-B/NaCl	4.05	6.34

4.2.1.4 Beet Juice Results

Beet Juice-A mix ratios were extensively evaluated at 20°F. The results in Figure 4.24 show that the best results occurred at a ratio of 15/85 Beet Juice-A/NaCl. All other chemical deicers used in this study produced the best results when not mixed with anything. The best results of Beet Juice-A occurred at a ratio of 15/85 because of the stickiness of the material. The Beet Juice-A and Beet Juice-B help the sodium chloride effectively stick to the ice resulting in a greater ice melting capacity. Mixes with a higher ratio of Beet Juice-A or Beet Juice-B do not perform as well because the advantage from the stickiness can no longer compensate for the smaller amount of sodium chloride in the mix.

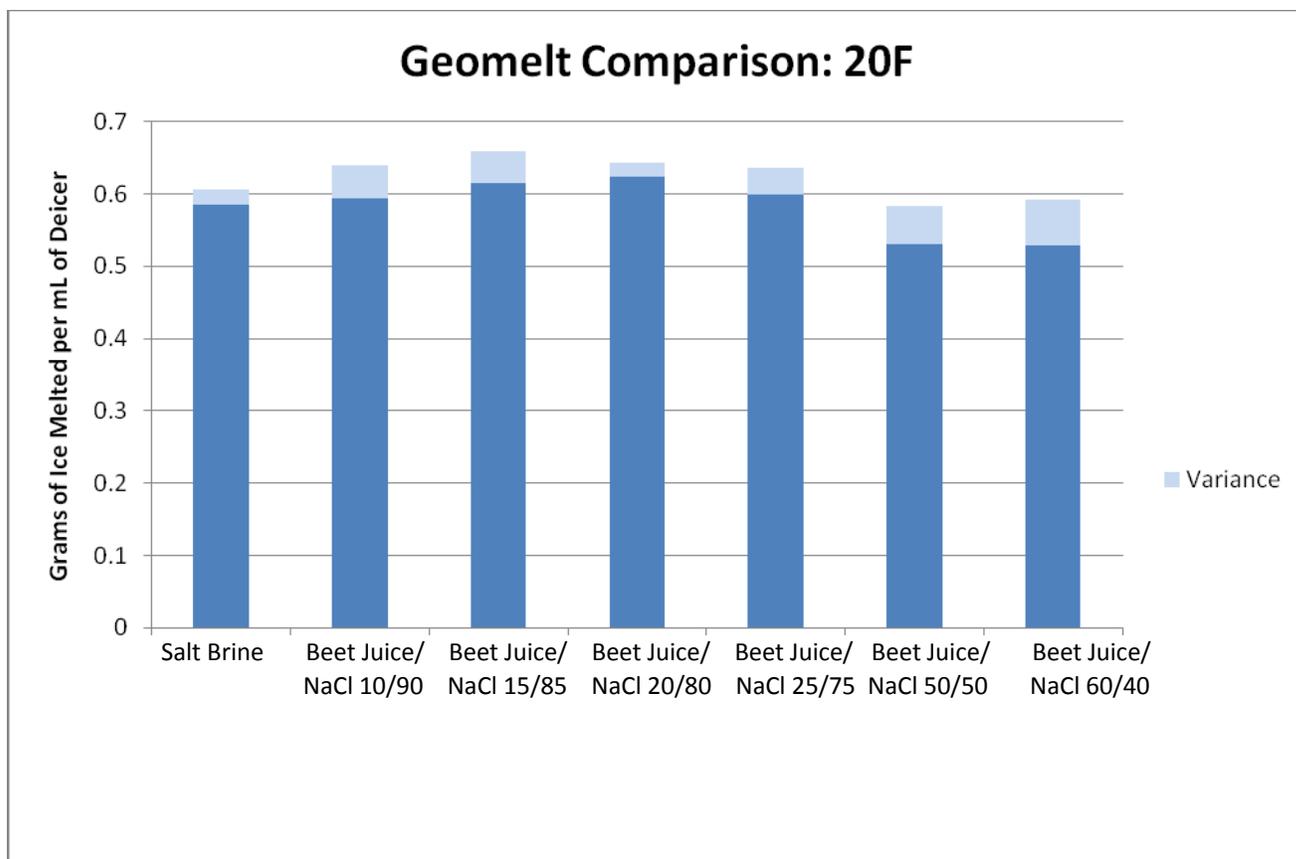


Figure 4.24: Shaker Test Results for Beet Juice-A Mixes at 20°F; Each Bar Represents 3 Tests

4.2.2 Sources of Error

The most significant error that affected the liquid, solid, and prewet road salt results is the size of the ice cubes used for testing. The weight of a group of 10 ice cubes was different from one test to the next. Tests that had very similar ice weights had very small variances. The best way to minimize this error is to measure the water for the ice cubes as accurately as possible and to use the cubes less than 24 hours after freezing.

The higher variances associated with the solid and the prewet road salt results are likely a result of the solids themselves. Some samples of solid deicers, though equal in

weight, may not contain the same amount of sodium chloride material. The angularity of the solid granules may also contribute to the variance.

A source of error unique to the prewet road salt results is the effect of soaking the solids in the prewet. The solids may have absorbed some prewet causing some samples to have more prewet than others. The best way to minimize this error is to use a measured amount of prewet similar to the application rate used in the field.

4.2.3 Test Evaluation

The results of the Shaker Test are promising. Liquid deicers were evaluated extensively at different deicer/NaCl ratios. The liquid and solid deicers produced consistent results with reasonable variances. More types of solids should be used in this test to further confirm the solid results. The results for the prewet road salt were not as consistent at 0°F. The prewet part of this test requires further study using a standardized prewetting procedure.

Limited testing with liquid deicers was performed at an auxiliary location to verify if the results were reproducible. The freezer used at the auxiliary location was part of an upright refrigerator. The freezer at the auxiliary location could not provide a temperature higher than -2°F. The results from the two locations are compared in Figure 4.25.

Sodium chloride did not melt ice at either location. The results for the potassium acetate are very similar. The results for the Mg-B and Mg-C were slightly lower at the auxiliary location, probably due to the lower temperature in the freezer. Overall, the results for these liquids from the different locations are similar. More tests should be performed at different locations to further confirm the repeatability of the Shaker Test.

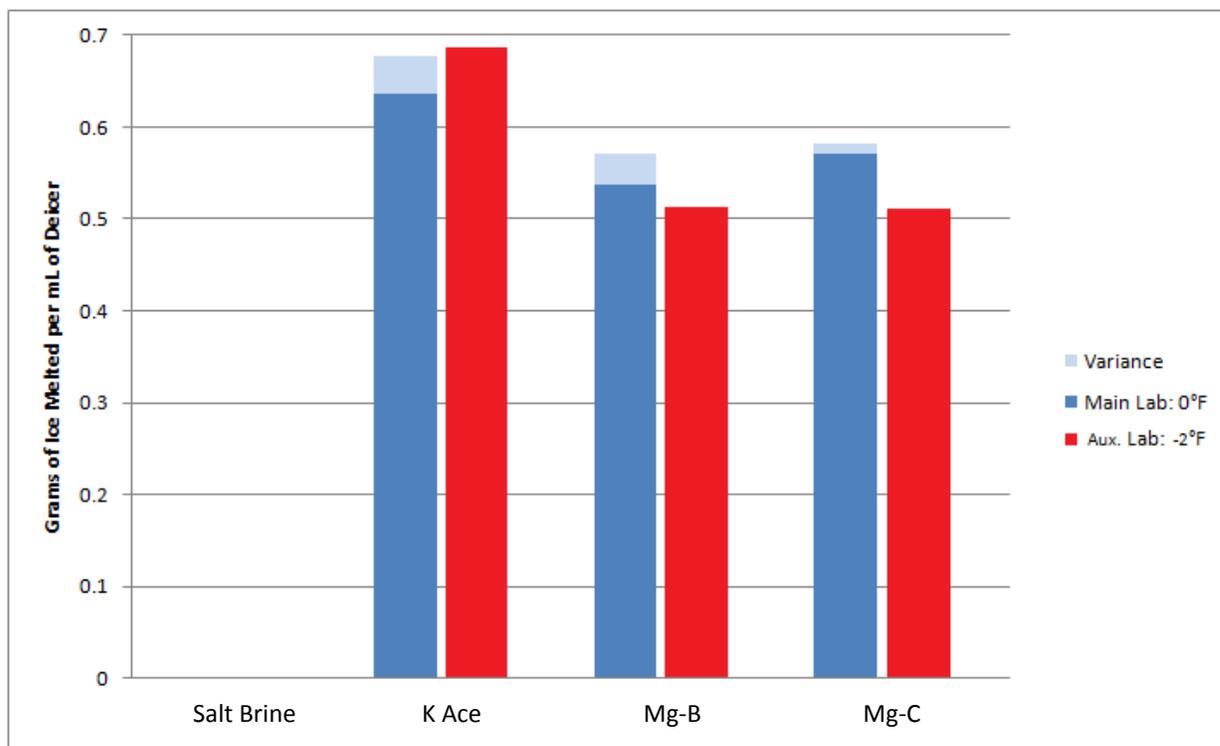


Figure 4.25: Repeatability of Shaker Test using Liquid Deicers

Much of the data from the Shaker Test correlates with reports from the field, observations from the field, and with some of the data from the SHRP Ice Melting Capacity Test. One example is how the magnesium chloride and the IceBan compare to each other in Figure 4.14. Another example is how the calcium chloride, potassium acetate, and the Mg-B compare to each other in Figure 4.15. These results correlate closely with the way how similar liquid deicers performed in the Shaker Test. These results also correlate closely with the way the Mg-C and Mg-D products compare to the other magnesium chloride products from the Shaker Test.

