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Report # MATC-UNL: 058

Final Report
WBS: 25-1121-0003-058

Development of Shaker Test as a Standardized Test Protocol for Deicing Chemicals Evaluation

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2014

A Coopertative Research Project sponsored by
U.S. Department of Tranportation-Research, Innovation and Technology Innovation Administration

MATC

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A Report on Research Sponsored by

Mid-America Transportation Center

University of Nebraska-Lincoln

July 2014

Technical Report Documentation Page

1. Report No.
25-1121-0003-058

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Development of Shaker Test as a Standardized Test Protocol for Deicing Chemicals Evaluation

5. Report Date
July 31, 2014

6. Performing Organization Code

7. Author/s
Christopher Y. Tuan, Tregan Albers II

8. Performing Organization Report No.
25-1121-0003-058

9. Performing Organization Name and Address
University of Nebraska- Lincoln, Department of Civil Engineering, Peter Kiewit Institute, 1110 South 67th Street, Omaha, NE 68182-0178

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Organization Name and Address
Mid-America Transportation Center
2200 Vine St.
PO Box 830851
Lincoln, NE 68583-0851

13. Type of Report and Period Covered
Final Report

15. Supplementary Notes

14. Sponsoring Agency Code
MATC TRB RiP No. 32781

16. Abstract
During a research project previously funded by MATC, a simple and economical test using a martini shaker for ice melting capacity evaluation showed potential in becoming a standardized test. The development of the shaker test was prompted by the inconsistent results from the SHRP ice melting capacity tests. Further, there is a general interest within the winter maintenance community (e.g., Clear Roads and TRB Committee AHD65) to further develop the shaker test into a deicing chemicals test protocol. This research focused on the use of a mechanical rocker for shaking instead of manually shaking, which can introduce significant error. The main objective of this research was to transform The Mechanical Rocker Test into a standardized testing procedure for an ice melting capacity evaluation of liquid deicing chemicals. A number of testing parameters need to be precisely specified to ensure repeatability and consistency in the test results. In this test, 33 ice cubes of 1.3-mL each and 30-mL of liquid deicing chemical were mixed in a vacuum sealed thermos on a mechanical rocking platform. The rocker was set to a frequency of 90 RPM with a tilt angle of ±10°. The time duration for rocking was set for 15 minutes. A Styrofoam dish or cup was used for measuring the mass of the ice. With these test parameters, a standard deviation of 1.15% has been achieved when testing with MeltDown Apex™. The Rocker Tests can be used to develop guidelines for efficient winter roadways maintenance operations involving the use of deicing chemicals. Guidelines for best practices under various weather and roadway conditions will improve snow removal operations and provide an adequate level of service and safety to the general public on the U.S. surface transportation system. This test procedure will be submitted to selected Departments of Transportation and Clear Roads for parallel testing and feedback.

17. Key Words
Winter Maintenance, Deicing Chemicals, Ice Melting Capacities, Experiments, Mechanical Rocker Tests

19. Security Classification (of this report)
Unclassified

18. Distribution Statement
This document is available to the general public via Nebraska Department of Roads.

21. No. of Pages
55

22. Price

Form DOT F 1700.7 (8-72) Reproduction of form and completed page is authorized

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This project was jointly sponsored by the Mid-America Transportation Center (MATC) of the University of Nebraska-Lincoln and the Materials & Research Division of the Nebraska Department of Roads (NDOR). The authors wish to thank Barbara Gerbino-Bevins, Jasmine Dondlinger, Jodi Gibson, Lieska Halsey, Wally Heyen, Mike Mattison, and Anna Rea of NDOR, and Molly Lamrouex, Melissa Maiefski, Sue Petracek, and Frank Rich of the Nebraska Division of the Federal Highway Administration (FHWA) for their collaboration and valuable feedback. The authors also wish to thank Robert Vanderveen and James Reitmeier for their efforts in the ice melting capacity rocker tests set-up and data collection during the early stages of this research project.

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Abstract

During a research project previously funded by MATC, a simple and economical test using a martini shaker for ice melting capacity evaluation showed potential in becoming a standardized test. The development of the shaker test was prompted by the inconsistent results from the SHRP ice melting capacity tests. Further, there is a general interest within the winter maintenance community (e.g., Clear Roads and TRB Committee AHD65) to further develop the shaker test into a deicing chemicals test protocol. This research focused on the use of a mechanical rocker for shaking instead of manually shaking, which can introduce significant error. The main objective of this research was to transform The Mechanical Rocker Test into a standardized testing procedure for an ice melting capacity evaluation of liquid deicing chemicals. A number of testing parameters need to be precisely specified to ensure repeatability and consistency in the test results. In this test, 33 ice cubes of 1.3-mL each and 30-mL of liquid deicing chemical were mixed in a vacuum sealed thermos on a mechanical rocking platform. The rocker was set to a frequency of 90 RPM with a tilt angle of ±10°. The time duration for rocking was set for 15 minutes. A Styrofoam dish or cup was used for measuring the mass of the ice. With these test parameters, a standard deviation of 1.15% has been achieved when testing with MeltDown Apex™. The Rocker Test can be used to develop guidelines for efficient winter roadways maintenance operations involving the use of deicing chemicals. Guidelines for best practices under various weather and roadway conditions will improve snow removal operations and provide an adequate level of service and safety to the general public on the U.S. surface transportation system. This test procedure will be submitted to selected Departments of Transportation and Clear Roads for parallel testing and feedback.

Chapter 1 Introduction

The use of deicing chemicals to maintain a certain level of service (LOS) on roadways during the winter months increases every year. Most city and state snow removal operations rely on dispensing deicing chemicals based on empirical rules of thumb that have not been validated by laboratory testing or are against field performance. Using too little deicing chemicals may not achieve the required safety and LOS for the general public using surface transportation. Using too much deicing chemicals will lead to accelerated pavement deterioration and environmental pollution. Proper utilization of chemical deicers on roadways would reduce loss of life, loss of time in travel delays, and property damage due to snow and ice storms.

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. There are many products available for use in highway and bridge deicing and new products are introduced each year. Data from the manufacturer provides only the eutectic point of the deicer mixed with ice under specific conditions. A simple and economic test procedure for acceptance of deicing chemicals is needed for a screening test protocol.

The performance of deicing chemicals has been studied extensively and there are numerous publications on the subject. Many state Departments of Transportation (DOT) have done testing to evaluate prospective deicing chemicals when the need arose to replace a particular deicing chemical. Valuable information has been compiled by organizations such as Clear Roads [6, 8], Pacific Northwest Snowfighters [7], and Aurora. Many tests that were used have come from the Strategic Highway Research Program's (SHRP) "Handbook of Test

Methods for Evaluating Chemical Deicers" [1]. Many of these tests were reported to have yielded inconclusive results or were too expensive to operate [2,3]. Some states [4] did field testing on chemical deicers only for a season, but instances of poor performance had costly consequences [5]. During a research project previously funded by MATC, a simple and economical test using a martini shaker for ice melting capacity evaluation showed potential in becoming a standardized test. The development of the shaker test was prompted by the inconsistent results of the SHRP ice melting capacity tests. Further, there is a general interest within the winter maintenance community (e.g., Clear Roads and TRB Committee AHD65) to further develop the shaker test into a deicing chemicals test protocol. This research focused on the use of a mechanical rocker for shaking instead of shaking by hand, which can introduce significant error due to the variability of shaking by the tester. A number of testing parameters need to be precisely specified to ensure repeatability and consistency in the test results. The Rocker Test can be used to develop guidelines for efficient winter roadway maintenance operations involving the use of various deicing chemicals. Guidelines for the best practices under different weather and roadway conditions will improve snow removal operations and provide an adequate level of service and safety to the general public on the U.S. surface transportation system.

The main objective of this research is to develop The Mechanical Rocker Test into a standardized testing procedure for an ice melting capacity evaluation of liquid deicing chemicals. In this test, 33 ice cubes of 1.3-mL each and 30-mL of liquid deicing chemicals were mixed in a vacuum sealed thermos on a mechanical rocking platform. The rocker was set to a frequency of 90 RPM with a tilt angle of ±10°. The time duration for rocking was set for 15 minutes. A Styrofoam dish or cup was used for measuring the mass of ice. With these test parameters, a standard deviation of 1.15% has been achieved when testing with MeltDown Apex™. The Mechanical Rocker Ice Melting Test procedure developed will be submitted to selected Departments of Transportation and Clear Roads for parallel testing and feedback. The Mechanical Rocker Ice Melting Test could also be used for screening the new deicing products submitted by vendors each year. The Mechanical Rocker Ice Melting Test may eventually be proposed to AASHTO for adoption to replace the unreliable SHRP II ice melting capacity test currently in use.

Chapter 2 Mechanical Rocker Ice Melting Test

This research aims to develop a simple and repeatable test to determine the ice melting capacity of a liquid deicer. The procedure is simple in that it can be used with relatively inexpensive equipment and in normal working laboratory environments. It does not require the use of a walk-in freezer, although it is important that procedures are followed quickly when working outside of the freezer to limit error. The use of the mechanical rocker may loosely simulate the effect of traffic, however, the primary purpose is to provide a consistent test method that is repeatable and relatively quick, with modest equipment requirements. Data shows that the test is repeatable and the test procedure produces consistent results. MeltDown Apex™, a product comprised of 28.0-31.0% magnesium chloride, was used as the control chemical for The Mechanical Rocker Ice Melting Tests. After the test procedure was finalized, several tests were also conducted using salt brine and calcium chloride for comparisons.

The general procedure of The Mechanical Rocker Ice Melting Test is described as follows. A small amount of deicer chemical (30 mL) is chilled to 0°F inside a thermos within the confine of a freezer. A small amount of ice cubes (33) with a specific volume (1.30 mL each) are frozen in the same 0°F environment. Styrofoam cups are weighed empty and then weighed again with the 33 ice cubes using a mass balance. The mass of the ice cubes is determined using a mass balance. Within the confines of the freezer, the ice cubes are placed inside the thermos with the deicer liquid. The thermos is removed from the freezer and placed on a mechanical rocking platform set to a specific tilt angle (10°) and rocked for a given period of time (15 minutes). After the time is up, the remaining ice and the melted ice are separated using a sieve (#4), and the remaining ice is weighed in another Styrofoam cup using the mass balance. The ice melting capacity of a liquid deicer is determined by subtracting the final mass of ice from the initial mass of ice and dividing this difference by the amount of liquid chemical deicer used in the experiment. For instance, if the amount of chemical deicer used was 30 mL, the initial ice mass was 35 grams, and the finial mass of the ice was 26 grams, the ice melting capacity would be: (35 grams - 26 grams) / 30 mL = 0.30 grams of ice per mL of deicer.

