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ABSTRACT: Common deicing chemicals include sodium chloride, magnesium chloride, calcium chloride, calcium magnesium acetate, potassium acetate, potassium formate, and corn or beet-based deicer solution. Liquid deicers are commonly used for pre-wetting road salt, sand or other solid deicers, or mixed with salt brine as liquid deicer. Although manufacturers provide performance data under specific conditions, a standardized test is very much needed. Samples of sodium chloride, magnesium chloride, calcium chloride, potassium acetate, and beet juice-based chemical deicers were selected for performance evaluation. The SHRP Ice-Melting Capacity Test has been used in many research projects, but the results do not always correlate well with field data. A simple and economical test has been developed to evaluate the ice-melting capacities of deicing chemicals using a martini shaker, which shows some potential to become a standardized test for ice-melting capacity evaluation. Field data was collected by the Nebraska Dept. of Roads using automatic vehicle location (AVL) and the maintenance decision support system (MDSS) installed on some plow trucks. The AVL takes roadway pictures from the cab and records vehicle location. The MDSS collects weather data from area weather stations. Although initial shaker test results correlate well with known deicer performance and limited field data provided by MDSS, further development work is necessary before the shaker test can be considered for official use.

KEYWORDS: deicing chemicals, ice-melting capacities, winter roadway maintenance, testing and evaluation.

Introduction

Common deicing chemicals include sodium chloride, magnesium chloride, calcium chloride, calcium magnesium acetate, potassium acetate, potassium formate, and mixtures of carbohydrate byproduct with deicers, in the form of pellets or liquids. Liquid deicers are commonly used for pre-wetting road salt, sand. or other solid deicers, or mixed with salt brine for deicing. In winter maintenance, deicing chemicals are used not to melt ice, but to break the bond between the ice or snow and the pavement to facilitate snow/ice removal. Essential properties of chemical deicers used for performance evaluation thus include: ice-melting capacity, ice penetration, ice undercutting, thermal properties, and the resulting friction coefficient of a treated roadway. Other properties, such as viscosity and specific gravity, are tested for applicability in different deicer dispensing equipment. Because many factors such as the return time that a plow truck will make another pass over the road, the volume of the traffic, etc., may affect the road condition, ice-melting tests cannot exclusively measure the performance of a deicer.

This paper focuses on the evaluation of ice-melting capacities of some common deicers. Several deicer performance tests have been developed under the Strategic Highway Research Program (SHRP) and described in the *Handbook of Test Methods for Evaluating Chemical Deicers* (Chappelow et al. [1]).

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SHRP Ice-Melting Capacity Test

SHRP ice-melting tests were conducted on samples consisting of 3 g of road salt prewet with 1 mL of liquid deicers. The tests were conducted at 0°F and 10°F in accordance with the SHRP test methods H205.1 and H205.2 (Chappelow et al. [1]). The road salt used in the tests passed through a #4 sieve. Because salt brine is less expensive than other liquid deicers, it is a common practice to mix it with other liquid deicers to lower the treatment cost. Different mixtures of 100 % liquid deicer, 50/50 liquid deicer/sodium chloride, 40/60 liquid deicer/sodium chloride, and 25/75 liquid deicer/sodium chloride were used in this study. The liquid deicers used in the tests are listed in Table 1.

Test Results

The test results are presented as ice amounts melted in 60 min for the different chemical deicers. The results for 0°F and 10°F are shown in Figs. 1 and 2, respectively. The 25 % bar indicates that a liquid mixture of 25 % deicer and 75 % of sodium chloride were used to prewet the road salt. The melting capacity as a result of using 100 % salt brine is used as the reference for comparison. The data from using 100 % beet juice-A is not available because of its high viscosity.

There is generally a lack of consistency in the results, as no correlation between a deicing chemical's concentration and its

TABLE 1—*Liquid deicers used in prewet solid 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

ice-melting capacity is evident. Potential sources of error include the use of a chest freezer for testing and the testing of prewet solids. Some liquid was retained in the cavities formed in the melting ice that could not be measured. Road salt contains small amounts of gravel, which would cause significant errors in test results.