The Shaker Test appears to produce results similar to that of the SHRP Ice Melting Capacity Test without the need of a walk-in freezer. The results from the Shaker Test also appear to correlate better with reports from the field in the State of Nebraska.

4.3 Friction Test

The purpose of this test was to determine if liquid chemical deicers could cause slippery conditions when applied to an ice covered roadway. These tests were done in a walk-in freezer at $20\pm 4^{\circ}\text{F}$. Only liquid deicers were used because the varying shape, size, and hardness of solid deicers would have caused considerable variance in the results.

Figure 4.26 describes how the static and kinetic friction coefficients are determined from the data. No force is applied when the load cell is initially activated. This occurs just before tightening and just after loosening the nut. The applied force will increase as tightening begins. The peak magnitude force occurs when static friction has been reached and the sled has begun to move. The peak force is the value used to calculate the static friction coefficient. The forces gradually decrease after the peak force as the sled is moving. The average of these values is used to calculate the kinetic friction coefficient. The results of the Friction Test are given in Table 4.5. Each value represents the average result of two tests.

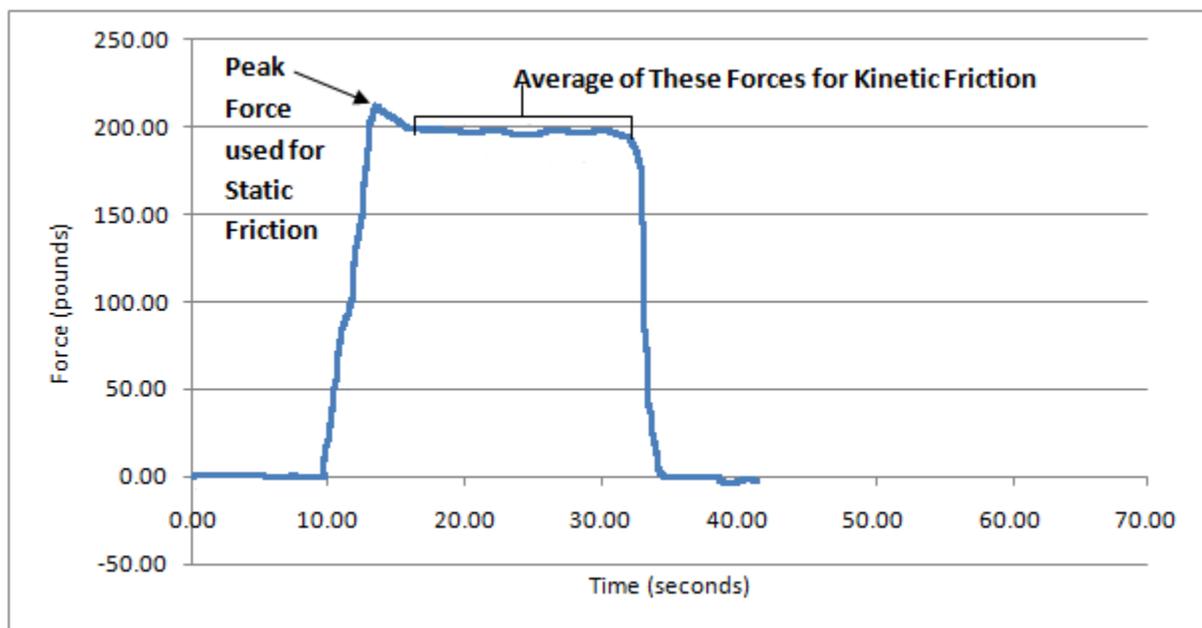


Figure 4.26: Friction Force vs. Time

4.3.1 Test Results

The kinetic friction coefficient for rubber on wet concrete is published in many engineering statics textbooks. The range is slightly lower than the coefficients measured in testing. One probable cause is that the friction in the moving mechanical parts of the test setup could have artificially increased the measured friction coefficients.

Table 4.5: Friction Test Results

	Static Friction Coef. (μ_s)	Kinetic Friction Coef. (μ_k)
Wet Concrete - Researched	--	0.45 - 0.75
Wet Concrete - Measured	0.873 ± 0.017	0.817 ± 0.028
Liquid Deicers: Final Results		
Sodium Chloride	0.755 ± 0.035	0.702 ± 0.022
Potassium Acetate	0.730 ± 0.056	0.654 ± 0.043
Mg-B	0.685 ± 0.007	0.647 ± 0.031
Mg-A	0.845 ± 0.091	0.801 ± 0.067
Beet Juice/NaCl 15/85	0.705 ± 0.021	0.653 ± 0.040
Mg-C	0.805 ± 0.049	0.740 ± 0.049
Mg-D	0.740 ± 0.014	0.702 ± 0.050
Calcium Chloride	0.795 ± 0.007	0.753 ± 0.007

The results for the deicers are generally lower than the measured results for wet concrete. None of the deicers produced slippery pavement conditions. Mg-A performed the best, but also had the largest standard deviation. A mix of 50/50 Beet Juice-A/NaCl was used in testing but produced relatively poor results because the mix was unable to melt all the ice.

The friction test results from Shi et al. (2009) using a tribometer and those from Alger et al. (1994) using a SAAB friction tester are compared with results from this study in Table 4.6. The results from this research compare well with the results from the SAAB friction tester.

Table 4.6: Friction Results Comparison

Deicer	SAAB	Tribometer	Sled (This Research)
Ice	0.3	0.5	0.45
NaCl	NA	0.65	0.702
MgCl₂	0.65	0.5	0.647 (Mg-B)
KAc	0.7	0.55	0.654
MgCl₂	NA	0.2	0.702 (Mg-D)

4.3.2 Sources of Error

The primary source of error in this test was temperature changes. The temperature stayed steady during the test, but could change as much as 8°F between tests. Other sources include the friction that exists in the moving mechanical parts and the human error from turning the nut.

The friction between the moving parts was probably consistent in all the tests because the parts were well greased. This would still cause the deviation from the known values shown in Table 4.5. The human error could be minimized by using an air ratchet or other mechanism to turn the nut.

4.3.3 Test Evaluation

This version of the friction test has a complicated procedure and requires a walk-in freezer. It may be more prudent to test a liquid deicer for potential fermentation, which can produce slippery roadways. The easiest way to test for fermentation is to smell the liquid deicer. If a product is suspected to cause slippery roadways without fermentation, it would be more practical to use a British Pendulum Tester to confirm the friction coefficient. The British Pendulum Tester is described in Chapter 2-Literature Review. It has a simpler procedure, does not require electricity, and is designed for use in the field.

4.4 Sunlight Test

The purpose of this test was to confirm that the darker color of the Beet Juice and the solid Pink Salt would enhance ice melting when exposed to direct sunlight. A typical result is shown in Figure 4.27. The test was performed at 15°F and the photos illustrate the effects of the deicers after 60 minutes. The labels along the side indicate the solid deicer used in that row. The labels along the top represent the liquid deicer used in that column. The areas of melted ice are circled in red.

The 50/50 mixes are darker than the 85/15 mixes. The shaded results do not show any obvious differences between melted areas. The sunlit results show the melted area of the 50/50 mix + road salt is larger than that of the 85/15 mix + road salt. The sunlit results also show the melted area of the 85/15 mix + Pink Salt is larger than that of the 85/15 mix + road salt. These results were consistent with the results from another Sunlight Test performed at 20°F.

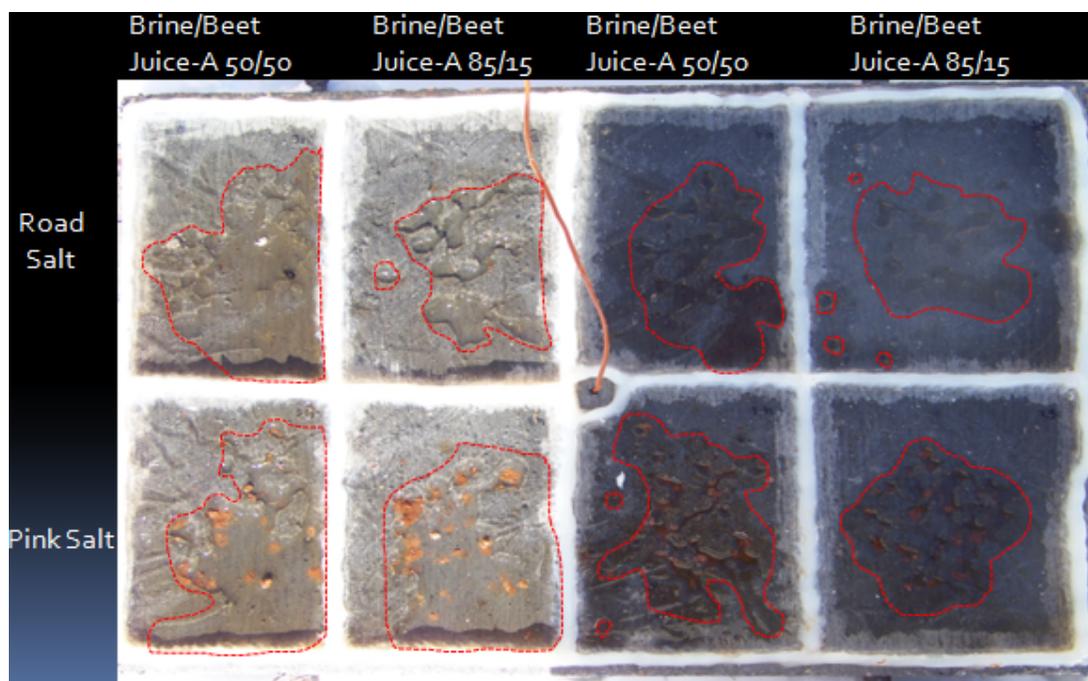


Figure 4.27:
Sunlight Test
Results

4.5 Refreeze Test

The purpose of the refreeze test was to determine the time elapsed between the applications and refreezing for particular deicers. A sample of deicer is applied on an ice sheet for a period of time. The resulting liquids are decanted from the ice surface for measurement and then returned to the ice surface to continue testing. As the liquids begin to refreeze, less liquid is able to be decanted and measured. This test can be used for liquid deicers and solid deicers. Prewet solid deicers were used for testing, but did not yield useful results.