The sensitivities of a number of test parameters were investigated to minimize the error while attempting to achieve the largest melting capacity that can be obtained. It is anticipated that the proposed test procedure will be applicable to other deicers and other temperatures, even though a single liquid deicer (i.e., magnesium chloride) was tested at 0°F. Comparisons of chemicals should be done at various temperatures to determine which one is the best value for certain conditions. It should be noted that the ice melting capacities obtained from this test should not be confused with those obtained from other test procedures previously developed by other researchers.

Chapter 3 Laboratory Equipment Requirements

Presented in this section is the equipment required for conducting The Mechanical Rocker Ice Melting Test. Most items are readily available in a typical chemical laboratory. The specific test parameters were selected based on a series of designed experiments described in Chapter 4.

3.1 Liquid Chemical Deicer

Any liquid chemical deicer can be used in this test, and the results of different liquid deicers can be compared. MeltDown Apex (magnesium chloride) was used in the development of this test. Magnesium chloride concentrations varied no more than ±0.7% during the development of the test. Concentrations used in the tests ranged from 27.6% to 29.0%. Magnesium chloride was selected as the baseline deicer for the test development due to its proven high melting capabilities in the field. It should be noted that this test does not take into account the ice that melts due to heat absorption from the sun, which results from the dark color of deicers containing beet juice.

3.2 Laboratory Freezer

A freezer set to 0°F was used to chill the liquid deicer and freeze the ice cubes for the experiments. The freezer must be large enough to hold at least three thermoses, one #4 sieve, two ice trays, one funnel, a spatula, and tweezers (see fig. 3.1). The freezer must be able to maintain a temperature of 0°F with an accuracy of ±1°F.

Figure 3.1 Freezer interior space

3.3 Mechanical Rocker

A Cole-Parmer Digital Rocking Shaker™ was used for the experiment (see fig. 3.2). The mechanical rocker should be capable of rocking with a frequency range of 60 to 120 revolutions per minute (RPM). It should also be capable of a tilt angle of ±10° at these rocking frequencies. The platform should be able to hold a weight of at least ten pounds. A different rocker from Cole-Parmer was used to achieve the 20° tilt angle in the experiments due to limitation of the initial rocker. A rocking frequency of 90 RPM was selected for testing. Many mechanical rockers have limited tilt angle ranges; therefore, a tilt angle of 10° was selected for testing.

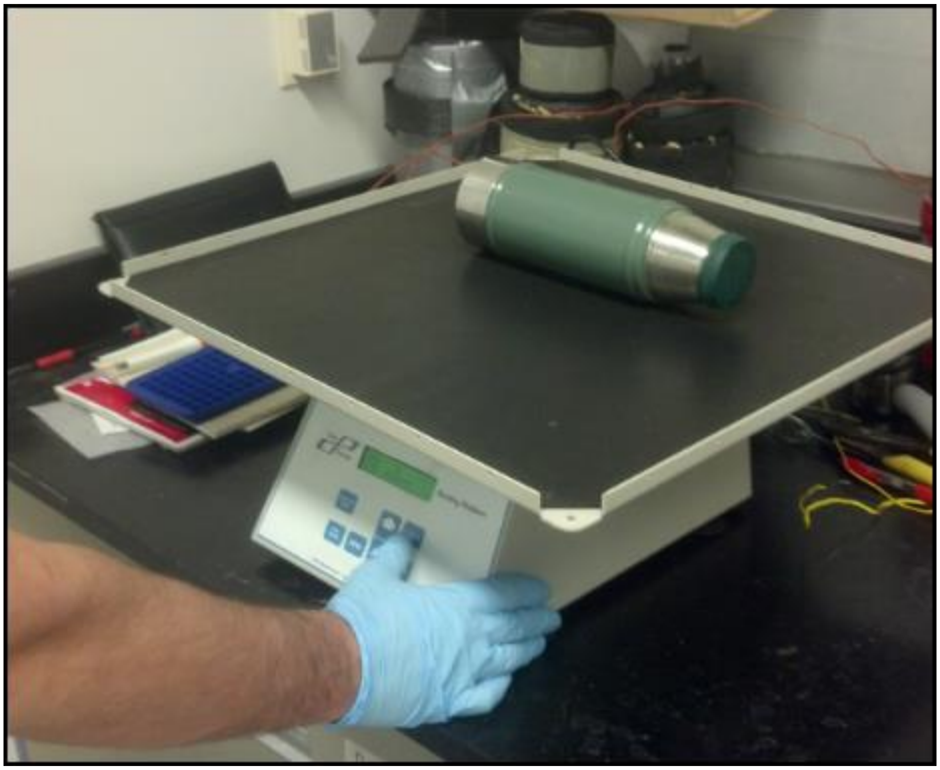

Figure 3.2 Mechanical rocking platform

3.4 Stop-watch

A stop-watch was used to track the duration of time while rocking the thermos. Some rocking platforms have a built-in timer. If the tester chooses to use a built-in timer, the timer must be verified for accuracy. A duration of 15 minutes was selected for testing.

3.5 Latex Gloves

A pair of latex gloves should be worn during the experiment. Oil from fingertips can affect the mass balance readings, and some deicer chemicals can be highly corrosive so contact with skin should be avoided. It is important to follow the safety protocols specified in the MSDS regarding the chemicals used for testing.

3.6 Thermoses

Vacuum sealed Thermos™ and Stanley™ brand thermoses were used for testing. There were no major differences in the performance of the thermoses. It is only important that the thermos be vacuum insulated. The vacuum seal will achieve the highest thermal insulation possible. The thermos should also be stainless-steel to protect against corrosion from the deicer after multiple uses. The standard capacity of the thermoses used was 16 fl oz.

3.7 No.4 Sieve

A No. 4 sieve was used with a plastic spatula and tweezers to separate the liquid deicer and melted ice from the remaining ice cubes. A No. 4 sieve allows particles no larger than 0.25 inches to pass through the mesh (see fig. 3.3). A coarser sieve may allow ice cubes to pass through, and a finer sieve may collect liquid on its mesh allowing for melting to continue. Therefore, using sieves of other sizes is not recommended.

3.8 Plastic Spatula and Plastic Tweezers

A plastic spatula (see fig. 3.3) and plastic tweezers were used to collect the residual ice chunks on the sieve. The ice should not be handled directly as it can affect the amount of ice melting.

Figure 3.3 No. 4 sieve and spatula

3.9 Dish or Cup to Weigh Ice

A Styrofoam cup or dish must easily contain 33 ice cubes (1.30 ml/each) and also fit in a mass balance for weighing. Styrofoam works well due to its thermal insulation properties. Ceramic dishes were initially used in the early experiments, but moisture condensation formed on the dish during weighing. Styrofoam was chosen thereafter to eliminate the error caused by condensation. When the cup or dish is removed immediately from the freezer for weighing, the reading of the mass should not increase significantly over time. Otherwise, the environment might be too humid such that the condensation on the cup or dish could cause significant error in the measurements.

3.10 Two Ice Cube Trays

The ice cube tray should be able to produce ice cubes with a cross-section of 7/16 in × 7/16 in and a depth of 7/16 in. For each experiment, a total of 103 ice cubes will be needed (33 ice cubes for 3 tests and at least 4 extra in case any ice cubes are dropped or do not freeze properly). As shown in fig. 3.4, thirty-three ice cubes of 1.3 mL volume were selected for use in the experiment.

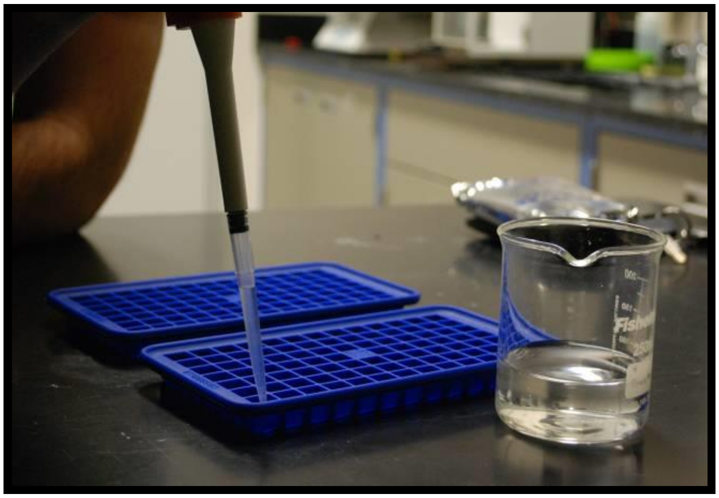

Figure **3.**4 Filling the ice cube trays

3.11 Micropipette

A micropipette (shown in fig. 3.5) is used to deliver 1.3 mL of water in a single delivery to each cell of the ice cube tray, within ±0.10 mL tolerance.

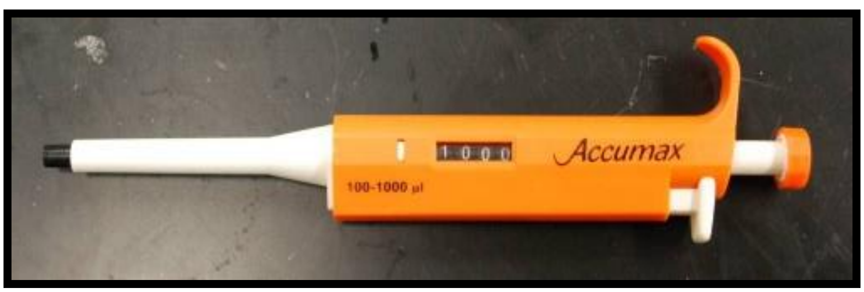

Figure 3.5 Micropipette

3.12 Funnel

A working funnel is used to allow for the ice cubes to pass through its small hole at one end. The diameter of the hole must not be less than 1 in.

3.13 Volumetric Pipette

A volumetric pipette is used to deliver 30 mL of liquid deicing chemicals into a thermos, within a tolerance of ±0.03 mL.