Walk-in freezers were utilized for conducting the SHRP ice-melting tests by Alger and Haase [2], Nixon et al. [3], Shi et al. [4], and Shi and Akin [5], which yielded more consistent results. Each of these research projects also used a slightly different procedure from the SHRP test, mostly having to do with the size of the ice sheet or deicer sample. SHRP test results [5] showed that at 15°F sodium chloride melted more ice than calcium chloride and magnesium chloride after 60 min of exposure. This is contrary to the known field observation that the latter two chlorides performed better. The 60-min ice-melting capacities of several liquid deicers were compared by Nixon et al. [3]. One test showed the performance of sodium chloride at 0°F was better than that at 10°F. It is well known that sodium chloride becomes ineffective below 15°F and that no deicers would perform better at lower temperatures. Alger and Haase [2] conducted the SHRP tests to determine how the prewetting rate, at 6, 8, or 10 gal/ton, would improve the ice-melting capacity of prewet road salt. Their results did not clearly show performance differences between deicers and the amount of prewet. Test also showed that solid sodium chloride performed better than several other deicing products, which are not consistent with field observations.

From the results obtained in this study as well as from other research cited, it is evident that the SHRP ice-melting capacity test is not repeatable, and test results often do not correlate well with field observations.

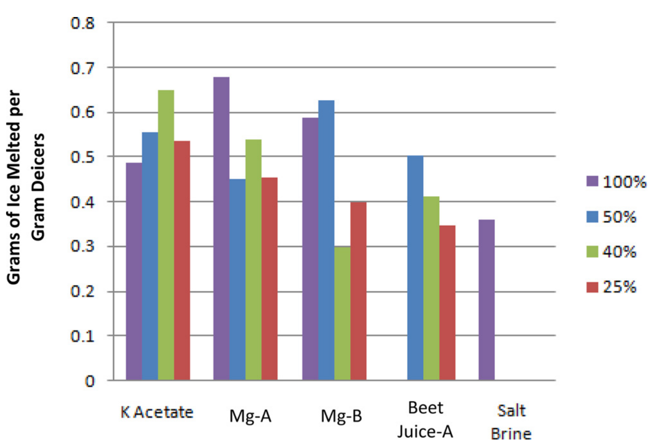

FIG. 1—*SHRP ice-melting capacity test results at 0°F for 60 min.*

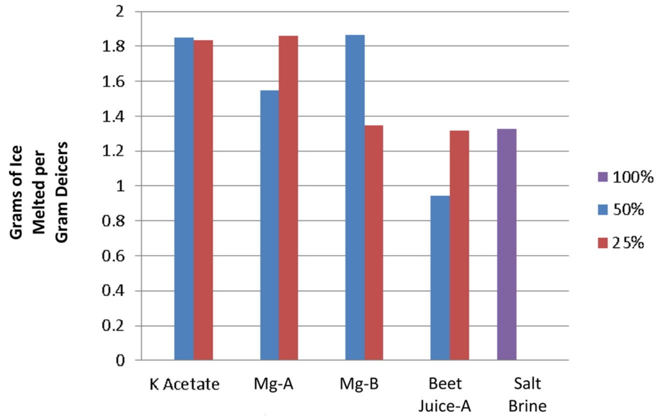

FIG. 2—*SHRP ice-melting capacity test results at 10°F for 60 min.*

The Shaker Test

A simple and economical test has been developed to evaluate the ice-melting capacities of deicing chemicals using a martini shaker. The testing procedure is easy to follow. The results from the shaker tests are consistent with field performance of the deicers and the tests are repeatable. Detailed accounts of the test development and test data are given by Gerbino-Bevins [6].

Modified Martini Shaker

Plastic martini shakers insulated with copper pipe insulation material are used for the shaker tests, as shown in Fig. 3. A thermocouple is used to monitor the temperature inside the shaker without having to open the shaker. The freezer in a refrigerator is generally large enough for testing. A thermostat is required to set the freezer temperature. Each shaker test is conducted in triplicate.