4.5.1 Test Results

The same 9 deicers and mix ratios that were used in the Shaker Test were used in the Refreeze Test. The temperature during the tests was $14 \pm 2^\circ\text{F}$. Three tests were performed for each deicer. The graphs of the Refreeze Test results are compiled in Appendix A.

4.5.1.1 Liquid Test Results

The results for the beet juice, 2 examples of magnesium chloride, and calcium chloride are shown in Figures 4.28, 4.29, and 4.30. The percentage in each figure's caption represents the amount deicer is present in the deicer/salt brine mix. For example, a caption "Beet Juice-B 15%" indicates a 15/85 mix of Beet Juice-B/salt brine. The data labeled "1st Test" does not have a data point for 2 hours.

The results from three tests are presented in one graph and evaluated visually. It is essential to look for the time instant where the peak amount of liquid was collected. The refreeze time is estimated from the gradual decrease in the amount of liquid versus time.

Most of these results indicate the liquids begin to refreeze after 2 to 3 hours. These results confirm the recommendation from Blackburn et al. (2004) to retreat areas every 1 ½ hours when using liquids below 20°F. This result holds true for all the liquid deicers except for calcium chloride. The results for 100% calcium chloride do not clearly indicate a point of refreeze in the 5-hour test period. This means calcium chloride has a refreeze time as long as 5 hours, much longer than the other deicers used in this test.

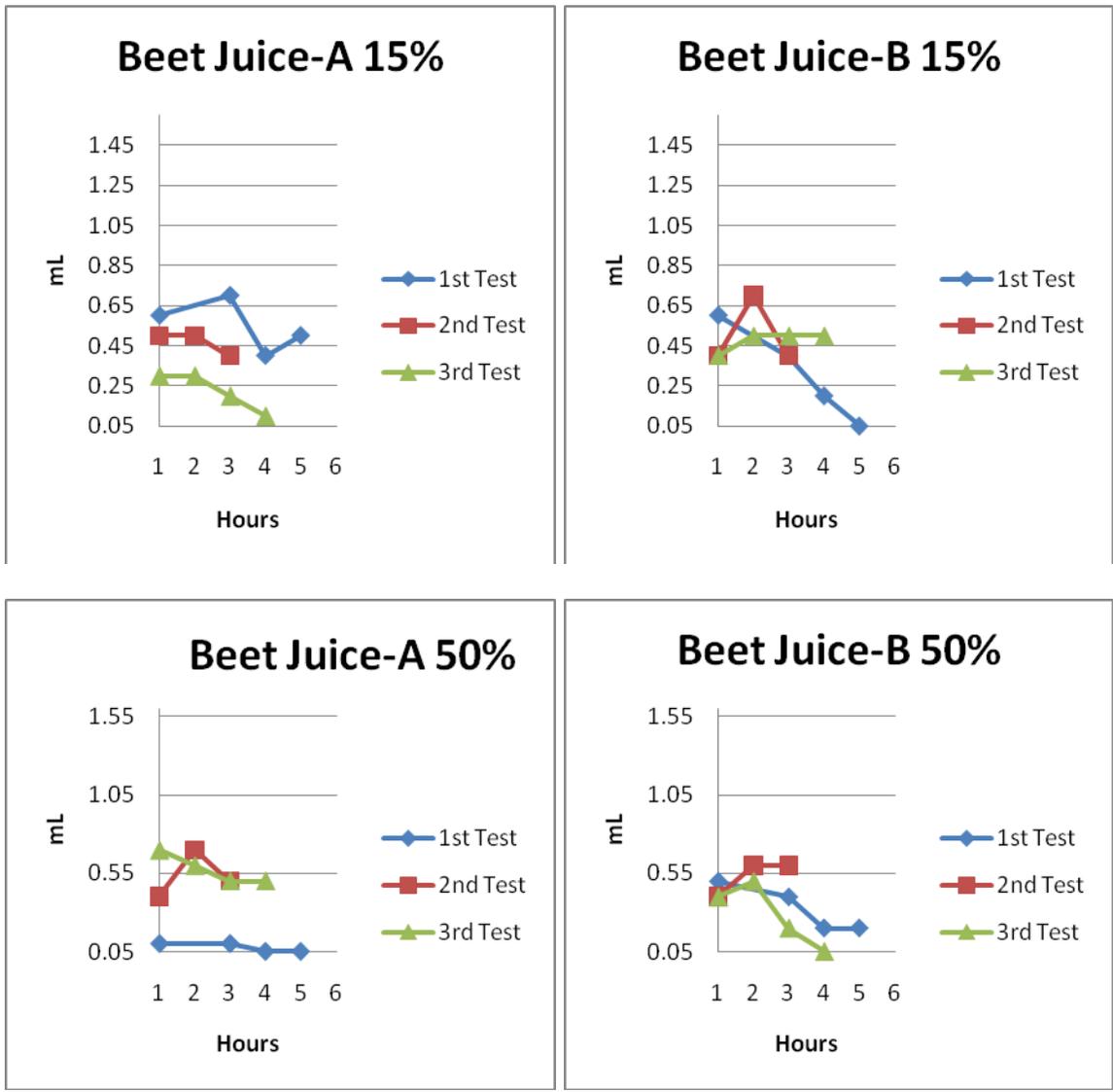


Figure 4.28: Refreeze Test Results for Agricultural Byproduct or “Beet Juice” Deicers

