# Comparative Study of Chemical Deicers 

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#### Abstract

The ice-penetration and ice-melting characteristics of seven commercially available chemical deicers that were tested at temperatures ranging from $0{ }^{\circ} \mathrm{F}$ to $25^{\circ} \mathrm{F}$ are examined in this paper. The materials tested included four discrete deicing chemicals and three blends: sodium chloride, calclum chloride, potassium chloride, urea, sodium chloride with traces of carboxymethylcellulose, a sodium chloride/potassium blend, and a sodium chloride/urea blend. The ice penetration tests were conducted using a Plexiglas ${ }^{\text {TM }}$ apparatus consisting of small cavities. Water was frozen in the cavities and penetration observed when pellets of deicer were placed on the exposed ice surface. The ice-melting tests were conducted using an apparatus consisting of a 9 -in.-diameter Plexiglas ${ }^{\top M}$ dish containing a $1 / 8$-in.-thick layer of ice. Deicers were placed on the ice surface at a selected rate. Melt brine was collected, measured, and reintroduced perlodically with a syringe. The extensive data base resulting from the tests was used to compare the several classes of deicers with regard to their ability to melt and penetrate ice as a function of time and temperature, to establish lower temperature limits for deicer use, and to relate observed behavior to chemical and thermochemical properties of deicers.


There are many manufacturers of chemical-based deicers. They are available for use in several market areas but generally compete in the industrial/institutional/residential markets. The objective of this research was to obtain valid data on the performance of several chemical deicers.

A study of the major products was conducted and it was determined that four discrete deicing chemicals and three blends are primarily used. They are

- Sodium chloride,
- Calcium chloride,
- Potassium chloride,
- Urea,
- Sodium chloride with traces of carboxymethylcellulose,
- A sodium chloride/potassium chloride blend with 1 percent urea, and
- A sodium chloride/urea blend.

Information on these chemical deicers (manufacturer, name, and assay) is presented in the Appendix. Calcium magnesium acetate (CMA) was also reviewed, but it is not included in this research. The test results of this material are discussed in a separate paper in this Record.

The two major concerns of deicer performance selected for testing were (a) the rate and extent of penetration of the deicers through a layer of ice and (b) the total ice-melting rate and

[^0]volume. All deicers were evaluated over a range of selected temperature and time intervals. This is because penetration is a measure of a deicer's ability to burrow through the ice and begin ice/pavement disbonding. The ice-melt volume is a measure of the amount of ice that has been melted and, in conjunction with penetration, is an indication of how much ice undercutting has occurred.

## TESTING METHODOLOGIES

At the time this program was initiated, there were no standard methodologies and procedures for specifically testing a deicer's penetration and ice-melting capabilities. Therefore, various means for carrying out these tests were researched and evaluated. Several approaches were rejected because they lacked reproducibility. The testing methodologies ultimately selected provided the type of results that were hypothesized and are fully reproducible.

An important consideration in the selection of these methodologies was that the tests could be photographed for documentation purposes without affecting the test results. The deicer particles were treated with a blue dye, Rhodamine B, so that particle penetration and the resultant brine would be visible in photographs. It is believed that this dye had no significant effect on the performance of the deicers.

All deicers were stored in predried, screw-cap bottles and kept inside a glove box until testing time. Special care was given to hygroscopic deicers in order to prevent them from absorbing moisture.
For temperature control, tests were conducted in a $42-\mathrm{in}$.long $\times 30$-in.-wide $\times 30$-in.-high insulated box placed inside a walk-in cold room. This arrangement prevented temperature changes caused by the opening and closing of the room's access door and body heat generated by researchers. The box was equipped with a hinged Plexiglas ${ }^{\text {TM }}$ window that had two hand ports and was completely insulated on all sides. Hand ports were equipped with lab jacket sleeves through which the operator's arms were inserted for manipulation of the apparatuses. Temperature inside the box was controlled by a thermostat and a small fan which circulated cold air. The cold room was maintained at a temperature slightly lower than that of the box.