FIG. 3—*Martini shaker with insulation and thermocouple wire.*

Procedure

1. Prepare Ice Cubes. Use a syringe to measure 1 mL (0.034 fl oz) of distilled water into each aperture of the mini ice cube tray.
2. Prepare Deicer Sample. If using a pure sample of liquid chemical deicer, use a syringe to measure 7 mL (0.237 fl oz) 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 (4.75 mm) 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 g (0.176 ± 0.001 oz) 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 h 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 two cycles a second for liquids and three cycles a second for solids and prewet solids. The shaker must be held at an upward angle of about 30°. Holding the shaker at this angle will prevent separation of the liquids from the solids.
11. Shake for 5 min while setting the shaker down after every minute to quickly take a temperature reading.
12. After 5 min, 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 min. 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.

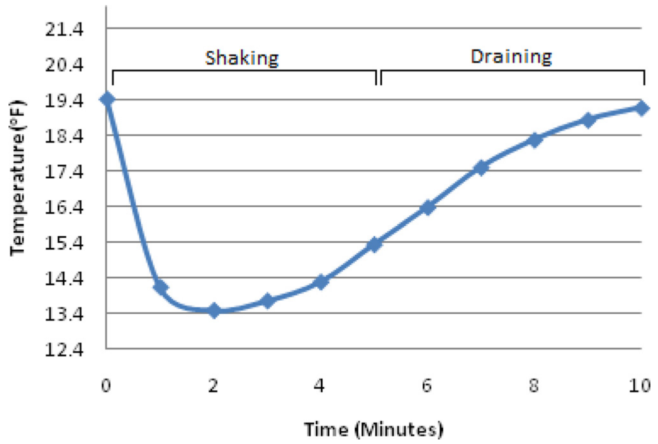

FIG. 4—*Temperature change inside the shaker during the shaker test.*

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.

   The temperature in the shaker drops sharply while shaking and then rebounds to its original temperature, as shown in Fig. 4. The temperature drop is a result of the ice-melting reaction that absorbs the heat energy in the shaker. When the ice stops melting, the temperature gradually returns to its original state. This observation of how the temperature inside the shaker changed during the procedure pertained to all the tests conducted.

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

$$\begin{aligned}&(\text{Weight of Bowl \#1 and 10 Ice Cubes} - \text{Weight of Bowl \#1})\\&\quad - (\text{Weight of Bowl \#2 and Spoon and Remaining Ice}\\&\quad - \text{Weight of Bowl \#2 and Spoon})\end{aligned} \tag{1}$$

The Shaker Test is well suited for testing liquid and solid deicers; however, modifications may be needed for testing prewet solids. Deicer samples consisted of 7 mL (0.237 fl oz) of liquid deicer, 5 g (0.176 oz) of dry solid deicer, or 5 g (0.176 oz) of solid deicer

TABLE 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 % $CaCl_2$

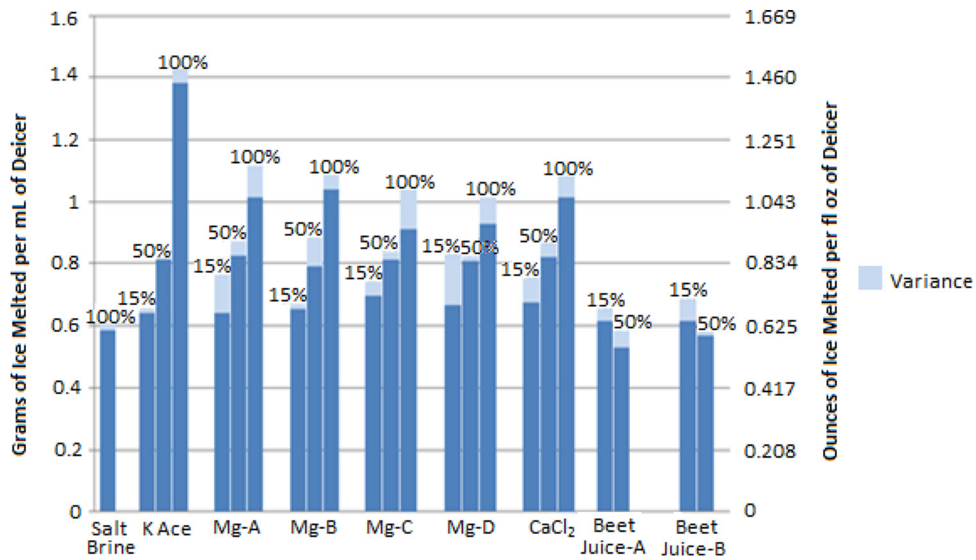

FIG. 5—*Shaker test liquid results at 20°F (−6.7°C).*

soaked in a liquid deicer to simulate prewetting. The liquid deicers evaluated are listed in Table 2. Pure liquid deicing chemicals and different deicer/brine ratios were evaluated using the shaker test.