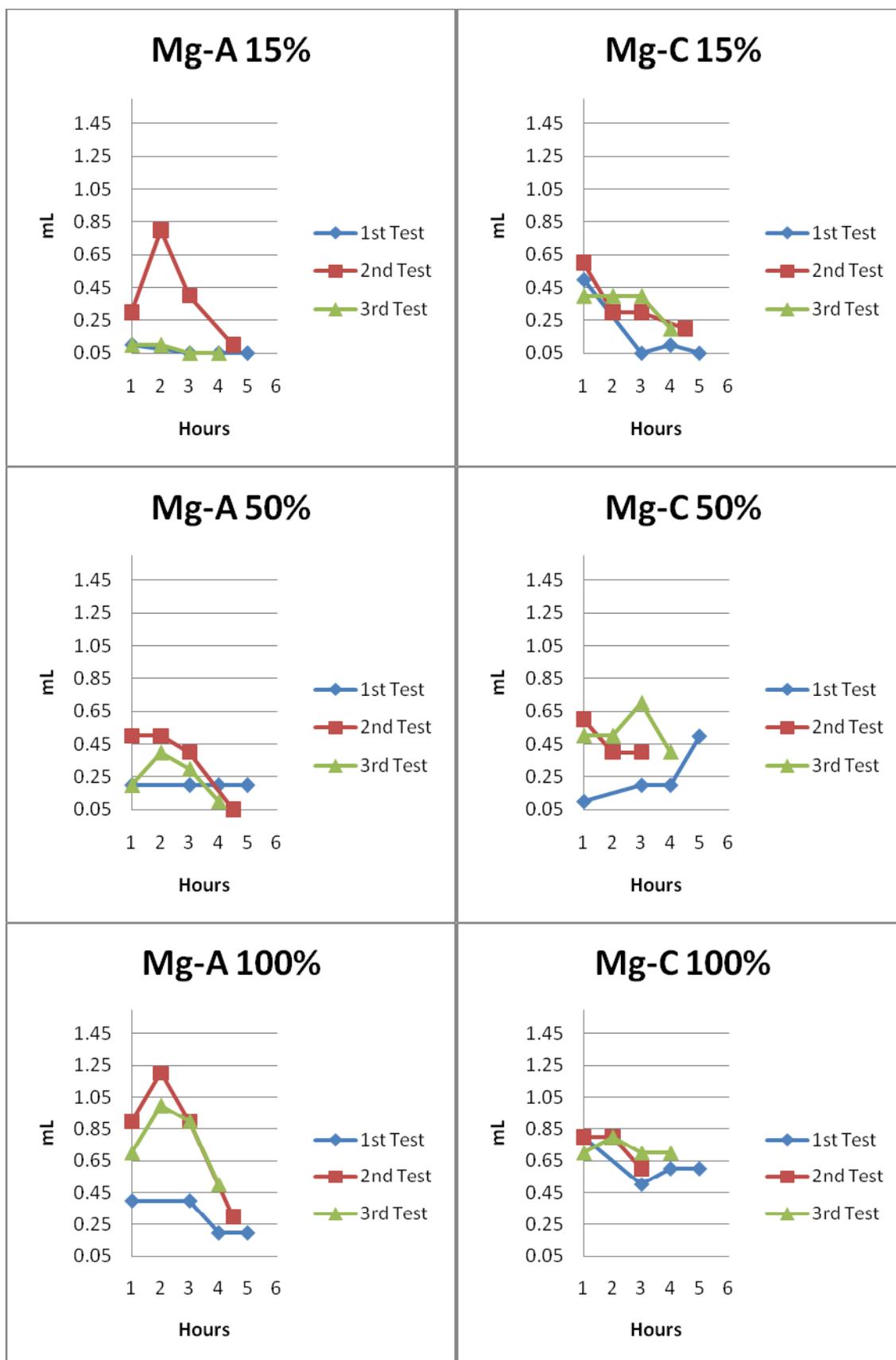
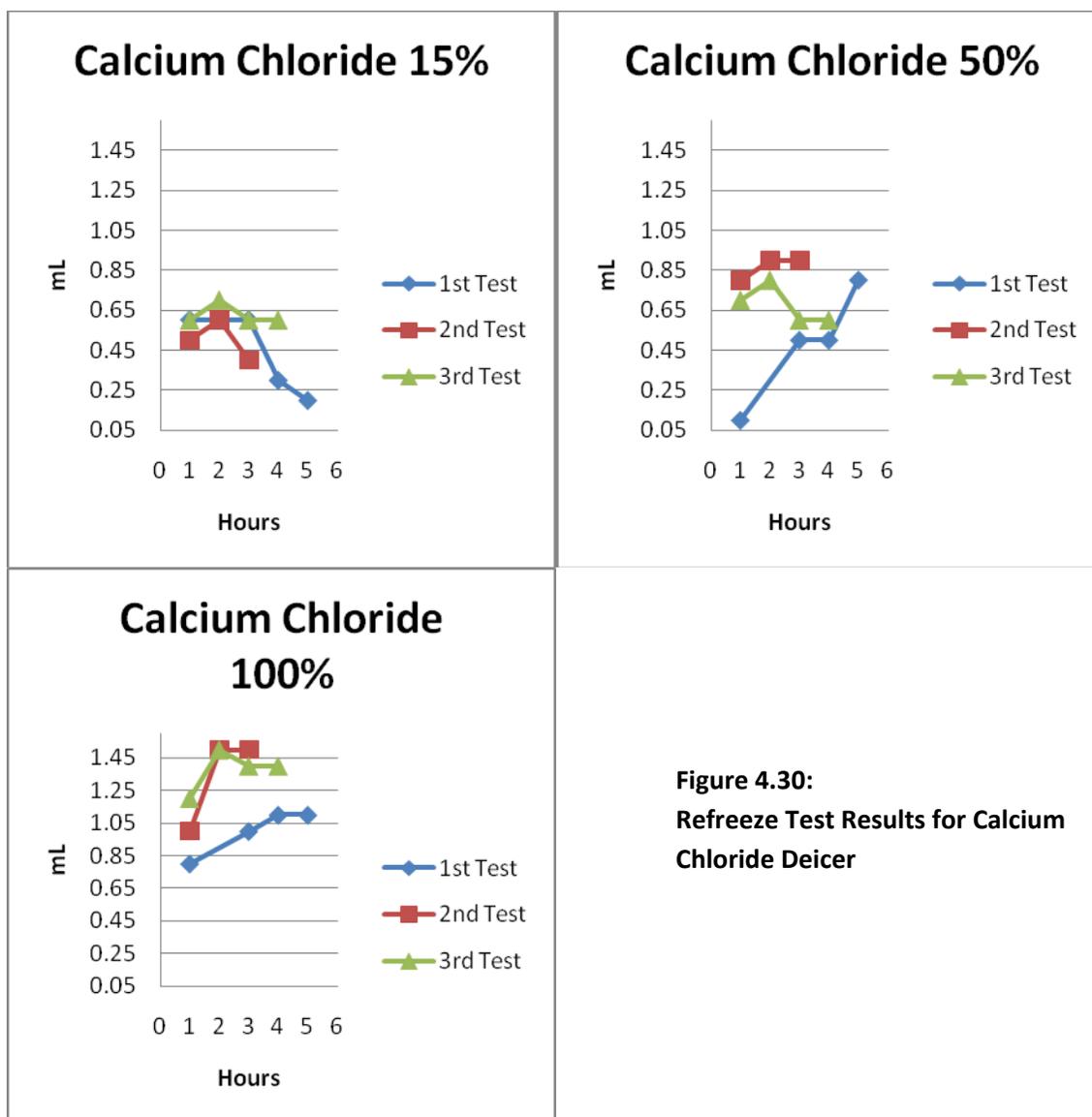


Figure 4.29: Refreeze Test Results for Magnesium Chloride Deicers



4.5.1.2 Solid Test Results

Road salt and Pink Salt were the solid deicers used in the Refreeze Test. They were each used at 3 different gradations: 0.422 mm (#40 sieve), 0.841 mm (#20 sieve), and 2.38 mm (#8 sieve). The particle size is indicated on the graphs shown in Figure 4.31.

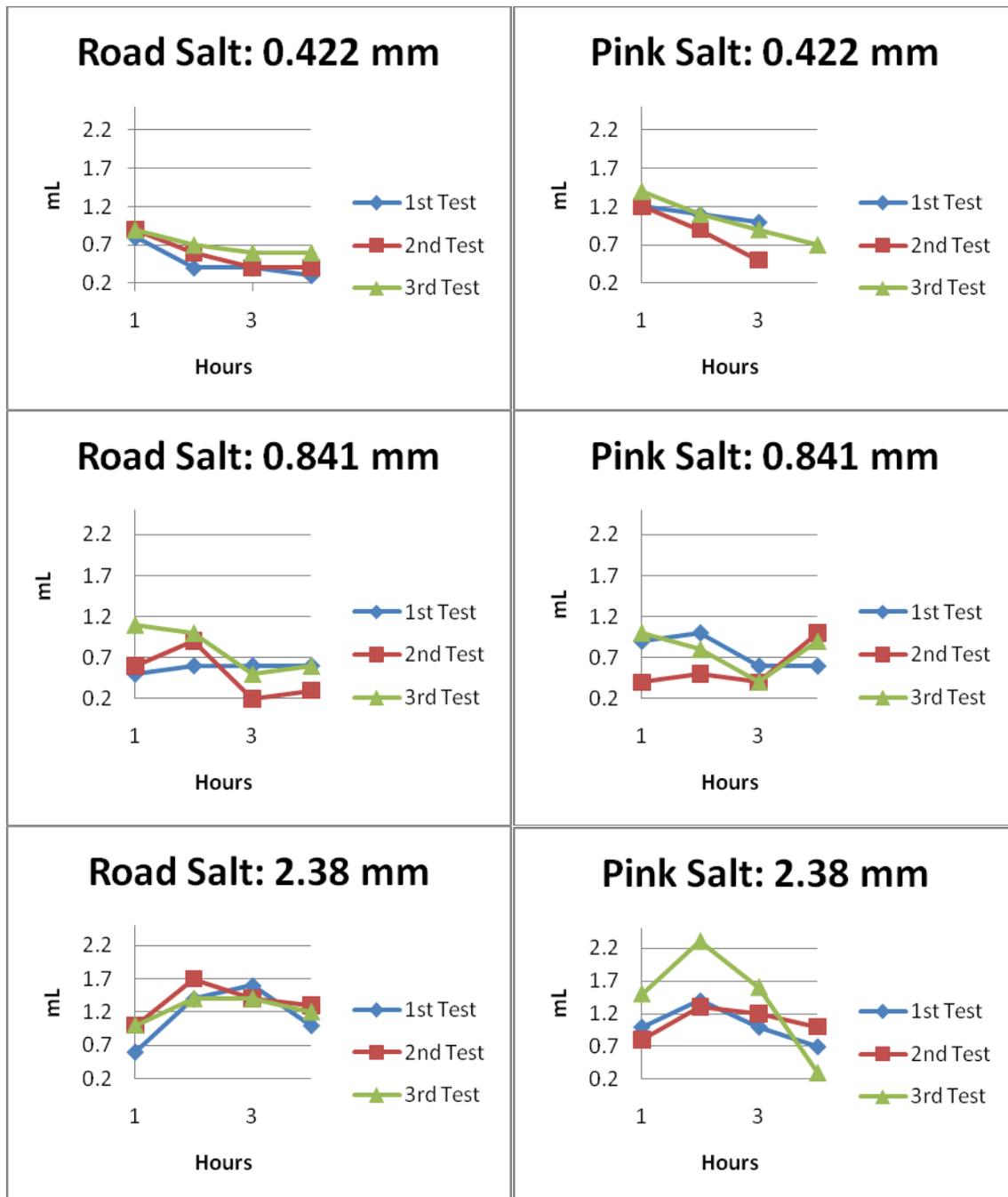


Figure 4.31: Refreeze Test Results for Solid Deicers

The results from the refreeze test show the road salt and Pink Salt have almost identical refreeze profiles at all three different gradation sizes. The results from the refreeze test also showed the gradation size has a significant effect on the refreeze time. Samples with

gradations smaller than 0.422 mm (#40 sieve) began to refreeze almost immediately.

Samples with a larger gradation of about 2.38 mm (#8 sieve) began to refreeze after two hours. The samples with a 0.841 mm (#20 sieve) gradation appear to be refreezing at 2 hours, but begin to rebound at 4 hours. This could be due to the solids begun to dissolve into smaller particles and then dispersed more evenly onto the ice.

4.5.2 Sources of Error

The primary source of error is from the liquid measurements. It was easy to misread the measurements by ± 0.1 mL. A way to eliminate this error would be to use smaller syringes, say 2.0 mL, for the liquid measurements. Other errors include conditions inside the freezer. The inconsistent temperature and humidity between tests is probably what caused much of the variation. Those errors did not exist for the solid deicer results because they were all performed at the same time.

4.5.3 Test Evaluation

The Refreeze Test did not produce completely consistent results, but was functional enough to discover some interesting information about calcium chloride and the gradation of solid deicers. It is a lengthy test, but much of that time is spent waiting for the ice to melt. Although the Refreeze Test was performed in a walk-in freezer for this project, the test could be adapted for use in a smaller freezer. The refreeze test shows the potential to become a cost-effective screening test for deicers, but further development to produce consistent results is necessary.