3.14 A Digital Mass Balance in a Confined Box

A digital mass balance in a confined box with ±0.001 gram accuracy is utilized for the mass measurements of the Styrofoam cups and the ice cubes. A box to confine the mass balance is used to eliminate the error caused by air flow within the room (see fig. 3.6).

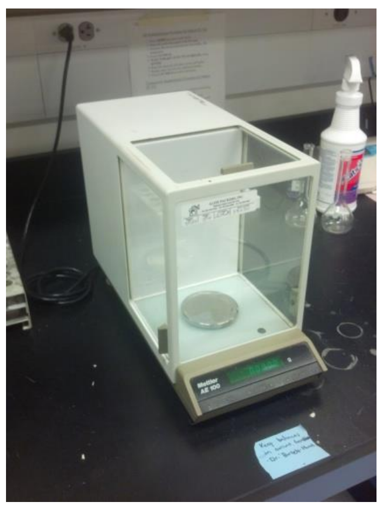

Figure 3.6 Digital mass balance (in a confined space)

Chapter 4 Test Parameters and Data Analysis

The sensitivities of the essential test parameters in the mechanical rocker ice melting experiments have been investigated. These parameters included the amount of ice cubes, the amount of deicer, the angle and the frequency of the rocker, and the rocking time. The original test data from all the experiments are attached in the Appendix of this report.

4.1 Ice Cube Volume/Liquid Deicer Volume

At the beginning of The Rocker Test procedure development, the amount of ice and the amount of deicer to be used for the experiment needed to be defined. A benchmark was first developed which consisted of using 10 ice cubes of 1-mL each, 7-mL of chemical deicer (MeltDown Apex™), a freezer temperature of 0°F, a rocking tilt angle of 10°, and a rocking frequency of 60 RPM. Each trial test was repeated three times and the benchmark produced an average ice melting capacity of 0.2911 g of ice/mL of deicer (fig. 4.1) and a standard deviation of 6.74% (fig. 4.2). To assess the impact of the amounts of ice and deicer, 40 ice cubes of 1-mL each and 28-mL of MeltDown Apex™ were tested. As expected, the ice melting capacity increased to 0.3506 g of ice/mL for the deicer (fig. 4.1), while the standard deviation decreased to 3.71% (fig. 4.2). This result showed that increasing the surface area and the liquid deicer would reduce the standard deviation in the test data. Next, the amount of ice cubes used was increased to 50 ice cubes of 0.8-mL each, such that the total amount of ice remained the same but produced an increased surface area. The amount of the liquid deicer was constant at 28 mL. The ice melting capacity was 0.3462 g of ice/mL for the deicer (fig. 4.1), while the standard deviation decreased to 3.37% (fig. 4.2). This result again showed that increasing the surface area of the ice would reduce the standard deviation in the test data.

In the subsequent experiments, 31 ice cubes of 1.3-mL each were used with 28-mL of MeltDown Apex™. A 1.3-mL volume is the maximum amount of liquid that could be dispensed into a single cell of the used ice cube tray. The ice melting capacity decreased to 0.3243 g of ice/mL deicer (fig. 4.1) with an increase in the standard deviation to 4.48%. (figure 4.2). This was consistent with the observation that increasing the ice cube surface area increased the rate of melting while the variance between trials decreased. To further reduce the standard deviation, 33 ice cubes of 1.3-mL each with 30 mL of MeltDown Apex™ were used. The ice melting capacity obtained was 0.3182 g of ice/mL of the deicer (fig. 4.1), while the standard deviation dropped to 3.55% (fig. 4.2). It was essential to use MeltDown Apex™ of the same concentration of magnesium chloride in this series of experiments so that the test data was not skewed.

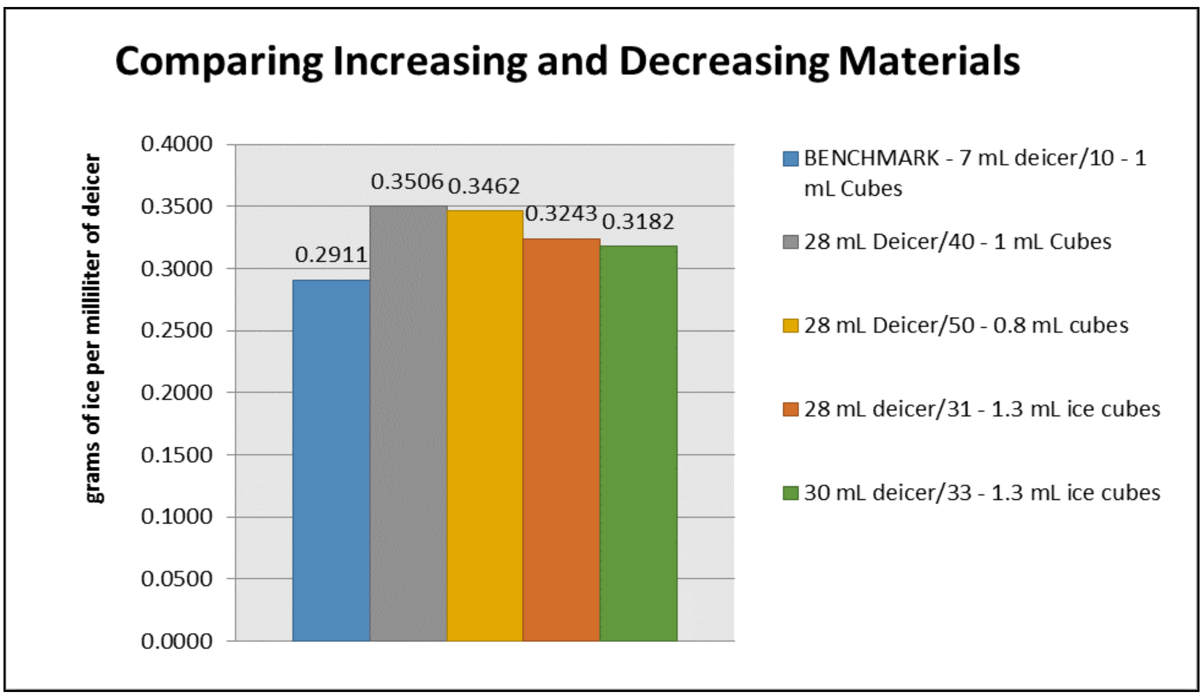

Figure 4.1 Increasing and decreasing materials - ice melting capacity

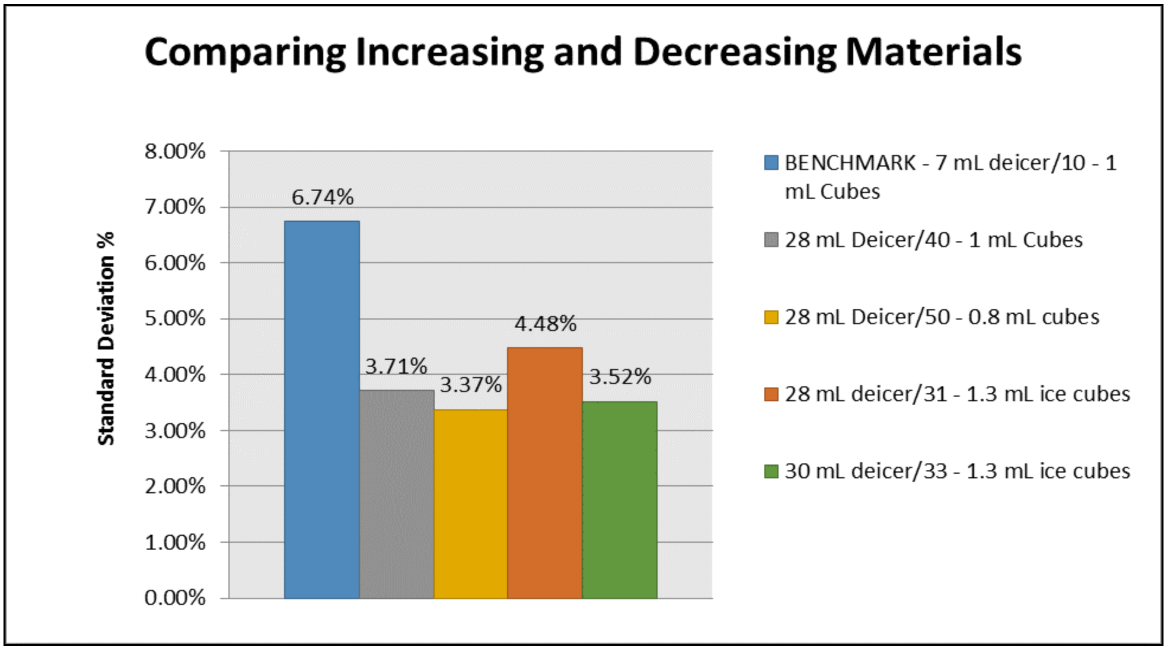

Figure 4.2 Increasing and decreasing materials - standard deviation

As shown in figure 4.3, no strong correlation between the ice melting capacity and initial ice mass used was identified, and it was therefore decided to use 33 ice cubes of 1.3-mL each and 30 mL of liquid deicer for the test procedure.

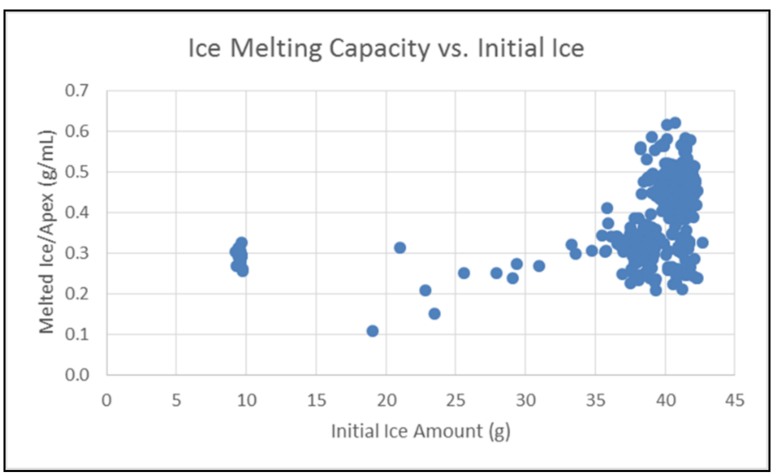

Figure 4.3 Correlation between ice melting capacity vs. initial ice amount

4.2 Type of Thermos

Many tests were done to determine whether a thermos with specific properties would produce different test results. In the next series of experiments, Stanley™ and Thermos™ brand thermoses were used in exactly the same test setting to assess the impact on the ice melting rate due to the use of different thermos types.