Test Results

Liquid Deicers—Nine different liquid deicers were evaluated at 20°F (−6.7°C), 10°F (−12.2°C), and 0°F (−17.7°C). 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. Facilities will sometimes use greater amounts of beet juice in the mix to compensate for lower temperatures.

Ice-melting capacities are presented as the amount of melted ice per amount of deicer. The standard deviation and variance are calculated for each data point. The results for liquid deicers are shown in Figs. 5, 6, and 7. The percentages at the top of each column represent the ratio of the chemical deicer in that deicer/brine mix. The variance is presented as a range on top of each bar. Each bar represents the results from three tests.

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, and calcium chloride consistently perform the best at each temperature with potassium acetate performing very well at 20°F (−6.7°C).
- 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.

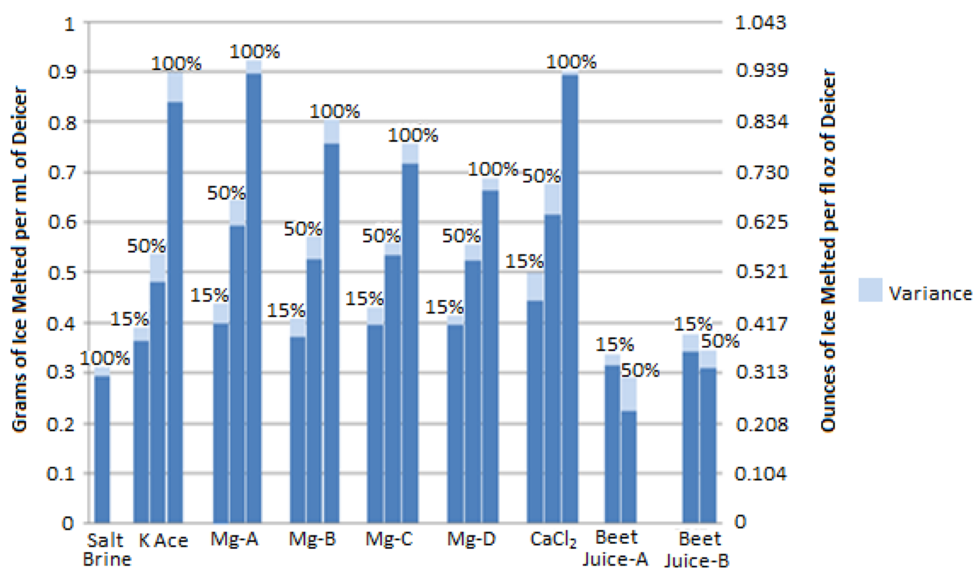

FIG. 6—*Shaker test liquid results at 10°F (−12.2°C).*

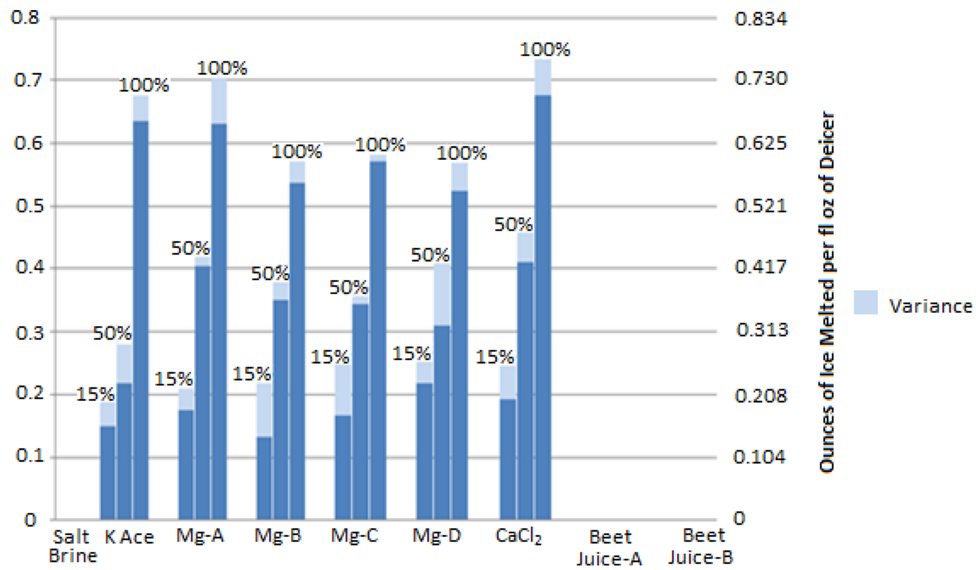

FIG. 7—*Shaker test liquid results at 0°F (−17.8°C).*

- 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.

Solid Deicers—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. The results are shown in Fig. 8. Field observations have shown that pink salt performs better than road salt. Both solids were passed through sieves so they have similar gradations for testing.

Results from the shaker test showed the rock salt and the pink salt to have almost identical ice-melting capacities at 20°F (−6.7°C) and 10°F (−12.2°C). The rock salt did not melt ice at 0°F (−17.8°C), 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 (−17.8°C).

Prewet Road Salt—The results for the prewet road salt are not as consistent as the results for liquids or dry solids. These