Chapter 5

Field Data Results and Correlation

The field data was collected by plow trucks equipped with Automatic Vehicle Location Systems (AVL) along with the Maintenance Decision Support System (MDSS) managed by Meridian Environmental Technology. The systems record real time information including vehicle location, amount of material being used per lane-mile, and pictures of the roadway condition taken from the cab of the truck. The MDSS collects weather data for specific routes from different weather stations across several states. Important weather data includes air temperature, roadway temperature, wind speed, type and amount of precipitation, and pictures from roadside cameras. This data is used to classify different storms and to decide roadway maintenance actions.

The maintenance actions performed and results during the storms are analyzed and, if possible, compared to different maintenance actions performed and results in similar storms. Different storms are grouped by temperature, wind speed, and type of precipitation. An analysis consists of confirming the type and amount of chemical deicer used on a particular route and looking at the pictures from the cab to see how treatment affected the level of service on that roadway.

A particular route must meet a certain criteria before it can be analyzed. The route can only have one truck treating the roadway, since not all trucks are equipped with AVL. There must be several good pictures from the route, either from the cab or a stationary roadside camera. At the moment, only the storms during daylight hours are used because the quality of

the pictures taken at night has been poor. The storm has to be severe enough to warrant using deicing material.

A rating system was developed to measure the changes in the level of service of the roadway. The rating system is completely governed by what can be seen from the pictures, therefore, the system does not include changes in ice cover. Table 5.1 defines the rating system used to process the pictures from the field. Very often a roadway with multiple lanes will have different levels of service in different lanes. Therefore, this rating system is a subjective measure due to the lack of a more precise methodology.

Table 5.1: Rating System for Roadway Level of Service	
Description	Picture
<p><u>Clear</u></p> <ul style="list-style-type: none"> • Can See Inner and Outer Lines • Very Little Snow on Roadway • Snow will not cause Traffic Issues 	
<p><u>25% Covered</u></p> <ul style="list-style-type: none"> • Can See 2 or more Wheel Tracks • Can See 1 or more Lines • Snow may cause some Slowdown 	

<p><u>50% Covered</u></p> <ul style="list-style-type: none">• Can See 2 Wheel Tracks• Cannot See Lines• Snow will cause Difficulty when Changing Lanes	
<p><u>75% Covered</u></p> <ul style="list-style-type: none">• Can See Some of the Dark Colored Roadway• Cannot See 2 Defined, Continuous Wheel Tracks	
<p><u>100% Covered</u></p> <ul style="list-style-type: none">• Cannot See the Roadway	

Table 5.2: Mg-A and Beet Juice-A Comparison

	7:05am	Time	6:15am	
	Mg-A 60 gal/ln-mi	Deicer App. Rate	30/70 Beet Juice-A/NaCl 50 gal/ln-mi	
	1.4in Snow	Cumulative Precipitation	0.5in Snow	
	2°F	Air Temp.	15°F	
	7°F	Road Temp	21°F	
	10mph	Winds	11mph	
	02/24/11	Date	01/19/11	
	US-26	Location	US-385	
	1:35pm	Time	1:06pm	
	Mg-A 180 gal/ln-mi	Deicer App. Rate	30/70 Beet Juice-A/NaCl 300 gal/ln-mi	
	1.9in Snow	Cumulative Precipitation	1.0in Snow	
	7°F	Air Temp.	14°F	
	16°F	Road Temp	20°F	
	11mph	Winds	11mph	
	02/24/11	Date	01/19/11	
	US-26	Location	US-385	

Table 5.2 is a comparison of the Mg-A deicer (left) and a 30/70 mix of Beet Juice-A/NaCl (right). The pictures on the left were taken by a stationary camera. The pictures on the right were taken by a plow truck near the same location marked by the motel sign in both pictures.

This comparison shows the Mg-A transforming the roadway from 100% covered to 0-25% covered in 6 ½ hours. The Beet Juice mix does not appear to have melted snow after about 7 hours. The roadway treated by the Mg-A had an average daily traffic (ADT) count of 4996 for the month of February, much busier than the roadway treated by the Beet Juice mix which had an ADT count of 1735 for the month of January. Hence, traffic may have played an important role. The weather seen in the pictures of the Beet Juice treatment is more overcast than that seen in the pictures of the Mg-A treatment. Nevertheless, this comparison shows that Mg-A significantly outperformed the 30/70 Beet Juice/NaCl at lower temperatures and with more snow. The results correlate with the performance comparison between the two deicers from the Shaker Test.

Table 5.3: Beet Juice-A Comparison

	8:14am	Time	10:32am	
	30/70 Beet Juice-A/ NaCl 340 gal/ln-mi	Deicer App. Rate	30/70 Beet Juice-A/ NaCl 340 gal/ln-mi	
	1.1in Snow	Cumulative Precipitation	1.1in Snow	
	5°F	Air Temp.	9°F	
	10°F	Road Temp	14°F	
	11mph	Winds	7mph	
	01/20/11	Date	01/20/11	
	US-385	Location	US-385	

Table 5.4: Road Salt Comparison: High Winds

	1:06p	Time	2:17p	
	Road Salt 141 lbs/ln-mi	Deicer App. Rate	Road Salt 241 lbs/ln-mi	
	2.3in Snow	Cumulative Precipitation	2.6in Snow	
	14°F	Air Temp.	12°F	
	15°F	Road Temp	14°F	
	25mph	Winds	27mph	
	02/01/11	Date	02/01/11	
	Hwy-34	Location	Hwy-34	

Table 5.3 is a comparison of the 30/70 Beet Juice-A/NaCl just before daylight (left) and on a sunny day about 2 hours later (right). The pictures are not taken at exactly the same location, but they are within 2 to 3 miles from each other. The pictures in Table 5.3 are also within 10 miles of the pictures from the previous day shown in Table 5.2 on the right.

The pictures from Table 5.2 and from the left in Table 5.3 show limited snow melting was made by the deicer mix when there was little daylight; the roadway went from 100% covered to 75-100% covered. The picture on the right in Table 5.3 show significant melting after 2 hours of direct sunlight, even though the temperature was lower than the previous day. These comparisons suggest direct sunlight can enhance the ice melting capacity of the 30/70 Beet Juice/NaCl mix, which has dark color to absorb heat from solar radiation.

Table 5.4 demonstrates how significant winds can affect the treatment process. These pictures were taken by a plow truck near the same location marked by the trees that can be seen in the top right corners of both pictures. The right lane shows little improvement after 71 minutes, but the level of service of the left lane has deteriorated. The road salt is not effective because of the wind and the melting may cause more snow to stick to the roadway. This data confirms the findings from Blackburn et al. (2004), Ketcham et al. (1996), and CTC & Associates LLC (2009) that wind speeds above 15 mph could inhibit winter maintenance operations.

Table 5.5: 10/90 Beet Juice-A/NaCl Mix: High Winds

	Time	8:34am
	Date	01/31/11
	Deicer App. Rate	10/90 Beet Juice-A/NaCl 70gal/ln-mi
	Cumulative Precipitation	0.1in Frost
	Air Temp.	16°F
	Road Temp	18°F
	Winds	11mph
	Location	Hwy-275
	Time	3:23pm
	Date	01/31/11
	Deicer App. Rate	10/90 Beet Juice-A/NaCl 140gal/ln-mi
	Cumulative Precipitation	0.5in Snow
	Air Temp.	9°F
	Road Temp	12°F
	Winds	22mph
	Location	Hwy-275
	Time	11:08am
	Date	02/01/11
	Deicer App. Rate	10/90 Beet Juice-A/NaCl 140gal/ln-mi
	Cumulative Precipitation	2.1in Snow
	Air Temp.	3°F
	Road Temp	8°F
	Winds	22mph
	Location	Hwy-275
	Time	9:56am
	Date	02/02/11
	Deicer App. Rate	10/90 Beet Juice-A/NaCl 140gal/ln-mi
	Cumulative Precipitation	2.6in Snow
	Air Temp.	0°F
	Road Temp	8°F
	Winds	17mph
	Location	Hwy-275

Table 5.5 is a comparison of the 10/90 Beet Juice-A/NaCl over a 3-day period. The top 3 pictures were taken at the same location **marked by the tree line in the pictures**. The picture at the bottom was not taken at the same location but within 2 to 3 miles from the others. The top picture was taken at 8:34am, the beginning of the observation. It shows a blurry but clear road. The roadway was reported to have a thin layer of frost and a wind speed of 11mph. The Beet Juice-A/NaCl mix was used to treat the frost.

By 3:23pm, a 1/2-inch of snow has fallen and the wind speed has increased to 22mph. The picture shows snow blowing across and sticking to the roadway. Snow sticking to the roadway at this wind speed means the roadway was still wet from the earlier treatment and was detrimental to the roadway's level of service.

At 11:08am the next day, a total of 2.1 inches of snow had fallen and roadway was reportedly clear. The picture shows the snow blowing across the roadway but was not sticking to the roadway. The roadway dried out sometime between 7 and 14 hours after the application, even with continuous precipitation. It is possible that the high wind had played a role in drying the roadway.

At 9:58am on the third day, the storm was over and the roadway was clear and appeared to be dry. The roadway was at the best level of service because the wind kept snow from accumulating on the road and the maintenance crews were able to keep snow drifts under control. The results from Table 5.5 contrast with the results from Table 5.4 because far less ice melting materials were used on the roadway in Table 5.5 than the roadway in Table 5.4. This comparison indicates using deicers during a blowing snow scenario can cause snow to stick to the roadway and result in a lower level of

service (Blackburn et al., 2004; Ketcham et al., 1996; CTC & Associates LLC, 2009).