## Penetration Test

The apparatus developed for the penetration tests consisted of an $11-\mathrm{in} . \times 2$-in. Plexiglas ${ }^{T M}$ plate, $3 / 8-\mathrm{in}$. thick in which 15 holes were drilled at $5 / 8-\mathrm{in}$. intervals, each $1 / 8$-in. in diameter and $1 \frac{1}{2} \mathrm{in}$. deep (Figure 1). These holes were countersunk to


IIGURE 1 Penetration apparatus.
produce an opening 6 mm in diameter and 3.5 mm deep, at the point where the cone and the $1 / 8-\mathrm{in}$. hole meet. This configuration provides a deicer particle the freedom of movement it needs as it begins penetration (Figure 2).

Degassed (by boiling), deionized water was partially cooled and placed in the cavities with a syringe and needle, taking care to force out any air bubbles. The apparatus was placed overnight in the freezer compartment of a refrigerator. Because water expands when it freezes, a globule of ice formed on top


FIGURE 2 Dimensions of penetration apparatus.
of each cavity. With an aluminum plate, the surface ice was melted but an excess of water was left. The apparatus was again placed in the freezer and allowed to equilibrate to temperature for about 5 hr .

Approximately 1 hr before test time, the surface ice was subjected to a final "ironing" with the aluminum plate. At this time excess water was removed and the surface of the ice was made flush with the Plexiglas ${ }^{\text {TM }}$ surface. This final surface preparation near the time of the test start effectively sealed the ice/Plexiglas ${ }^{\top \mathrm{M}}$ interface at the surface. With these precautions, no evidence of preferential melting was observed at the ice/ Plexiglas ${ }^{\text {TM }}$ interface.

Two particle sieve-sizes were used for each deicer: +10 mesh and +8 mesh. Twenty to thirty calcium chloride pellets were weighed to determine the average weights for the two mesh sizes. These average weights were then used for all deicers. The weights were 11.5 to 14 mg for the +10 mesh material and 22 to 24 mg for the +8 mesh material. If necessary, the sieved, nonhygroscopic deicers were typically filed to achieve these weights.

For the sodium chloride/potassium chloride blend, chemical analysis, physical separation, and weighing of the individual particles revealed its composition to be approximately $50: 50$ by weight. Therefore, particles used in testing this material consisted of one particle of sodium chloride and one particle of potassium chloride, each weighing 6 to 7 mg for the +10 mesh sample and 11 to 12 mg for the +8 mesh sample. The combined weight of these two materials was equal to the weight of one nonblended deicer. For the sodium chloride/carboxymethylcellulose mix, only trace amounts of the carboxymethylcellulose were found. Therefore, the particle primarily used in testing this material was sodium chloride taken directly from the deicer as supplied from the manufacturer's package.

One hour before testing, all deicers were brought to the cold room so the materials could reach equilibrium temperature to simulate actual winter conditions. To ensure that each deicer was placed on the penetration apparatus simultaneously, a Plexiglas ${ }^{\text {TM }}$ caddy was constructed which measured 15 in . long $\times 2 \mathrm{in}$. high $\times \frac{1}{2} \mathrm{in}$. wide. Small cups were drilled in the caddy and the penetration apparatus was inverted over it so that the cups and the cavities were aligned; then both pieces were inverted again so that the particles dropped on top of the ice columns. Forceps were used to center each particle over an icefilled cavity (Figure 3). The loaded penetration apparatus was immediately placed in position inside the cold box located in the cold room and a timer was started.

The penetration depth for each deicer was recorded as follows. When penetration occurred uniformly and evenly in the cavity, one depth was recorded [e.g., second cavity in Figure 3 $(15 \mathrm{~mm})]$. When penetration deviated and tendrils appeared (due to pellet size, density, or shape; the thermodynamics of ice/deicer interaction; or temperature), two depths were recorded. The first represented the uniform depth, or the point at which penetration continued to occur uniformly and evenly (Figure 3, fourth cavity, 7 mm ). The second represented the maximum depth, or the farthest point reached by a tendril (Figure 3, fourth cavity, 20 mm ). These two numbers were added together and the result divided by 2 to obtain the average penetration depth ( 13.5 mm ).