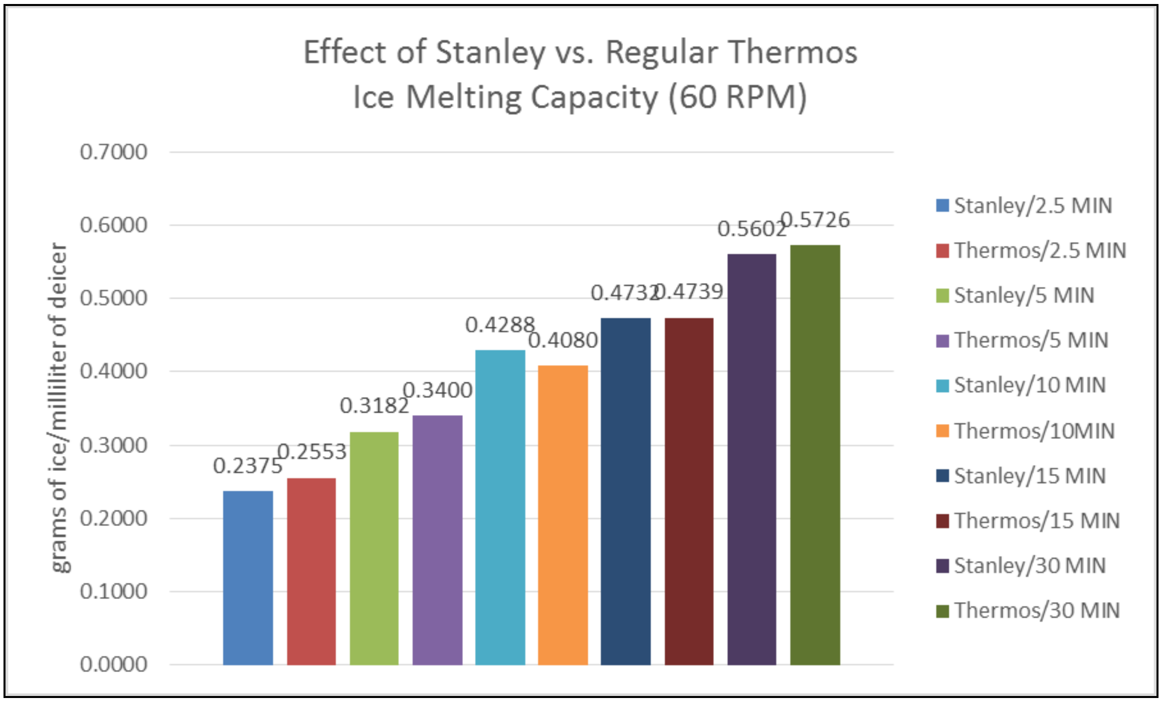

Figure 4.4 Stanley vs. Thermos - ice melting capacity

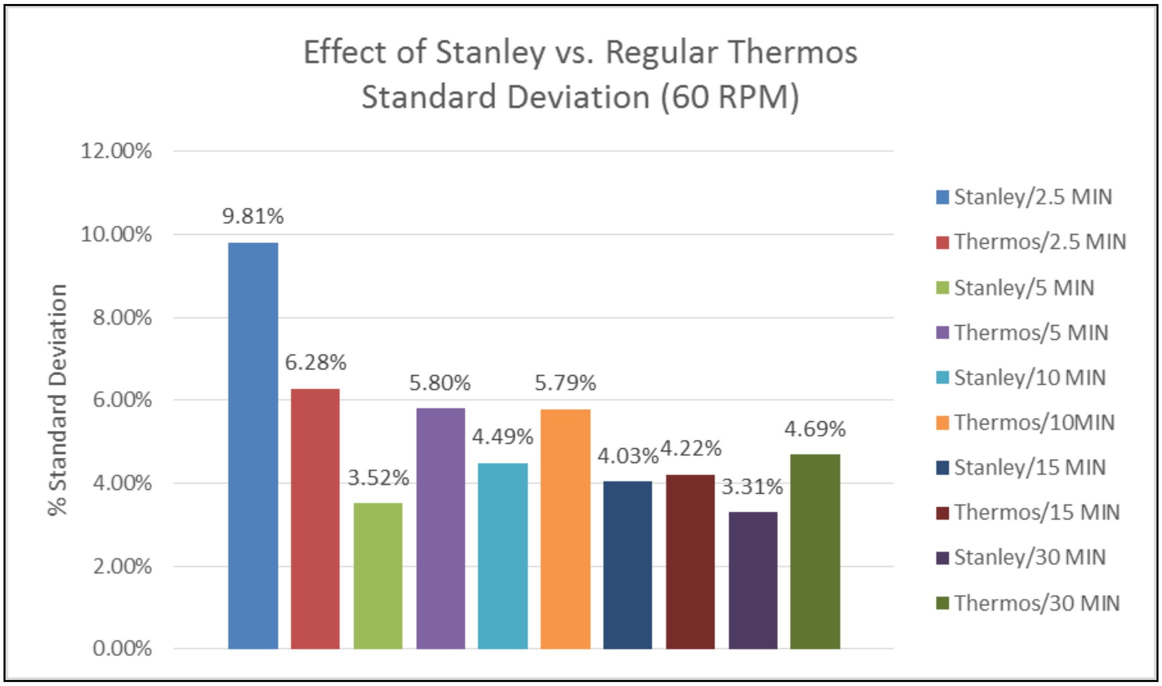

Figure 4.5 Stanley vs. Thermos - standard deviation

The rocking frequency was held constant at 60 RPM and the time durations ranged from 2.5 minutes to 30 minutes in these experiments. At this point in the testing, the ceramic bowls (as opposed to Styrofoam cups) were still being used for measuring, and the standard deviations in the test data were higher. Figure 4.4 shows that the Thermos™ consistently produced slightly higher ice melting capacities, but the difference is negligible. The standard deviation appears to be inconsistent for the 2.5 minute and 5 minute test durations, as shown in fig. 4.5. The scatter in the test data was probably due to an insufficient rocking time. However, for the 10 minute, 15 minute, and 30 minute test durations, the Stanley thermos performed more consistently than the Thermos™. It should be noted that the Thermos™ had a thermocouple wire installed inside of it to take temperature readings. The wire was well insulated but tiny air gaps around the wire could have contributed to error in the test data. It is inconclusive, based on this data comparison, to state one brand is better than the other. It was concluded that as long as a thermos is vacuum sealed for thermal insulation, it can be used for the test.

4.3 Revolutions Per Minute (RPM)

This series of tests was conducted at three rocking frequencies: 60 RPM, 90 RPM, and 120 RPM. One revolution of the rocking platform is defined as one edge of the platform that would start at its highest position, move to its lowest position, and then return to its highest position. This cycle of platform movement corresponds to one revolution of the motor shaft of the mechanical rocker. Data presented in figs. 4.6 and 4.7 were obtained using ceramic bowls for weighing and a tilt angle of 10° for rocking. Also, Thermos™ was used in these experiments.