Table 5.6: Liquid Sodium Chloride Comparison at Low Temperatures		
	Time	8:08am
	Date	01/23/11
	Deicer App. Rate	NaCl 150gal/ln-mi
	Cumulative Precipitation	2.7in Snow
	Air Temp.	-9°F
	Road Temp	0°F
	Winds	5mph
	Location	Hwy-275
	Time	9:47am
	Date	01/23/11
	Deicer App. Rate	NaCl 200gal/ln-mi
	Cumulative Precipitation	2.7in Snow
	Air Temp.	-9°F
	Road Temp	3°F
	Winds	3mph
	Location	Hwy-275
	Time	12:02pm
	Date	01/23/11
	Deicer App. Rate	NaCl 300gal/ln-mi
	Cumulative Precipitation	2.7in Snow
	Air Temp.	-3°F
	Road Temp	18°F
	Winds	4mph
	Location	Hwy-275
	Time	1:23pm
	Date	01/23/11
	Deicer App. Rate	NaCl 350gal/ln-mi
	Cumulative Precipitation	2.7in Snow
	Air Temp.	-1°F
	Road Temp	20°F
	Winds	5mph
	Location	Hwy-275

Table 5.6 is a comparison of the liquid sodium chloride over a single day. The top 2 pictures are taken at the same location. The bottom 2 pictures were not taken at the same location, but are within 2 to 3 miles of the others. All the snow fell the previous evening and there is no precipitation during the observation.

The plow began working on this route at 4:30am, so at 8:08am when the top picture was taken, the roadway has been exposed to the sodium chloride for 3 ½ hours and was still 100% covered. This observation correlates with data from the Shaker Test that shows liquid sodium chloride melting little to no ice at 0°F.

At 9:47am, the roadway has gone from 100% covered to 75%-100% covered. The liquid sodium chloride has made little progress after 99 minutes of further treatment even with total application of 200 gal/lane-mile. This observation correlates with the rule-of-thumb that sodium chloride does not work well at temperatures lower than 18°F.

The roadway temperature begins to rise quickly between 11am and 12pm because of sunlight exposure. At 12:02pm, the roadway temperature is 18°F and the roadway has gone from 75%-100% covered to 50% covered. 81 minutes later, at 1:23pm, the roadway is almost clear. This observation also correlates with the 18°F rule-of-thumb mentioned above.

Table 5.7: Liquid Sodium Chloride Comparison

	12:47p	Time	3:18p	
	NaCl 44gal/In- mi	Deicer App. Rate	NaCl 44gal/In- mi	
	0.3in Snow	Cumulative Precipitation	0.4in Snow	
	25°F	Air Temp.	25°F	
	25°F	Road Temp	25°F	
	13mph	Winds	15mph	
	02/24/11	Date	02/24/11	
	US-6	Location	US-6	

Table 5.8: Road Salt Prewet with 5gal/ton MgCl₂ Comparison

	8:09am	Time	10:47am	
	None	Deicer App. Rate	NaCl 200lbs/In- mi	
	0.5in Snow	Cumulative Precipitation	0.9in Snow	
	18°F	Air Temp.	20°F	
	20°F	Road Temp	23°F	
	9mph	Winds	11mph	
	01/09/11	Date	01/09/11	
	Hwy 2	Location	Hwy 2	

Table 5.7 is a before and after comparison of liquid sodium chloride. The pictures are not taken at exactly the same location, but they are within 2 to 3 miles from each other. Less than ½-inch of snow falls from this storm, but wind speeds are at or just below 15mph, the speed indicated by Blackburn et al. (2004), Ketcham et al. (1996), and CTC & Associates LLC (2009) that begins to cause problems with blowing snow.

The roadway condition went from 25%-50% covered to clear in 2-1/2 hours. It demonstrates how effective liquid sodium chloride can be at 25°F, even with 15mph wind. The wind speed at or below 15mph did not cause problems with blowing snow, however, there was little snowfall in this storm.

Table 5.8 is a before and after comparison of road salt prewet with 5gal/ton of MgCl₂. The pictures were taken from the plow truck at the same location. The roadway condition went from 100% covered to 25%-50% covered in about 2-1/2 hours. The lane shown in the pictures was a turning lane, which means it was very likely the snow on that lane had been compacted. This comparison shows how effective the solid deicer was at penetrating snowpack, but an observation with a liquid deicer on snowpack is also needed for confirmation.

Table 5.9: A Storm producing High Volume of Snow		
	Time	5:19 pm
	Date	01/09/11
	Deicer App. Rate	NaCl 150 gal/lb-mi
	Cumulative Precipitation	3.5 in. Snow
	Air Temp.	20°F
	Road Temp	20°F
	Winds	13 mph
	Location	Hwy-32
	Time	9:17am
	Date	01/10/11
	Deicer App. Rate	No Application Since the 9 th
	Cumulative Precipitation	8.3 in. Snow
	Air Temp.	21°F
	Road Temp	18°F
	Winds	6 mph
	Location	Hwy-32
	Time	4:09 pm
	Date	01/10/11
	Deicer App. Rate	No Application Since the 9 th
	Cumulative Precipitation	9.1 in. Snow
	Air Temp.	23°F
	Road Temp	20°F
	Winds	12 mph
	Location	Hwy-32
	Time	9:24am
	Date	01/11/11
	Deicer App. Rate	No Application Since the 9 th
	Cumulative Precipitation	10.0 in. Snow
	Air Temp.	4°F
	Road Temp	4°F
	Winds	15 mph
	Location	Hwy-32

Table 5.9 is an observation of the methods used to remove high volumes of snow from the roadway. The pictures were taken at different locations within 2 to 3 miles of each other along the route. The storm produced 10 inches of snow with 6.5 inches falling throughout the observation. A total of 150 gal/lane-mile of liquid sodium chloride had been applied on the roadway the morning of January 9th, before the observation was made. Most of the snow fell between 5:00 pm January 9th and 12:00 pm January 10th. The sodium chloride was probably diluted by the snow to render ineffective.

The pictures taken at 9:17 am and 4:09 pm on January 10th showed the roadway going from 100% covered to near 50% covered just with plowing the roadway. The picture taken the next day at 9:24 am still shows the roadway to be about 50% covered. This observation shows that plowing can improve the level of service of a roadway from 100% covered to 50% covered, but does not facilitate further improvement. Once part of the pavement is exposed, direct sunlight can heat the pavement and melt the rest of the snow on the roadway. In this case, direct sunlight was not available at the critical point on January 10th when the snow stopped at 12:00 pm and before high wind started at about 5:00 pm. Additional deicing chemical could have been applied during this timeframe to clear the roadway.

Winter 2010 was the first season the Nebraska Department of Roads used the AVL and the MDSS to record field data. The system did very well at recording vehicle location and weather data, but data were missing regarding the type and amount of deicer used during an event. As a result, large amounts of MDSS data could not be used for the correlation studies. To address this issue in future operations, the districts should document the deicers' usage and the application rate manually as a backup for the AVL and MDSS data.

Chapter 6

Conclusions and Recommendations

This chapter summarizes the essential findings and proposed practices for each chemical deicer studied. Table 6.1 shows the results of the Shaker Test for the liquid chemical deicers used in this research. The numbers shown for each chemical at 20°F, 10°F, and 0°F are the grams of ice melted per milliliter of deicer. The best way to use these results is to compare the deicers to each other. The table is only showing the results for the 15/85 optimum ratios for Beet Juice-A and Beet Juice-B. Results for the solid chemical deicers will be discussed separately.

Table 6.1: Shaker Test Results for Liquids (Grams of Ice Melted per mL of Deicer)

Product	Chemical Base	20°F	10°F	0°F
Mg-A	29% Magnesium Chloride	1.065	0.91	0.667
Calcium Chloride	30% Calcium Chloride and “Beet Juice” Byproduct	1.051	0.898	0.704
Potassium Acetate	49% Potassium Acetate	1.405	0.868	0.656
Mg-B	30% Magnesium Chloride	1.062	0.781	0.553
Mg-C	26.9% Magnesium Chloride and Carbohydrate Byproduct	0.978	0.736	0.577
Mg-D	25% Magnesium Chloride and Carbohydrate Byproduct	0.969	0.675	0.546
Beet Juice-B/NaCl 15/85	15/85 Mix of “Beet Juice” Byproduct/23% NaCl	0.652	0.359	0.0
Beet Juice-A/NaCl 15/85	15/85 Mix of “Beet Juice” Byproduct/23% NaCl	0.636	0.326	0.0
Sodium Chloride	23% Sodium Chloride	0.595	0.302	0.0

6.1 Sodium Chloride

Sodium chloride (NaCl) in its liquid and solid forms has been used in roadway winter maintenance for many decades. It has been used for so long because the material is readily

available and relatively inexpensive, but the material is corrosive and has an adverse impact on the environment. It also becomes much less effective below 18°F when large quantities of sodium chloride are required at lower temperatures.

Sodium chloride is known to corrode steel on vehicles, bridge components, roadside signs, and other apparatus. Many industries have found ways around this problem by using stainless or galvanized steel. Many new bridge designs use concrete girders rather than steel girders. However, much of the existing infrastructure still deteriorates rapidly due to the corrosive effects of sodium chloride.

Major environmental concerns include sodium chloride contamination in the soil and waterways. Sodium chloride build-up in soil can make the soil less cohesive and cause difficulties for plant growth. High sodium chloride concentrations in the waterways can destroy the ecosystem by depleting oxygen in the water (Schueler et al., 2009). In Canada, the sodium chloride build-up in local water supplies has caused heavy metals leaching into drinking water.