FIGURE 3 Representative penetration behavior.

## Ice-Melting Rate and Volume Test

There were two primary considerations to the ice-melting test: the ability to (a) isolate and measure the brine at various time intervals and (b) return that brine to the ice/deicer system so that melting could continue and further measurements be made.

The apparatus used in the ice-melting test consisted of two pieces of Plexiglas ${ }^{\top M}$, one $1 / 4 \mathrm{in}$. thick, one $1 / 2$ in. thick, and both 11 in . square. A hole 9 in . in diameter was cut through the $1 / 2$-in.-thick piece. The two pieces were then glued together under pressure, thereby producing a hole 9 in . in diameter and $1 / 2 \mathrm{in}$. deep (Figure 4). Ten dishes were constructed in this manner so that simultaneous testing could be carried out.


FIGURE 4 Melting apparatus.
For each test, the dishes were charged with 130 ml of deionized water and placed overnight in a level freezer compartment of a refrigerator. This volume of water corresponded to an ice thickness of $1 / 8 \mathrm{in}$. Before each test, it was necessary to smooth the ice surface. Therefore, a thick aluminum plate was placed on the ice surface and rotated by hand for several seconds until the surface ice was melted. The dishes were then placed on a level surface inside the testing cold room until the melted water was refrozen.

Next, the dishes were placed on edge in the temperature control box and allowed to equilibrate for a minimum of 2 hr . Placing the dishes on edge (a) assured that the dish and ice were exposed principally to the cold air and (b) permitted circulation of the air over and around the specimens causing more rapid temperature equilibration.

The deicers to be used for the day's operation were also placed inside the temperature control box before testing and allowed to equilibrate to simulate actual winter conditions. Material was taken directly from samples submitted by the manufacturer.

The deicer application rate used was $3 \mathrm{oz} / \mathrm{yd}^{2}(1,320 \mathrm{lb}$ per lane mile). This rate created amounts of brine from each deicer that were both measurable and manageable at all test temperatures and within the test time limitations. The application rate also corresponded to recommendations from the deicer manufacturers for use as residential/commercial deicers.
Samples for the ice-melting tests were taken from bulk samples of packaged commercial products. Accordingly, particle size distributions in these samples were representative of distributions in package products. The deicer designated as sodium chloride is commonly known as rock salt or halite. The particle size distribution of this product conformed to ASTM Specification D632 for highway deicing sodium chloride (percent passing: $3 / 8$ in., 95 to $100 ; 4$ mesh, 20 to $90 ; 8$ mesh, 10 to 60; 30 mesh, 0 to 10 ). The several products consisting chiefly of sodium chloride or potassium chloride (or both) generally conformed to this specification, with the exception that most of the materials passed a 4-mesh screen. Thus, these materials contained few of the larger particles commonly present in sodium chloride, designated as halite or rock salt. Approximately 90 percent of the calcium chloride particle passed a 6 -mesh screen with the bulk of the material being distributed among +8 -mesh, +10 -mesh, and +12 -mesh screens. Essentially all of the urea passed a 6 -mesh screen, with the majority being held by 8 -mesh and 10 -mesh screens.

To measure the amount of melt after a specified time period, each dish was tipped so that the brine flowed to the perimeter of the dish. Using a syringe and needle, the brine was quickly withdrawn and measured. The amount was recorded, then replaced in the deicer holes using the same syringe and needle.

## RESULTS

## Penetration Test

To ensure accurate and consistent test results, a minimum of three runs were recorded for each time period and temperature level and the average of those results was recorded. After each test run, the cavities were thoroughly flushed and rinsed with distilled water before preparing the next test.
Penetration tests for both +10 -mesh and +8 -mesh sieve sizes were conducted at temperatures of $5^{\circ} \mathrm{F}, 15^{\circ} \mathrm{F}, 20^{\circ} \mathrm{F}$, and $25^{\circ} \mathrm{F}$. Depths were recorded at $3,5,10,15,20,30,45$, and 60 min .