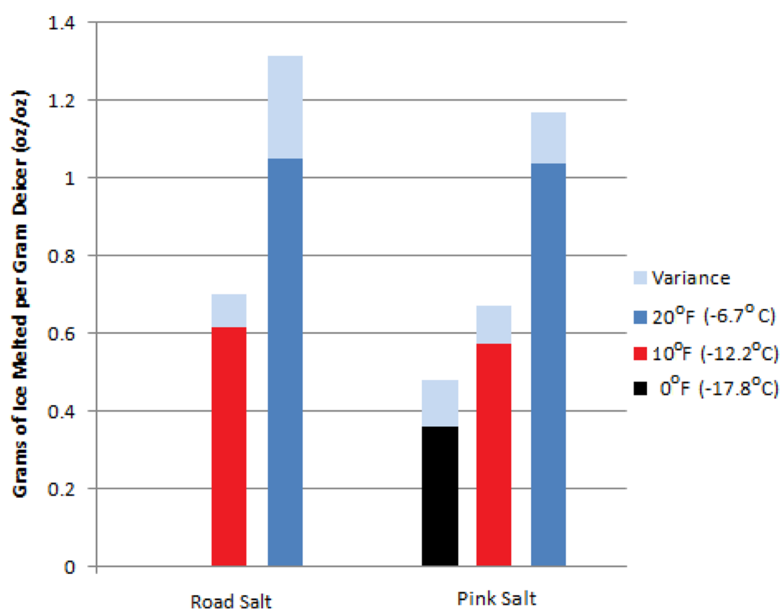

FIG. 8—*Shaker test solid results.*

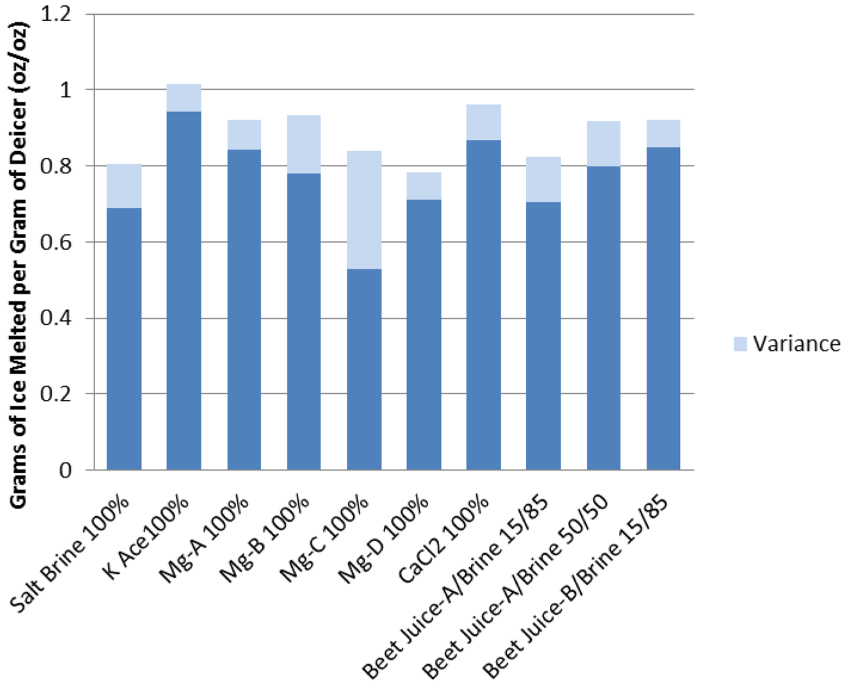

FIG. 9—*Shaker test results for prewet road salt at 10°F (−12.2°C).*

inconsistencies are most likely caused by the preparation of the deicer samples. For serviceability reasons, the samples of road salt were prewet 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 cannot be measured with certainty. A better way would be to prepare prewet samples at 8 gallons of deicer per ton of road salt.

The results for prewet road salt are shown in Figs. 9 and 10. The potassium acetate results are not shown because the potassium acetate reacted with the road salt during the prewet process, producing a pudding-like precipitate.

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 liquid deicer. Prewet using the 50/50 mix of beet juice-A/NaCl outperformed the 15/85 mix, which correlates well with field reports in Nebraska. The performance of beet juice-A as a