In recent years many winter maintenance organizations have begun to use other chlorides and acetates in an attempt to reduce the amount of deicing chemicals dispensed. Learning how to use deicing chemicals more effectively will have positive results for the environment, the winter maintenance budget, and maintenance assets vulnerable to corrosion.

6.2 Magnesium Chloride

Magnesium chloride mixes are widely used in the State of Nebraska. This research studied four magnesium chloride mixes: Mg-B, Mg-A, Mg-C, and Mg-D.

The Mg-C and Mg-D products are very similar to each other. Both chemicals have settling solids and are byproducts of the ethanol industry. There have been some problems reported with similar products in the State of Nebraska and from the Maine Department of Transportation. It has been reported that these magnesium chloride products may significantly decrease the roadway friction after treatment, however, the results from the Friction Test show neither product has a more detrimental effect to roadway friction than the other chemical deicers tested. Mg-C and Mg-D products are prone to ferment. If the fermentation was left unchecked, the product could cause slick roadways.

The Mg-C and Mg-D products had a similar performance in the Shaker Test, but were consistently outperformed by Mg-A and Mg-B at 20°F and 10°F. The magnesium chloride products did not have more prolonged refreeze times than other chemical deicers. The Friction Test results showed the Mg-A, Mg-C, and the Mg-D products to have comparable friction coefficients to the other chemical deicers, while Mg-B had lower roadway friction than the other chemical deicers.

6.3 Calcium Chloride

Calcium chloride is a liquid chemical deicer. It was the only calcium chloride product tested in this research. It is a 30% calcium chloride mix in a “beet juice” solution. The “beet juice” solution makes the product very dark in color and very sticky. These traits will be discussed more in the section on “beet juice” solutions.

Mg-A, potassium acetate, and calcium chloride had comparable ice melting capacities in the Shaker Test, with potassium acetate being exceptional at 20°F. The results from the Friction Test showed calcium chloride would not cause slippery roadway surfaces.

The calcium chloride showed a clear advantage over all the other chemical deicers in the Refreeze Test. While as most of deicers and deicer/NaCl mixes had refreeze times of 2 hours or less, the refreeze time of calcium was longer than the allotted test time of 4-5 hours. The refreeze results from the Beet Juice products suggest the extraordinary refreeze time of calcium chloride was due to the calcium chloride, not the “beet juice.”

Observations of calcium chloride during testing suggest this product is corrosive to stainless steel. It was not an objective of this research to determine the corrosiveness of the chemical deicers, but the effect was very pronounced. Small spills or incidental drops of calcium chloride would begin to rust stainless table tops after one or two days, even if they had been wiped clean.

The results from the Shaker Test show calcium chloride had similar performance to magnesium chloride chemical deicers. The results from the Refreeze Test show the calcium chloride has a refreeze time possibly longer than 5 hours. These results suggest using a calcium chloride product on a roadway just before sunset or temperature drops may prevent the refreezing of liquids on the roadway

6.4 Potassium Acetate

The Nebraska Department of Roads uses potassium acetate exclusively for the treatment of bridges because it is believed to have less corrosive effect to the environment. It is only used on bridges also because of the high cost of the material. Although it is not usually done in Nebraska, it has been proposed to mix potassium acetate with sodium chloride or another chemical deicer to reduce the overall cost.

This research discovered mixing potassium acetate with sodium chloride was a futile exercise. When used in the Shaker Test, the potassium acetate melted about twice as much ice as sodium chloride at 20°F and almost three times as much at 10°F. But, a 50/50 mix of sodium chloride and potassium acetate would melt an amount ice only slightly higher than that of the sodium chloride by itself.

The mixing of these two liquid chemicals would also produce large amounts of solid precipitate. Using potassium chloride as a prewet for road salt also produced a jelly-like precipitate on the salt. The amount of precipitate produced by mixing with either solid or liquid sodium chloride could potentially clog the mechanisms on certain distribution systems.

The results from the Refreeze Test did not show the refreeze time of potassium acetate to have any advantage over the other chemical deicers. The results from the Friction Test showed potassium acetate to have a slightly more detrimental effect on roadway friction than the other chemical deicers.

As a result of these findings, potassium acetate should not be mixed with other solid or liquid chemical deicers.

6.5 Calcium-Magnesium Acetate

Calcium-magnesium acetate (CMA) was not used for this research because of the known performance issues associated with this chemical deicer (Blackburn et al., 2004; EPA, 1999; Shi et al., 2004). It requires much larger amounts of CMA than sodium chloride to achieve the same level of service.

Many winter maintenance organizations use calcium-magnesium acetate because it is believed to have very few environmental effects. However, this chemical is commonly known to have poor performance in the field and test results from Nixon et al. (2007) and Shi et al. (2009) show CMA to have less performance than sodium chloride and many other deicers. CMA is more expensive than sodium chloride by a factor of 10-20 (Schueler et al., 1999).

Many departments attempt to compensate for this chemical's poor performance by using much more of the chemical, which causes concern about its unknown environmental effects.

6.6 Carbohydrate or “Beet Juice” Solutions

Beet Juice-A and Beet Juice-B are byproducts of the beet industry. They are very dark colored, almost black, and very sticky. These chemicals tend to seep through the small spaces around the lids and through the plastic seam of the containers.

These kinds of chemicals should be classified as a performance enhancer, rather than a deicer. The results from the SHRP Ice Melting Capacity Test and the liquid results from the Shaker Test show these chemicals do not have a significant ice melting capacity when used alone. Field reports tend to support these test results especially on days without direct sunlight. The manufacturers recommend mixing this chemical with sodium chloride, usually at a ratio of 15/85 beet juice solution/sodium chloride.

The liquid results from the Shaker Test show mixes of 15/85 Beet Juice-A/NaCl and 15/85 Beet Juice-B/NaCl performed slightly better than sodium chloride alone. However, mixes of 50/50 Beet Juice-A/NaCl and 50/50 Beet Juice-B/NaCl performed slightly worse

than sodium chloride, as shown in Figure 4.24 in Chapter 4. Although Figure 4.24 only shows results for liquids at 20°F, the results for 15/85 and 50/50 mixes of Beet Juice-A/NaCl and Beet Juice-B/NaCl had the same distribution in the liquid tests at 10°F and 0°F.

The liquid test results from the Beet Juice-A and Beet Juice-B show the best results occurring at a ratio of 15/85 while all other chemical deicers used in this study produced the best results when not mixed with salt brine. The best results occur at a ratio of 15/85 because of the optimum concentration of these materials. The Beet Juice-A and Beet Juice-B help the sodium chloride stick to the ice more efficiently, resulting in a greater ice melting capacity. Mixes with a higher ratio of Beet Juice-A or Beet Juice-B do not perform as well because the advantage from the stickiness can no longer compensate for the smaller amount of sodium chloride in the mix.

The results from the Shaker Test for prewet road salt suggest a prewet of a 50/50 mix of Beet Juice-A/NaCl produced a better performance than a prewet of a 15/85 mix of Beet Juice-A/NaCl at a temperature of 10°F. The results from the two mix ratios were about the same at 0°F. More research is needed to make the prewet results of the Shaker Test more consistent, but these results do corroborate the field performance of prewet mixes of Beet Juice-A.

The dark color of these chemicals offers an advantage in direct sunlight. The performance of Beet Juice-A mixes improves drastically when exposed to sunlight. The Sunlight Test was developed specifically to study the effect of the darker color. For instance, a 50/50 mix of Beet Juice-A/NaCl clearly outperformed a 15/85 mix of Beet Juice-A/NaCl,

as shown in Figure 6.1. Beet Juice-A and sodium chloride were the only liquid deicers used in the Sunlight Test.

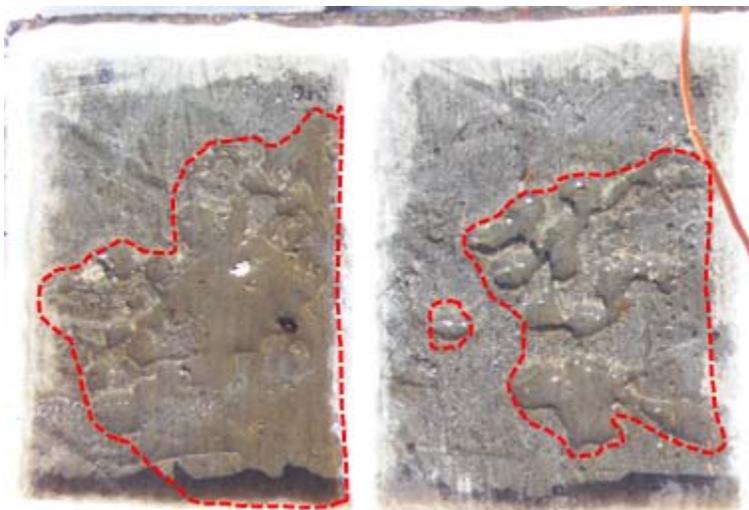


Figure 6.1: Sunlight Test Results

The area on the left was treated with road salt prewet with a 50/50 mix of Beet Juice-A/NaCl. The area on the right was treated with road salt prewet with a 15/85 mix of Beet Juice-A/NaCl. The area encircled in red depicts the sections of ice melted by the deicer. Both areas had the same amount of road salt and prewet. The encircled area on the left is clearly larger than the encircled area on the right.

The results of this research suggest Beet Juice-A and similar products are not chemical deicers but rather chemical performance enhancers. These products must always be mixed with a chloride, acetate, or another chemical deicer. When used as a liquid treatment with sodium chloride, the ratio for the best performance is 15/85 chemical/NaCl. This is also the ratio suggested by the manufacturers of Beet Juice-A.