Penetration test results with the +8 -mesh-size material are presented in Table 1 and Figures 5, 6, 7, and 8 as a function of time and temperature. (Note: For simplicity, 3- and 15-min data and $3-5-$, and $15-\mathrm{min}$ data are omitted from Table 1 and Figures 5-8, respectively.) The +8 -mesh-size material is representative of the bulk material found within the tested deicers. Consequently, +10 -mesh-size test results are not provided.

TABLE 1 AVERAGE PENETRATION DEPTH MEASUREMENTS FOR CHEMICAL DEICERS TESTED AS A FUNCTION OF TIME AND TEMPERATURE

| Time (min) | Sodium Chloride | Calcium Chloride | Potassium Chloride | Urea | Sodium Chloride with <br> Carboxymethylcellulose | Sodium <br> Chloride/ <br> Potassium <br> Chloride | Sodium <br> Chloride/ <br> Urea |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $25^{\circ} \mathrm{F}$ |  |  |  |  |  |  |  |
| 5 | 2.3 | 3.6 | 1.3 | 1.7 | 2.4 | 1.7 | 2.6 |
| 10 | 3.7 | 7.2 | 2.3 | 2.5 | 3.6 | 2.8 | 4.0 |
| 20 | 8.8 | 11.9 | 4.1 | 4.3 | 8.4 | 5.3 | 8.3 |
| 30 | 13.8 | 14.3 | 6.7 | 5.9 | 12.8 | 7.8 | 13.7 |
| 45 | 18.7 | 16.5 | 12.3 | 7.8 | 17.7 | 11.0 | 18.7 |
| 60 | 21.3 | 18.5 | 15.8 | 9.3 | 20.8 | 13.8 | 20.6 |
| $20^{\circ} \mathrm{F}$ |  |  |  |  |  |  |  |
| 5 | 1.1 | 2.8 | 1.0 | 0.4 | 1.7 | 1.5 | 1.1 |
| 10 | 2.3 | 4.5 | 1.4 | 0.9 | 2.8 | 2.7 | 2.7 |
| 20 | 4.8 | 8.9 | 2.6 | 2.0 | 5.1 | 4.8 | 5.1 |
| 30 | 7.8 | 10.3 | 3.6 | 3.1 | 9.4 | 7.3 | 9.0 |
| 45 | 12.0 | 11.8 | 5.2 | 4.5 | 14.2 | 8.8 | 15.7 |
| 60 | 14.0 | 13.1 | 7.1 | 6.1 | 16.5 | 10.7 | 17.6 |
| $15^{\circ} \mathrm{F}$ |  |  |  |  |  |  |  |
| 5 | 1.4 | 2.3 | 0.0 | 0.0 | 1.4 | 1.7 | 0.9 |
| 10 | 2.2 | 5.5 | 0.1 | 0.1 | 2.3 | 3.0 | 2.1 |
| 20 | 4.2 | 9.7 | 0.6 | 0.7 | 4.1 | 5.6 | 3.8 |
| 30 | 6.4 | 11.1 | 1.0 | 1.4 | 6.2 | 8.3 | 6.0 |
| 45 | 9.9 | 11.7 | 1.2 | 1.6 | 9.7 | 10.4 | 9.6 |
| 60 | 12.2 | 12.0 | 1.7 | 2.0 | 13.4 | 10.9 | 12.5 |
| $5^{\circ} \mathrm{F}$ |  |  |  |  |  |  |  |
| 5 | 0.9 | 1.1 | 0.0 | 0.0 | 0.7 | 0.3 | 0.8 |
| 10 | 1.7 | 2.1 | 0.0 | 0.0 | 1.4 | 0.8 | 1.4 |
| 20 | 2.2 | 4.8 | 0.0 | 0.0 | 2.1 | 1.9 | 2.5 |
| 30 | 3.1 | 6.9 | 0.0 | 0.0 | 2.8 | 3.0 | 3.1 |
| 45 | 3.8 | 8.1 | 0.0 | 0.0 | 3.6 | 4.7 | 4.0 |
| 60 | 4.7 | 8.5 | 0.0 | 0.0 | 4.5 | 7.0 | 4.9 |

Notes: Penetration depth measurements in mm . Deicer particle sieve size: +8 mesh.