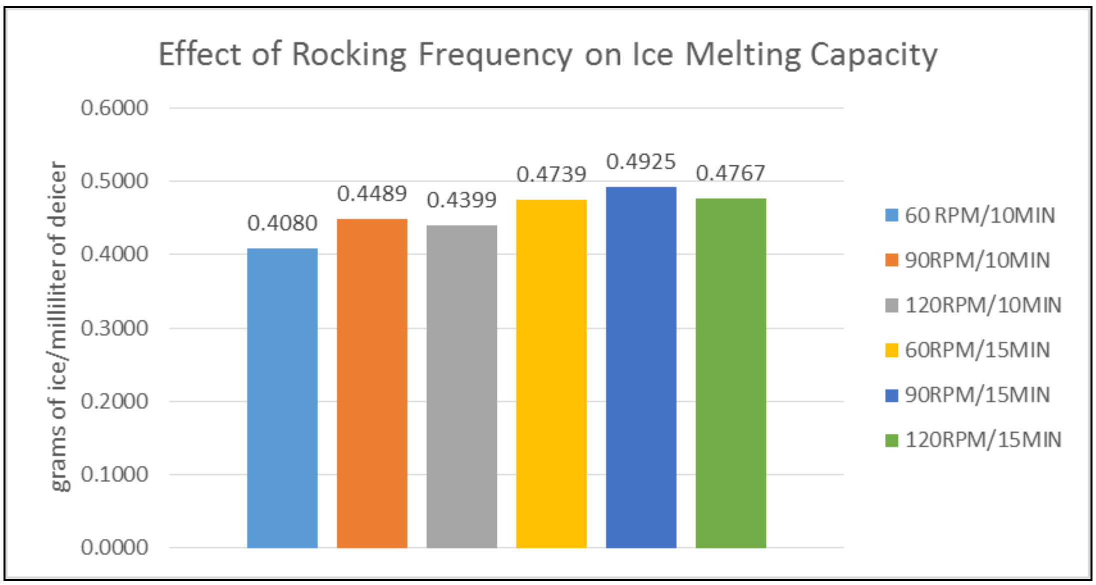

Figure 4.6 Rocking frequency - ice melting capacity

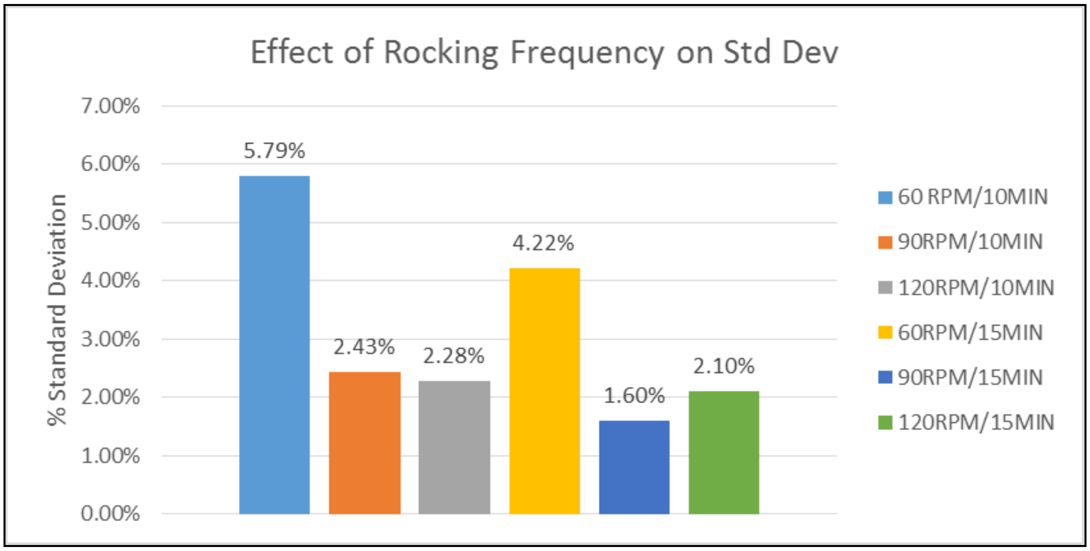

Figure 4.7 Rocking frequency - standard deviation

Comparing data obtained at 10 minute and 15 minute time durations, it can be seen that the 90 RPM parameter produced a slightly higher ice melting capacity than at 60 RPM and 120 RPM. Rocking the thermos faster does not produce more melting. Further, the standard deviations in figure 4.7 showed that 60 RPM did not produce the consistent results that 90 RPM or 120 RPM did. While the 90 RPM and 120 RPM results are comparable at a 10 minute duration, the 90 RPM produced more consistent data than the 120 RPM at 15 minutes. The results suggest that a 90 RPM rocking frequency at a 15 minute duration time would produce the most consistent test data.

4.4 Duration of Rocking

It seems that the best time duration for The Rocker Test would be the time required to reach a thermal equilibrium inside the thermos. The maximum amount of melting will have been achieved at this point because the temperature would continue to drop if additional melting was in progress. In this series of tests, a thermocouple wire was inserted inside the thermos to take temperature readings every thirty seconds. While the initial air temperature and the temperature when equilibrium was reached inside the thermos varied considerably, it was determined that thermal equilibrium was probably reached between 15 and 20 minutes. The temperature time-histories from a 60 RPM and a 90 RPM test are shown in figures 4.8-4.9, respectively. In these tests, very little temperature changes were noted between the 15 and 20 minute marks, indicating that ice melting had been complete within this time frame.

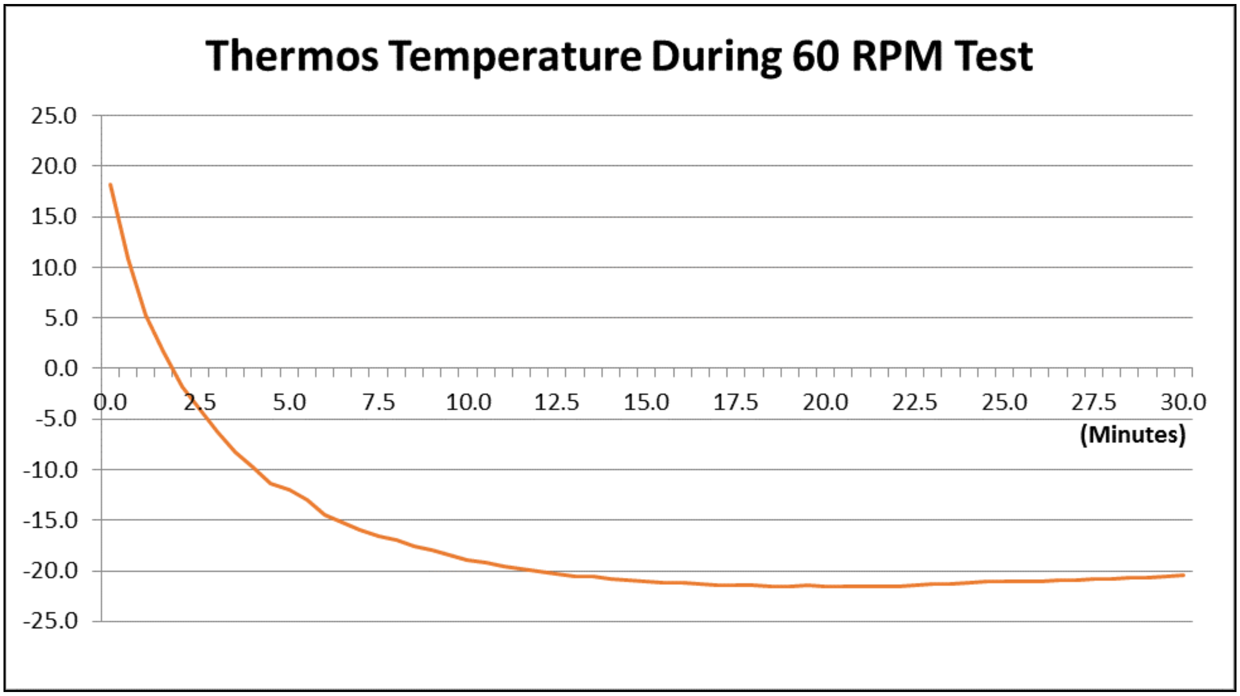

Figure 4.8 Thermos temperature during a 60 RPM test

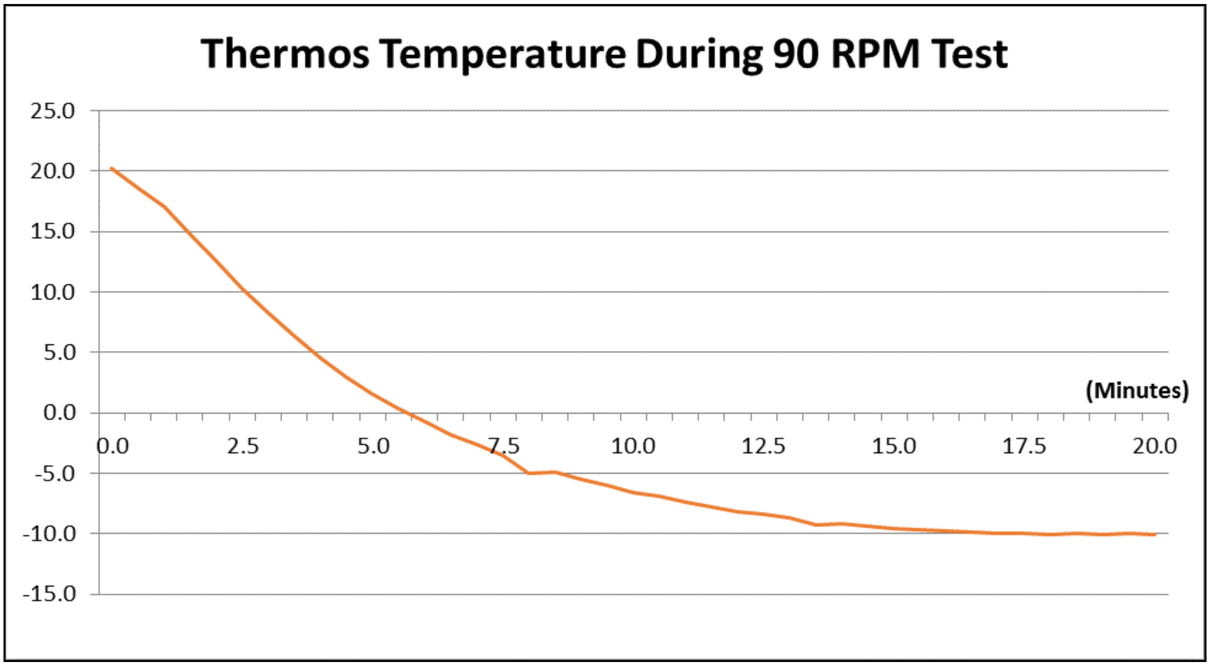

Figure 4.9 Thermos temperature during a 90 RPM test

These series of tests were conducted at 60 RPM and 90 RPM for 10 minute, 15 minute, and 20 minute durations each. As shown in figure 4.10, the ice melting capacity increases as the time duration increases. It is not apparent from the data, however, that melting really diminished after 15 to 20 minutes of rocking.

As shown in figure 4.11, the standard deviations are smaller at a 90 RPM than at a 60 RPM rocking frequency. Since the 90 RPM was selected to be the rocking frequency for the test procedure, it can be assumed that a 15 minute time duration would produce the least amount of scatter in the test data.