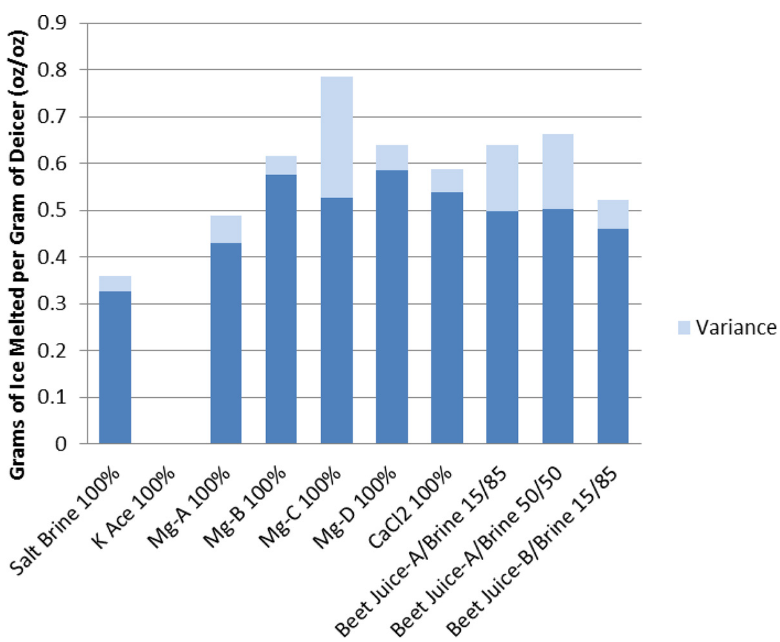

FIG. 10—*Shaker test results for prewet road salt at 0°F (−17.8°C).*

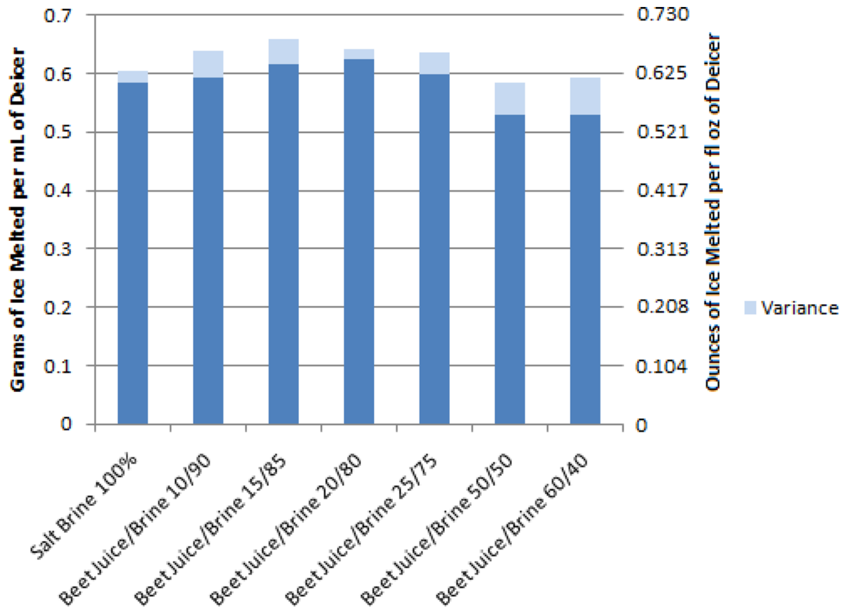

FIG. 11—*Shaker test results for beet juice-A mixes at 20°F (−6.7°C).*

liquid mix does not correlate with field observation, but it is consistent with data collected from the MDSS. The prewet results at 10°F (−12.2°C) correlate well with the liquid results except for the beet juice-A and beet juice-B mixes. The prewet results at 0°F (−17.8°C) do not correlate well with the liquid results.

Beet Juice Deicers—Beet juice-A mix ratios were extensively evaluated at 20°F (−6.7°C). The results in Fig. 11 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 used without brine. 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.