FIGURE 5 Average penetration depth (mm) at $5^{\circ} \mathrm{F}$ for No. 8 sieve size.


FIGURE 6 Average penetration depth (mm) at $15^{\circ} \mathrm{F}$ for No. 8 sieve size.

Examination of these data reveals the following:

- At all test temperatures, calcium chloride deicer penetrates to substantially greater depths than do the remaining deicers, at 10,20 , and 30 min .
- At $15^{\circ} \mathrm{F}, 20^{\circ} \mathrm{F}$, and $25^{\circ} \mathrm{F}$, penetration depths achieved by calcium chloride and sodium-chloride-based deicers are approximately the same after 45 and 60 min .
- At $5^{\circ} \mathrm{F}$, penetration by calcium chloride deicer is substantially greater than that by the other deicers at all time intervals.
- Potassium chloride and urea penetrate little (1.7 to 2.0 mm ) at $15^{\circ} \mathrm{F}$ and, as expected, do not penetrate ice at $5^{\circ} \mathrm{F}$.

There is a significant difference between the penetration behavior of calcium chloride and the other deicers, which is not indicated by the penetration data. The calcium chloride deicer tends strongly to melt all the ice above the penetration front. The other deicers tend strongly to produce slender melt tendrils, and thus only partially melt the ice above the penetration front. This difference is consistent with the exothermic heat of dissolution of calcium chloride in water and the slighty endothermic heat of dissolution of the other deicer in water. This fundamental difference in thermochemistry is likewise believed to be the primary reason that calcium chloride deicers
penetrate more rapidly in the early stages (up to 30 min ) of penetration events.

Evaluation of the penetration data in terms of effectiveness under field-use conditions leads to the conclusion that the calcium chloride deicers should be substantially more effective in promoting disbondment of ice from pavement materials. For example, undercutting of a $1 / 8$-in.-thick layer of ice should commence in the following time intervals for the various deicers, considering only +8 -mesh-size particles.

| Temperature ( ${ }^{\circ} \mathrm{F}$ ) | Time Interval (min) |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{CaCl}_{2}$ | NaCl | KCl | Urea |
| 25 | 5 | 10 | 15 | 15 |
| 20 | 6-7 | 15 | 30 | 30 |
| 15 | 7-8 | 17-18 | $>60$ | >60 |
| 5 | 15 | 30 | - N | etratio |

## Ice-Melting Rate and Volume Test

Tests were conducted at temperatures of $0^{\circ} \mathrm{F}, 5^{\circ} \mathrm{F}, 10^{\circ} \mathrm{F}, 15^{\circ} \mathrm{F}$, $20^{\circ} \mathrm{F}$, and $25^{\circ} \mathrm{F}$. The melt volume at each temperature was measured at $10,15,20,25,30,45$, and 60 min . These results are presented in Table 2 and Figures 9-13. (Note: For simplicity, $15-$ and $25-\mathrm{min}$ data and $0^{\circ} \mathrm{F}$ and $10^{\circ} \mathrm{F}$ data are


FIGURE 7 Average penetration depth (mm) at $20^{\circ} \mathrm{F}$ for No. 8 sieve size.
omitted from Table 2. Likewise, $15-$ and $25-\mathrm{min}$ data and $10^{\circ} \mathrm{F}$ data are omitted from Figures 9-13.)

Examination of the results of the ice-melting tests indicates that the trends and comparative differences of the data generally parallel those exhibited by the penetration data, as enumerated below:

- Calcium chloride deicer melts substantially more ice than sodium chloride deicers after 10 to 45 min at $15^{\circ} \mathrm{F}, 20^{\circ} \mathrm{F}$, and $25^{\circ} \mathrm{F}$. At 10 min the ratio of melt volumes is of the order of $2: 1$. At 45 min the ratio of melt volumes is of the order of $1.3: 1$.
- At $5^{\circ} \mathrm{F}$, calcium chloride deicer melts three to five times the quantity of ice melted by sodium chloride deicers at 10 to 45 min , and more than twice the quantity of ice melted by sodium chloride deicers at 60 min .
- Urea and potassium chloride are inferior to sodium chloride and calcium chloride at all temperatures and times and melt little ice at $15^{\circ} \mathrm{F}$ and none at $5^{\circ} \mathrm{F}$.
- At 60 min calcium chloride is modestly superior to sodium chloride at $25^{\circ} \mathrm{F}$, and is increasingly superior to sodium chloride as the temperature is lowered. Visual observations of the
dissolution of deicer pellets indicate that all calcium chloride pellets dissolve completely in the early stages of melting tests and that larger sodium chloride pellets are only partially dissolved at lower temperatures- $5^{\circ} \mathrm{F}$ in particular.


## CONCLUSIONS

## Penetration Test

- Calcium chloride deicers initially penetrate ice at all temperatures, at a rate approximately twice the rates exhibited by other deicers.
- Sodium chloride deicers penetrate ice at a lower rate initially than does calcium chloride; perform similarly to calcium chloride over a 45 - to $60-\mathrm{min}$ period at $15^{\circ} \mathrm{F}$ to $25^{\circ} \mathrm{F}$; and are substantially inferior to calcium chloride at $5^{\circ} \mathrm{F}$.
- Urea and potassium chloride are substantially less active than sodium chloride and calcium chloride, and they become essentially nonpenetrating at $15^{\circ} \mathrm{F}$ and lower temperatures.


FIGURE 8 Average penetration depth (mm) at $25^{\circ} \mathrm{F}$ for No. 8 sieve size.

- From the standpoint of undercutting and ice disbondment, the order of preference is $\mathrm{CaCl}_{2}>\mathrm{NaCl}>\mathrm{KCl}$ and urea.
- Sharp-edged crystal deicers, such as sodium chloride, tend to behave differently than spherical deicers. Spherical deicers tend to produce a uniform penetration front; crystal deicers penetrate with a nonuniform melting front with tendrils.


## Ice-Melting Rate and Volume Test

- At all temperatures and in equal lengths of time, calcium chloride outperformed the other chemical deicers in melt-volume products.
- The performance differences in melt volume increased between calcium chloride and the other deicers as temperature decreased.


## Penetration and Ice Melting

- Calcium chloride deicers are substantially superior to other deicers, from the standpoint of ice-melting volumes and
ice penetration/undercutting in the early stages ( 30 min or less) of ice melting.
- Potassium chloride and urea are indicated to be substantially less effective as expected from theoretical considerations. Both are essentially inert at the lower end of the range of temperatures tested in this program.
- Deicer blends tested were equal to or less effective than the sodium chloride at all test temperatures.
- Rapid melting of ice/snow in the first 15 min after deicer application is critical in determining deicer usefulness.


## SUMMARY

In summary, calcium chloride appeared to be more effective than the other deicers in terms of ice penetration and melt volume, particularly at lower temperatures and in shorter lengths of time.