Results from the Shaker Test and the Sunlight Test suggest liquid mixes used as a prewet for road salt may have a better performance with greater amounts of Beet Juice-A.

Direct sunlight may also give these products an advantage because of their darker color. Also, the stickiness of these chemicals is advantageous to any anti-icing activities because they help the deicers stick to the road.

6.7 Solid Chemical Deicers

Two solid chemical deicers, road salt and Pink Salt, were studied in this research. Road salt is solid sodium chloride and Pink Salt is an orange colored, finely graded solid, mostly made of sodium chloride with small amounts of magnesium chloride, calcium chloride, and other chemicals. Field observations have shown Pink Salt to perform better than road salt. Both solids were used in the Shaker Test, Sunlight Test, and Refreeze Test. Both solids were passed through sieves so their performance could be compared at the same gradation.

Results from the Shaker Test showed the rock salt and the Pink Salt to have almost identical ice melting capacities at 20°F and 10°F. The rock salt was ineffective at 0°F, but the Pink Salt was effective. It is unclear if this contrast at 0°F is a result of the chemical composition or due to the gradation of the Pink Salt. Even though similar gradations were used for both chemicals, larger granules of road salt tend to be solid pieces, while larger granules of Pink Salt tend to be smaller granules pressed together. These granules broke apart during the Shaker Test and were able to perform at 0°F.

Smaller gradations may perform more quickly than larger gradations. Samples measuring 4 grams with a gradation of 2.38 mm (#8 sieve) melted about 0.10 more grams of ice than samples measuring 5 grams with a gradation of 4.75 mm (#4 sieve).

The results from the sunlight test did not show Pink Salt to have an obvious advantage over road salt when exposed to direct sunlight. However, field observations have suggested that Pink Salt performs better than road salt when exposed to direct sunlight.

The results from the refreeze test showed road salt and Pink Salt have almost identical refreeze times at all the different gradation sizes used for testing. The results from the refreeze test also showed the gradation size has an effect on the refreeze time. Samples with gradations smaller than 0.422 mm (#40 sieve) began to refreeze almost immediately. Samples with a larger gradation of about 2.38 mm (#8 sieve) began to refreeze after two hours.

The results of this research suggest the Pink Salt's superior performance in the field over road salt may be due to its much finer gradation. The majority of the Pink Salt sample used for testing had a gradation smaller than 4.75 mm (#4 sieve). The majority of the road salt sample used for testing had a gradation larger than 4.75 mm (#4 sieve). The orange color of the Pink Salt may also be advantageous in direct sunlight.

6.8 Standards of Practice

The following is a list of observations and suggestions for chemical use in the field based on the findings from this research. Table 6.2 outlines the recommended deicer usage.

Table 6.2: Recommendations for Deicer Usage				
	Temperature Range, °F			
Weather/Road Conditions	Above 32	32-20	20-12	Below 12
Rain	Use little to no treatment unless the temperature is expected to drop. In that case pre-treat with road salt less than 100 lbs/lane-mile.	Pre-treat with road salt prewet with 8-10 gal/ton NaCl at less than 100 lbs/lane-mile. During event, prewet is not necessary.	Not Applicable	<p>Reports from the field in NDOR indicate deicers are effective below 12°F, but these findings are not supported by the literature.</p> <p>NDOR is moving away from using abrasives because of Spring cleanup.</p> <p>If abrasives are used, prewet with 8-10 gal/ton of NaCl to help "root" the abrasives.</p> <p>Using MgCl₂ or CaCl₂ could cause slippery conditions.</p> <p>Do not use Beet Juice in a liquid application unless it is a sunny day.</p>
Freezing Rain			Use Road Salt prewet with 8-10 gal/ton NaCl.	
Sleet			Using MgCl ₂ or CaCl ₂ could cause slippery conditions.	
Ice	If not preceded by any of the above, pre-treat with liquid NaCl 20-50 gal/lane-mile. Post-treat with road salt prewet with 8-10 gal/ton NaCl.		If liquids must be used, retreat every 1.5-2hrs to prevent refreeze	
Light Snow (less than 0.5 in/hr)	If not preceded by rain, freezing rain, or sleet liquid NaCl can be used for pre and post-treatment and during the event.		Use Road Salt prewet with 8-10 gal/ton. Use MgCl ₂ or CaCl ₂ if humidity is low.	
Moderate to Heavy Snow (greater than 0.5 in/hr)	Pre-treat with liquid NaCl 20-50 gal/lane-mile. A mix of 15/85 Beet Juice/NaCl can be used. Use road salt during and after the event. Prewet is not necessary during the event.		If liquids must be used, patrol every 1.5-2hrs to prevent refreeze. Beet Juice can be used in direct sunlight.	
Compacted Snow	Use Road Salt if Necessary	Use Road Salt prewet with 8-10 gal/ton NaCl	Use Road Salt prewet with 8-10 gal/ton. Use MgCl ₂ or CaCl ₂ if humidity is low.	
	A prewet mix of 15/85 Beet Juice/NaCl is recommended on sunny days			
Winds Greater than 15 mph	Treatment may cause blowing snow to stick to roadway. Beet Juice is NOT recommended on overcast days.			No Treatment

Some information provided in Table 6.2 was compiled from the literature survey and is cited herein:

- Chemical deicers are typically not used in temperatures below 12°F (Shi et al., 2004; Blackburn et al., 2004; Ketcham et al., 1996).

6.8.1 Solid Deicers

- Solid deicers work best if applied early in the storm event (Blackburn et al., 2004).
- When there are large amounts of ice on a roadway, greater than ¼-inch, solid deicers will work better than liquid deicers (Kuhl et al., 1999). Solid deicers will penetrate to the bottom of an ice sheet whereas liquid deicers tend to quickly flow off the ice without having much effect.
- Smaller gradations of solid deicers tend to work more quickly, but may also refreeze more quickly (Blackburn et al., 2004).
- Coarse grained deicer should be used during precipitation rates greater than 0.5 inches per hour (CTC & Associates LLC., 2009).

6.8.2 Liquid Deicers

- Liquid deicers work well in temperatures above 28°F, but have a tendency to freeze in temperatures below 20°F (Blackburn et al., 2004; Peterson et al., 2010).
- Liquid deicers are the best choice for anti-icing procedures because when the liquids evaporate a stratum of crystallized chlorides or acetates is left on the roadway (Alger et al., 1994).

- The best time to perform anti-icing procedures is before snow events at temperatures higher than 20°F (Blackburn et al., 2004; CTC & Associates LLC., 2009).
- Anti-icing will not be effective for rain or freezing rain events because the deicers will be washed off the road.
- Wind speeds above 15mph can inhibit anti-icing operations (Blackburn et al., 2004; Ketcham et al., 1996; CTC & Associates LLC., 2009).
- Calcium and magnesium chlorides absorb water from the air and can cause slippery roadways if the humidity is greater than 40% (CTC & Associates LLC., 2009).
- Calcium chloride can leave a roadway wet for several days while sodium chloride will dry a few hours after a storm (Donahey and Burkheimer, 1996).

6.8.3 Prewet Solid Deicers

- Prewet can increase material retention on the roadway by 26% (Shi and O’Keefe, 2005).
- A prewet of 10-12 gallon per ton is sufficient to minimize bounce and scatter (Blackburn et al., 2004).
- Prewet is not needed if snow events are preceded by rain or for use on wet snow at about 32°F (Roosevelt, 1997).
- Using prewet results in additional cleaning of the application equipment, but this can be minimized if prewet is applied at the spinner.

6.8.4 Abrasives

- Abrasives or sand are used at temperatures below 12°F (Shi et al., 2004 and Blackburn et al., 2004)

- Sand prewet with salt brine is more effective than dry sand (Shi and O’Keefe, 2005).
- Sands with gradation between 0.04 and 0.08 inches work well at all temperatures (Al-Qadi et al., 2002).

6.8.5 Other Observations

- Potassium acetate should not be mixed with other deicers or used as a prewet for solid deicers. This has been confirmed by field observations in the City of Fort Collins, Colorado to cause large amounts of sludge.
- Solutions of “Beet juice” mixed with sodium chloride are best used in sunlit areas. It may be prudent to use a different deicer in areas with many trees or shaded areas.
- It may be prudent to use calcium chloride right before sunset and temperature drops because it may not refreeze as quickly as other chemical deicers.

6.9 Evaluation of Performance Tests

Due to the many sources of error, it is evident that the SHRP Ice Melting Capacity Test is not repeatable between different laboratories. Furthermore, the results from this test often do not correlate with field observations.

The Shaker Test appears to produce results similar to that of the SHRP Ice Melting Capacity Test without the need of a walk-in freezer. The results from the Shaker Test also correlate well with reports from the field in the State of Nebraska. The test results are repeatable between laboratories, but more tests should be performed at different locations to further confirm this observation.

This version of the Friction Test has a complicated procedure and requires a walk-in freezer. If a product is suspected to cause slippery roadways without fermentation, it would be more practical to use a British Pendulum Tester to confirm the friction coefficient. It has a simpler procedure, does not require electricity, and is designed for use in the field.

The Sunlight Test is difficult to perform because it must be conducted outdoors during specific environmental conditions. Furthermore, field data from the MDSS can be used to come to the same conclusions as the Sunlight Test concerning the effect of sunlight exposure on dark colored deicers.

The Refreeze Test did not produce completely consistent results, but was functional enough to discover some interesting information about calcium chloride and the gradation of solid deicers. The refreeze test shows the potential to become a cost-effective test for deicer, but requires further development to produce consistent results.

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Appendix A

Refreeze Test Results