The shaker test has the potential to become a standardized deicer performance test. Liquid deicers were evaluated extensively at different deicer/NaCl ratios. The liquid and solid deicers produced consistent results with reasonable variances. More types of solid deicers should be tested using the shaker test to further confirm the consistency. The results for the prewet road salt were not as consistent at 0°F (−17.8°C).

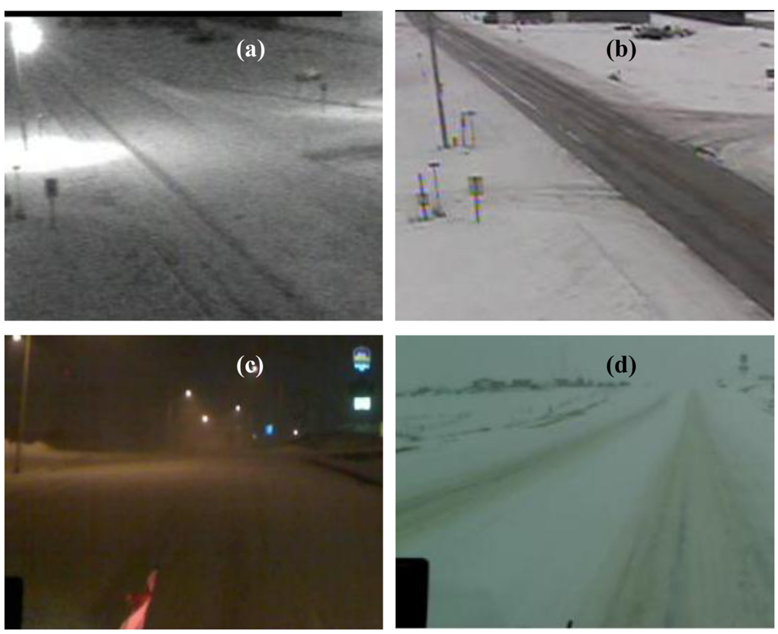

FIG. 12—*Mg-A and beet juice—A comparison.*

TABLE 3—*Summary of field data by MDSS.*

Figure	12(*a*)	12(*b*)	12(*c*)	12(*d*)
Date	02/24/11	02/24/11	01/19/11	01/20/11
Time	7:05 a.m.	1:35 p.m.	6:15 a.m.	1:06 p.m.
Location	US-26	US-26	US-385	US-385
Precipitation	1.4 in. snow	1.9 in. snow	0.5 in. snow	1.0 in. snow
Air temperature	2°F	7°F	15°F	14°F
Road temperature	7°F	16°F	21°F	20°F
Winds	10 mph	11 mph	11 mph	11 mph
Deicer app. rate	Mg-A 60 gal/lane-mile	Mg-A 180 gal/lane-mile	30/70 beet-A 50 gal/lane-mile	30/70 Beet-A 300 gal/lane-mile