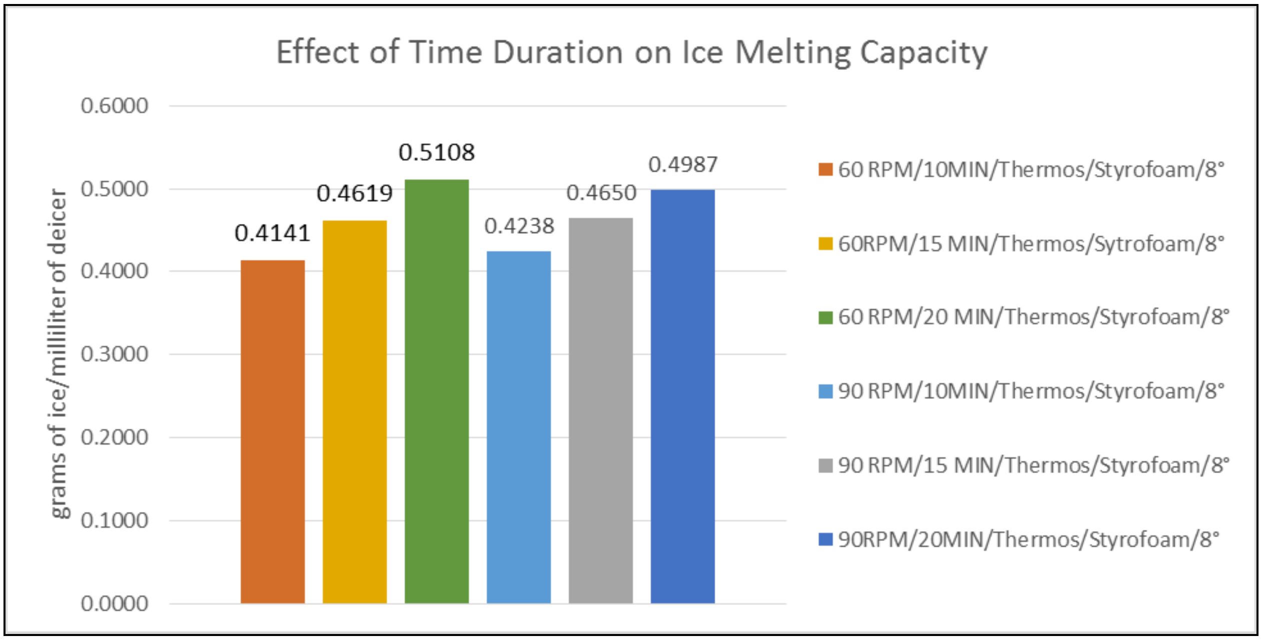

Figure 4.10 Time duration - ice melting capacity

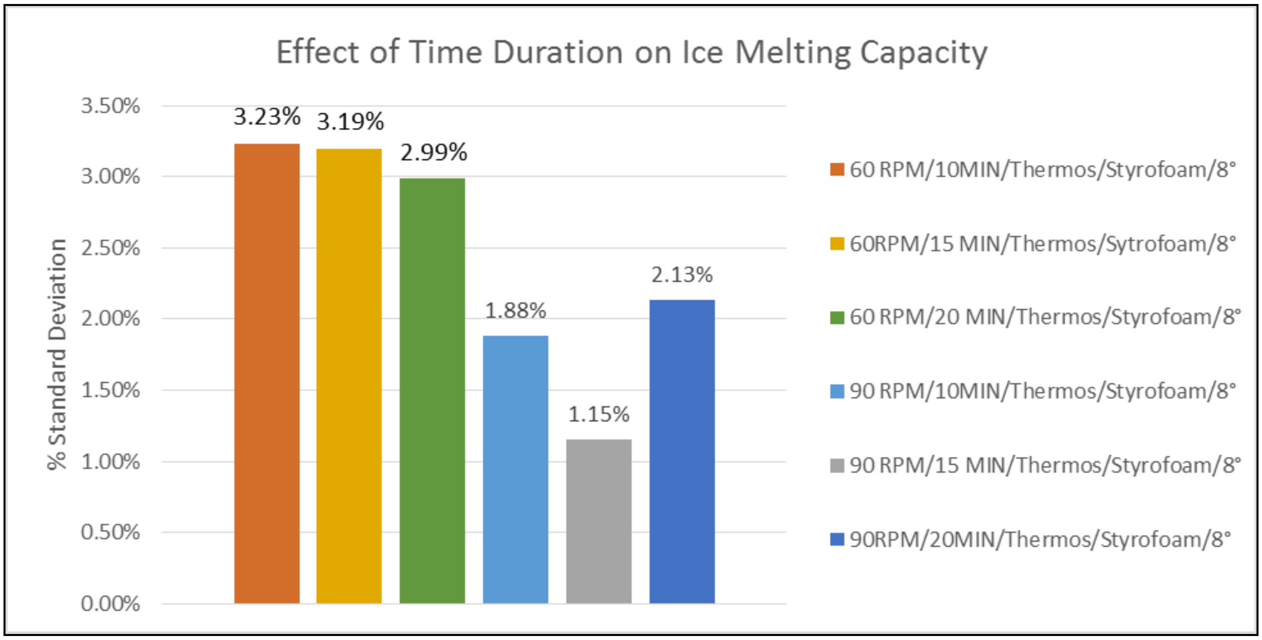

Figure 4.11 Time duration - standard deviation

4.5 Tilt Angle (10° vs. 20°)

Experiments were conducted to assess the impact of the tilt angle of the rocking platform at 10° and 20° tilt angles. Problems were encountered when adjusting the tilt angle of the rocking platform. The maximum tilt angle achievable by the Cole-Parmer rocking platform was 10°. As a result, another Cole-Parmer rocking platform that could achieve a 20° tilt angle had to be rented to accomplish the comparative studies. However, the maximum rocking frequency of this second platform was only 80 RPM.

As shown in figures 4.12-4.13, the 20° tilt angle produced better results than the 10° tilt angle at the 60 RPM rocking frequency. The increased tilt angle provides greater agitation of the ice cubes and deicer, which increases the amount of ice melted. For the 60 RPM tests, this also resulted in a lower standard deviation (see fig. 4.13). This result implies that the mixing in the 60 RPM tests at a 10° tilt angle was not sufficient to reach the maximum ice melting capacity of the MeltDown Apex™. Test data from the 80 RPM with a 20° tilt angle are compared to those from the 90 RPM with a 10° tilt angle in figures 4.14 and 4.15. Comparing the 90 RPM at a 10° tilt angle to the 80 RPM at a 20° tilt angle, shows that the ice melting capacities also increase with the higher tilt angle (fig. 4.14). The standard deviation did not drop at a higher tilt angle, however, because adequate mixing had already been achieved at 90 RPM (fig. 4.15). The standard deviation of 1.63% from an 80 RPM/20° tilt angle compares very close to the standard deviation of 1.60% from a 90RPM/10° tilt angle. The concentration of the magnesium chloride used in these tests was at 28.7%.