TABLE 2 AVERAGE MELT VOLUME MEASUREMENTS FOR CHEMICAL DEICERS TESTED AS A FUNCTION OF TIME AND TEMPERATURE

| Time (min) | Sodium <br> Chloride | Calcium Chloride | Potassium Chloride | Urea | Sodium Chloride with Carboxymethylcellulose | Sodium <br> Chloride/ <br> Potassium <br> Chloride | Sodium Chloride/ Urea |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $25^{\circ} \mathrm{F}$ |  |  |  |  |  |  |  |
| 10 | 6.1 | 13.8 | 3.8 | 4.9 | 5.3 | 5.0 | 6.5 |
| 20 | 13.0 | 21.4 | 9.3 | 6.4 | 12.7 | 10.3 | 13.6 |
| 30 | 19.5 | 25.3 | 13.8 | 8.9 | 20.1 | 16.0 | 21.5 |
| 45 | 24.8 | 28.9 | 18.6 | 11.1 | 25.2 | 21.3 | 26.9 |
| 60 | 29.0 | 31.3 | 21.9 | 12.9 | 29.6 | 25.4 | 30.2 |
| $20^{\circ} \mathrm{F}$ |  |  |  |  |  |  |  |
| 10 | 3.0 | 8.4 | 1.6 | 3.6 | 4.1 | 5.7 | 5.7 |
| 20 | 7.8 | 15.7 | 3.2 | 4.8 | 9.1 | 8.8 | 9.9 |
| 30 | 12.3 | 18.8 | 6.1 | 6.0 | 14.0 | 12.4 | 14.8 |
| 45 | 15.8 | 20.8 | 8.5 | 6.6 | 17.9 | 16.2 | 19.5 |
| 60 | 20.2 | 22.7 | 11.2 | 7.2 | 21.5 | 18.3 | 21.8 |
| $15^{\circ} \mathrm{F}$ |  |  |  |  |  |  |  |
| 10 | 2.3 | 5.2 | 0.4 | 1.1 | 2.1 | 1.8 | 2.4 |
| 20 | 5.2 | 11.2 | 1.0 | 2.0 | 4.3 | 4.7 | 5.8 |
| 30 | 8.2 | 14.3 | 1.4 | 2.6 | 7.8 | 7.6 | 9.3 |
| 45 | 10.3 | 15.3 | 1.9 | 2.9 | 10.3 | 9.7 | 12.6 |
| 60 | 12.2 | 16.3 | 2.4 | 3.2 | 12.8 | 11.8 | 14.7 |
| $5^{\circ} \mathrm{F}$ |  |  |  |  |  |  |  |
| 10 | 1.0 | 4.1 | 0.0 | 0.0 | 0.8 | 0.5 | 0.7 |
| 20 | 1.5 | 8.7 | 0.0 | 0.0 | 1.3 | 1.2 | 1.8 |
| 30 | 2.6 | 10.5 | 0.0 | 0.0 | 2.1 | 1.8 | 2.9 |
| 45 | 3.8 | 11.3 | 0.0 | 0.0 | 3.6 | 2.4 | 3.8 |
| 60 | 5.2 | 12.1 | 0.0 | 0.0 | 4.8 | 3.2 | 5.2 |

Notes: Melt volume measurements in mi.
Deicer application rate: $3 \mathrm{oz} / \mathrm{yd}^{2}$.


FIGURE 9 Average melt volume (ml) at $0^{\circ} \mathbf{F}$ (application rate, $3 \mathrm{oz} / \mathrm{yd}^{2}$ ).


FIGURE 10 Average melt volume (ml) at $5^{\circ} \mathrm{F}$ (applicatlon rate, $3 \mathrm{oz} / \mathrm{yd}^{2}$ ).


FIGURE 11 Average melt volume (ml) at $15^{\circ} \mathrm{F}$ (application rate, $3 \mathrm{oz} / \mathrm{yd}^{2}$ ).


FIGURE 12 Average melt volume (ml) at $20^{\circ} \mathrm{F}$ (application rate, $3 \mathrm{oz} / \mathrm{yd}^{2}$ ).


FIGURE 13 Average melt volume (ml) at $25^{\circ} \mathrm{F}$ (application rate, $3 \mathrm{oz} / \mathrm{yd}^{2}$ ).

## APPENDIX

## Sodium Chloride

| Manufacturer: | Morton-Thiokol, Inc. |
| :--- | :--- |
| Trade Name: | Halite Safe-T-Salt <br> TM |
| Assay: | 99 percent sodium chloride |
| Calcium Chloride |  |
| Manufacturer: | The Dow Chemical Company |
| Trade Name: | PELADOWTM calcium chloride |
|  | pellets |
| Assay: | 90.8 percent calcium chloride |


| Potassium Chloride |  |
| :--- | :--- |
| Manufacturer: | Howard Johnson Enterprises, Inc. |
| Trade Name: | Zero Ice ${ }^{\text {M }}$ Melting Crystals |
| Assay: | 99 percent potassium chloride |

## Urea

Distributor:
Principal
Ingredient:
Assay:

| Sodium Chloride withCarboxymethylcellulose <br> Manufacturer: | Morgro Chemical Company |
| :--- | :--- |
| Trade Name: | Ice-Fighter Plus ${ }^{\text {TM }}$ |


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