Correlations of Lab Results with Field Data

Field Data Acquisition and Analysis

The field data was collected by plow trucks equipped with automatic vehicle location systems (AVL) along with the maintenance decision support system (MDSS). 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. 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, because 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, consisting of five categories: clear, 25 % covered, 50 % covered, 75 % covered, and 100 % covered roadways, is completely governed by what can be seen from the pictures. Very often, a roadway with multiple lanes will have different levels of service in different lanes. Therefore, this rating system is a subjective measure because of the lack of a more precise methodology.

Case 1—Performance Comparison of Mg-A and Beet Juice-A

Figures 12(*a*) and 12(*b*) were pictures taken by a stationary roadside camera, where Mg-A was used for deicing. Figures 12(*c*) and 12(*d*) were pictures taken by a plow truck near the same location marked by the motel sign in both pictures, where beet juice-A was used for deicing. The field data provided by the MDSS are given in Table 3.

This comparison shows the Mg-A improving the roadway from 100 % covered to 0–25 % covered in 6.5 h. The beet juice mix does not appear to have melted snow after about 7 h. The roadway treated by the Mg-A has an average daily traffic (ADT) of 5461, whereas the roadway treated by the beet juice has a lower ADT of 1740. 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. These field data observations correlate well with the shaker test results of the two deicers.

Case 2—Liquid Sodium Chloride

The plow began treating this route with salt brine at 150 gallons per lane-mile at 4:30 a.m. A snowfall of 2.7 in. (68.6 mm) had taken place the night before. The pavement temperature was 0°F (−17.8°C) and the wind speed was 3 mph (4.83 km/h). At 8:08 a.m., the roadway was still 100 % covered after 3.5 h as Fig. 13 shows. This field observation correlates with the shaker test that shows liquid sodium chloride melting little to no ice at 0°F.

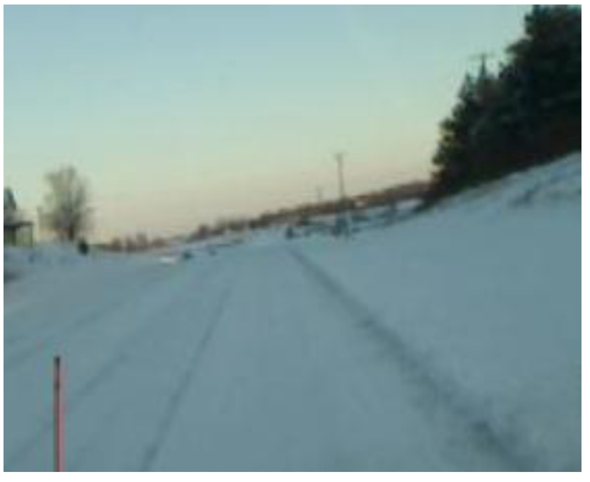

FIG. 13—*Liquid sodium chloride performance at 0°F.*

Concluding Remarks

A simple and economical test has been developed for ice-melting capacity evaluation of deicing chemicals using a martini shaker. 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 liquid deicer tests showed that higher concentrations produced a higher amount of ice melting, at 0°F, 10°F, and 20°F. The results from the shaker test also correlate well with limited field data and field reports in the State of Nebraska. The test procedure has produced repeatable results.

Although the shaker test shows potential to become a standardized test, further development is necessary before the shaker test can be adopted for official use:

- A mechanical shaking device should be used to verify test results at different frequencies and at various angles.
- It was shown that the temperature inside the shaker drops during shaking until the thermal equilibrium has been reached. Thus, it is desirable to determine the shake time at which no temperature drop is observed before the ice-melting measurement.
- A shaker test procedure needs to be developed for evaluation of prewet solid deicers.
- More field data from MDSS should be used to validate the results from the shaker tests.
- The shaker test may be conducted by other researchers and organizations such as Clear Roads, Pacific Northwest Snowfighters, and Aurora to confirm its repeatability and value.

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