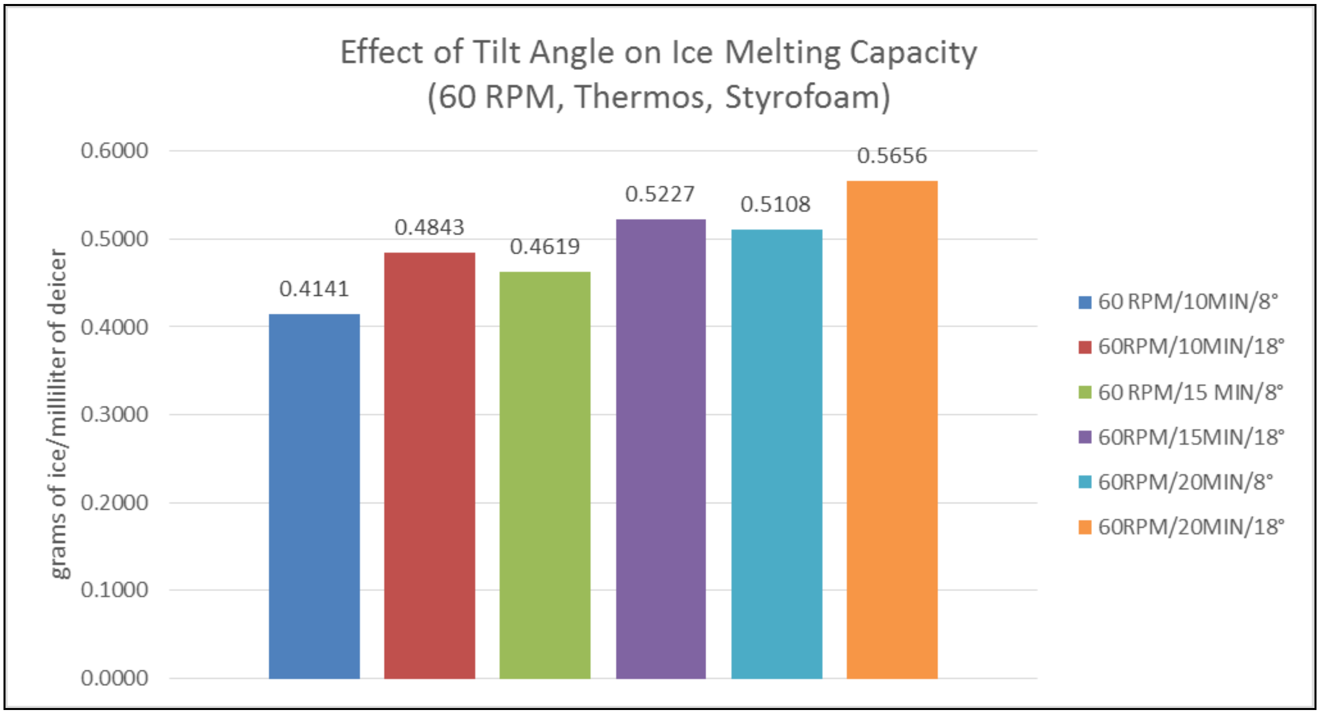

Figure 4.12 Tilt angle at 60 RPM - ice melting capacity

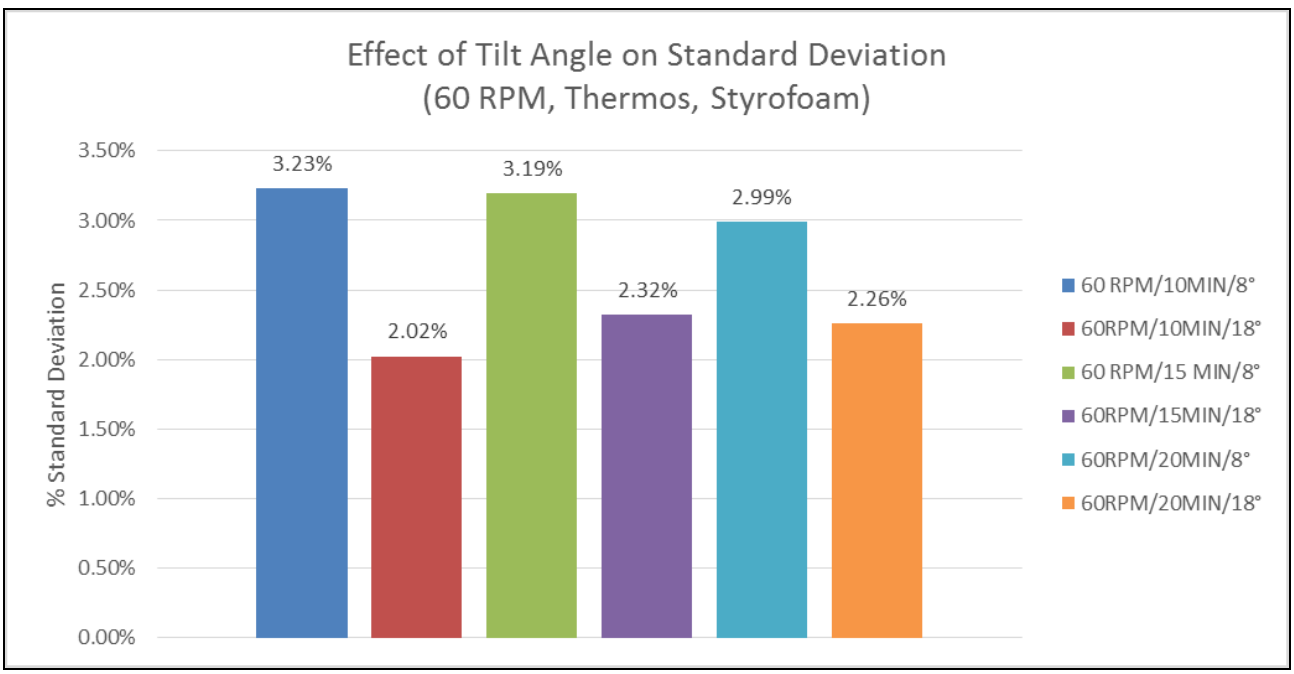

Figure 4.13 Tilt angle at 60 RPM - standard deviation

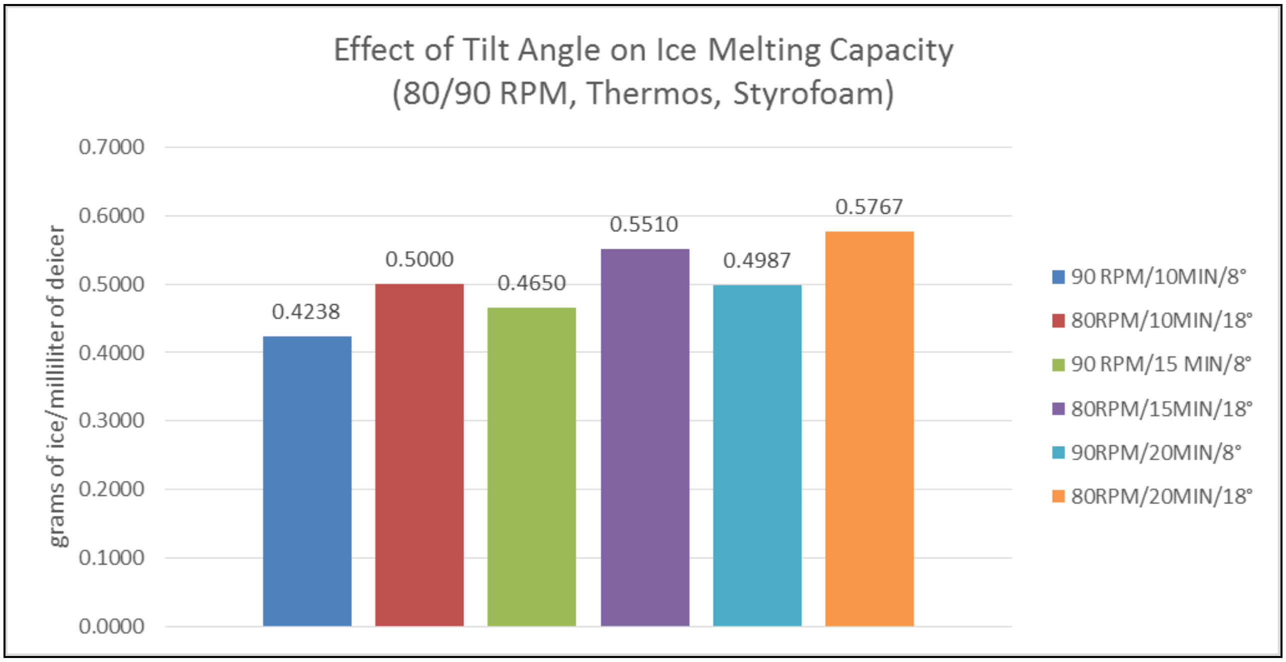

Figure 4.14 Tilt angle at 90 RPM - ice melting capacity

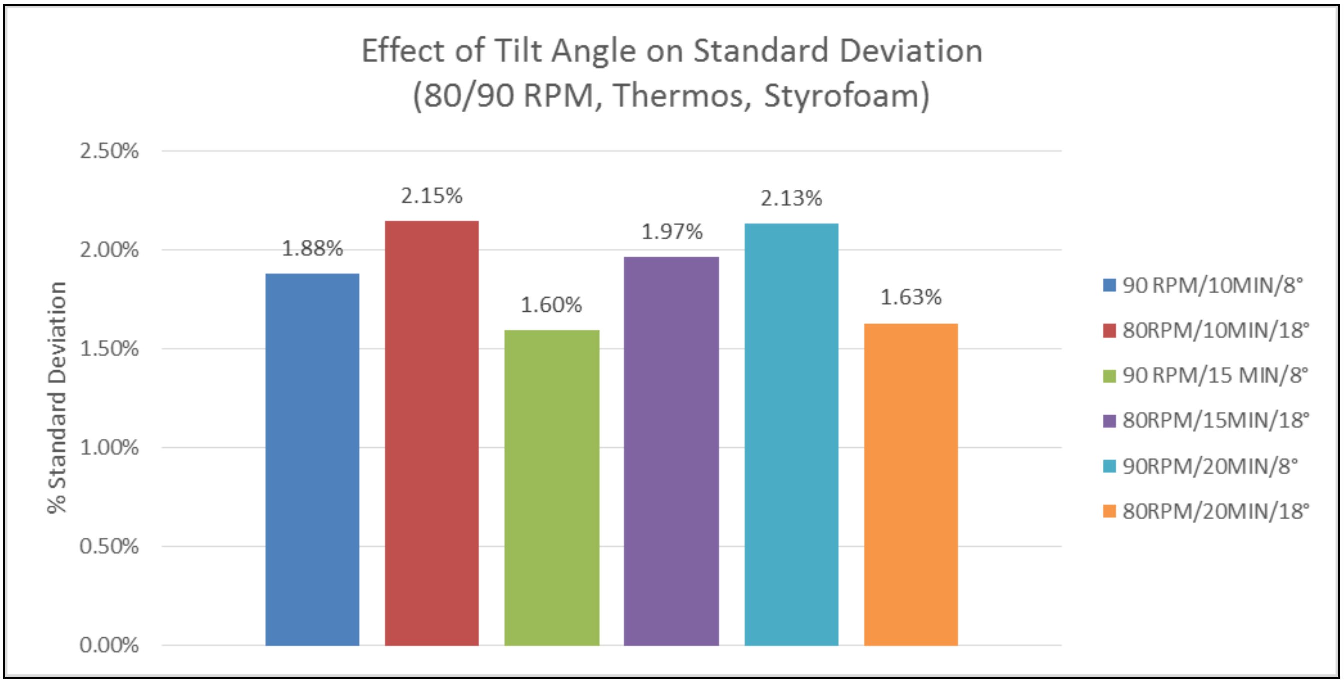

Figure 4.15 Tilt angle at 90RPM - standard deviation

Given that many commercial mechanical rockers have limitations on tilt angles of the platform, it was decided that a 90 RPM rocking frequency with a 10° tilt angle will be used for the test procedures because those settings are achievable by most mechanical rockers. A user is not limited to the lesser tilt angle specified in this report. The results by the user should be compared to the data given in figures 4.12-4.15 herein to see if similar standard deviations are obtained.

4.6 Styrofoam Cup vs. Ceramic Dish

During the earlier stages of The Rocker Test development, a ceramic bowl was used to weigh the ice. It was observed that the reading on the mass balance increased over time while weighing the ice in the ceramic bowl. When the ice contents were removed from the freezer, moisture in the room immediately built upon the ice in the form of condensation. Condensation also formed on the ceramic dish that had acclimated to the temperature of the freezer. This reaction made it difficult to determine the true mass of the dish. The first value observed on the mass balance was recorded. While it was unclear what percentage of error was introduced, it was decided that the use of a Styrofoam dish or cup would resolve this issue. Styrofoam has higher thermal insulation properties and does not conduct heat as easily as ceramic. Tests were conducted using both the ceramic dishes and a regular coffee cup. Test results are shown in figures 4.16-4.17.

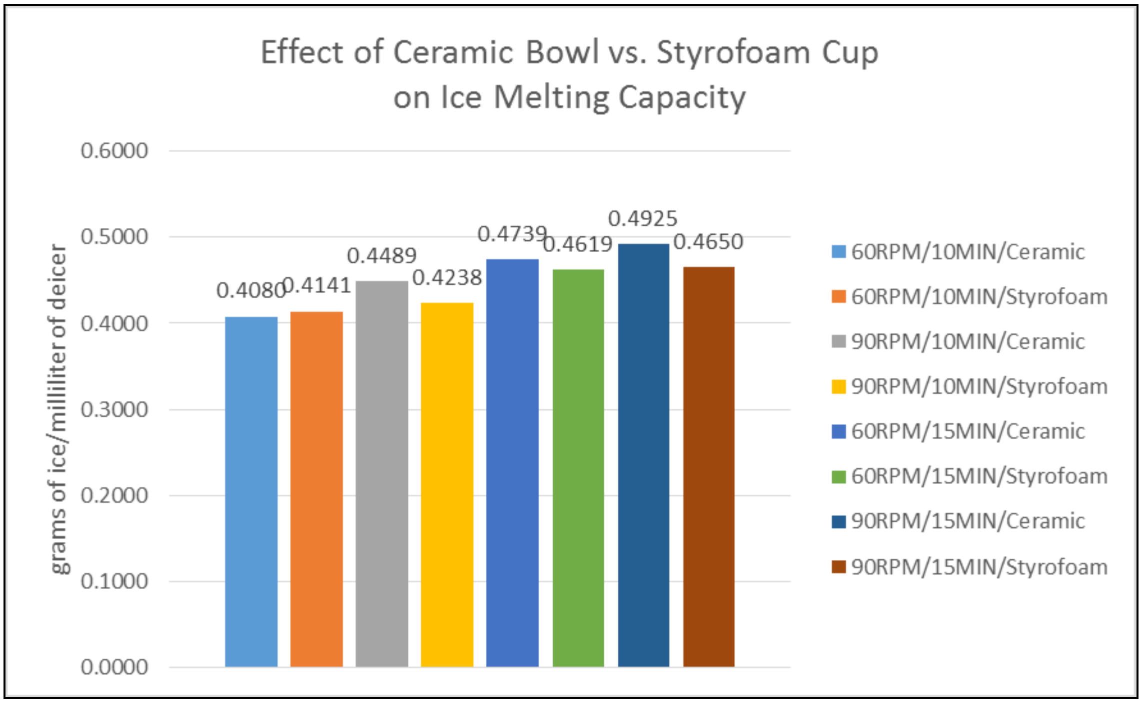

Figure 4.16 Ceramic bowl vs. Styrofoam cup - ice melting capacity

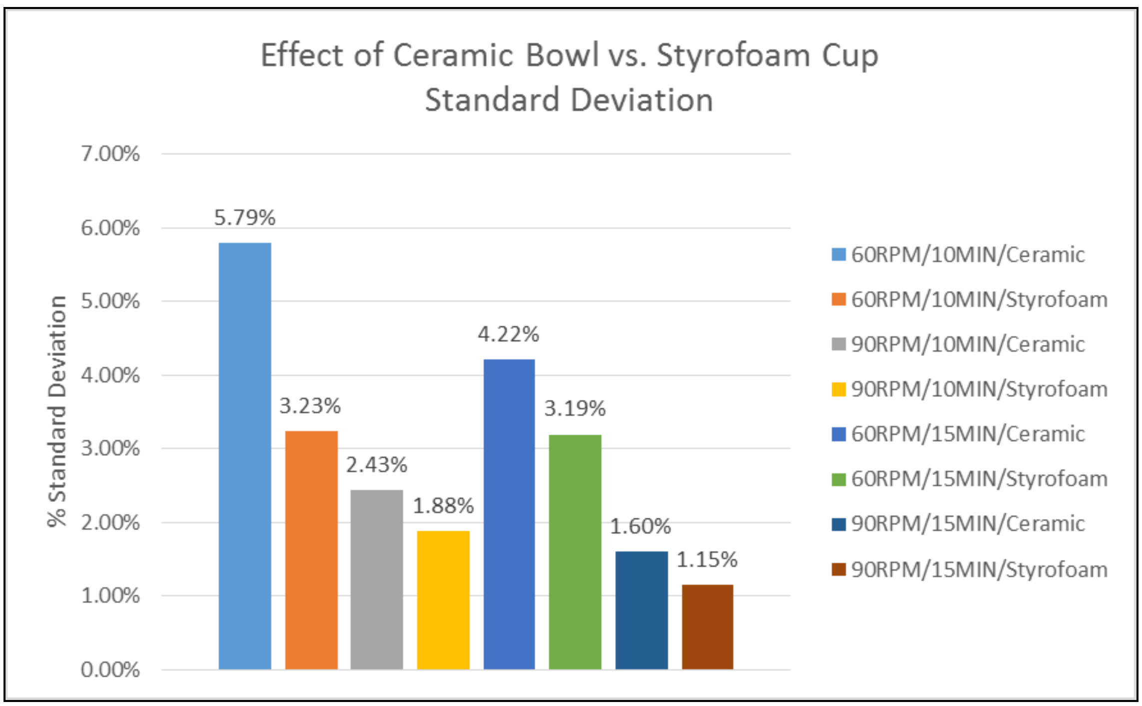

Figure 4.17 Ceramic bowl vs. Styrofoam cup - standard deviation

As anticipated, the percentage error decreased by at least 0.45% (as in the case of 90 RPM for 15 minutes) or more. Styrofoam proved to be beneficial in minimizing the moisture condensation. It reduced the error significantly and stabilized the mass balance reading.

4.7 Rocker Test Data Using Other Chemicals

After the development of The Mechanical Rocker Test, the test was performed using two additional chemicals, calcium chloride and salt brine, to show that the test produced consistent results. Only a set of three tests were conducted for each chemical. Figure 4.18 shows the different ice melting capacities of the three deicers. Magnesium chloride has the highest melting capacity at 0.4650 g/mL, calcium chloride has a melting capacity of 0.3793 g/mL, and salt brine has a considerably lower capacity at 0.1071 g/mL. As the ice melting capacities of the deicing chemicals decreased, the standard deviation percentages increased as shown in figure 4.19. The standard deviation percentage of magnesium chloride, calcium chloride, and salt brine were 1.15%, 2.33%, and 6.96%, respectively. Although the percentage standard deviations vary significantly, the actual standard deviations from the tests were comparable among the three deicers. The standard deviations of magnesium chloride, calcium chloride, and salt brine were 0.0054 g/mL, 0.0089 g/mL, and 0.0075 g/mL, respectively. These standard deviation values indicate that The Rocker Test procedure developed produces test results with reasonable accuracy.

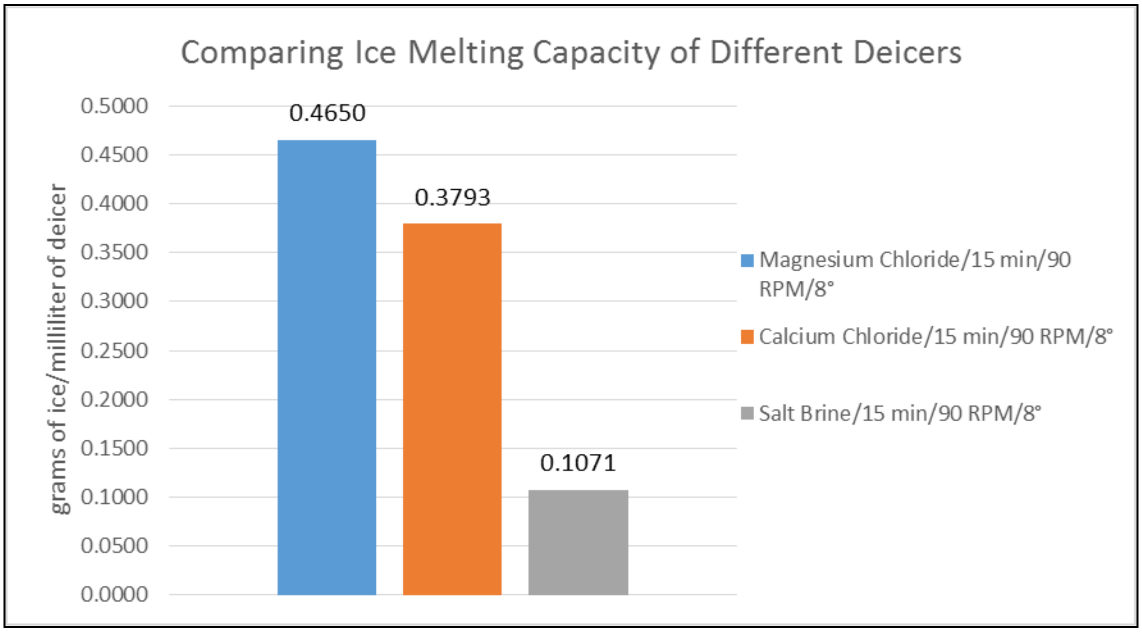

Figure 4.18 Different deicer chemicals - ice melting capacity

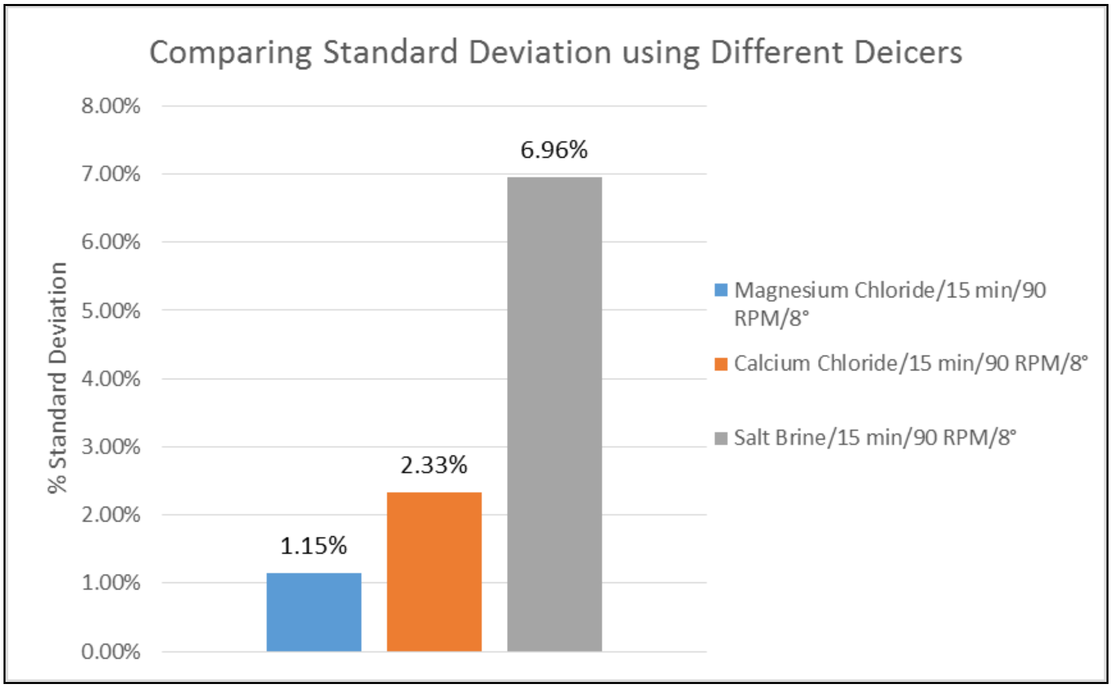

Figure 4.19 Different deicer chemicals - standard deviation

Chapter 5 The Proposed Mechanical Rocker Testing Procedure

The following is the proposed Mechanical Rocker Testing Procedure written in conformance with the ASTM standard format for parallel studies by other laboratories.

Mechanical Rocker Testing Procedure – for evaluation of the Ice Melting Capacity of Liquid Deicers:

1. Scope

1.1 This practice covers a procedure for testing the ice melting capacity of liquid deicers. The purpose is to affordably compare different liquid deicers for effectiveness.

1.2 This procedure does not pertain to the environmental effects or the corrosive effects of liquid deicers.

1.3 This procedure does not address the effects of sunlight upon a deicer chemical.

1.4 This standard does not address the safety concerns of handling different deicer chemicals. It is the responsibility of the user to address any safety concerns that may arise.

2. Referenced Document

2.1 ASTM Standards:

D345 Standard Test Method for Sampling and Testing Calcium Chloride for Roads and Structural Applications

3. Significance and Use

3.1 This test method describes procedures to be used for testing the ice melting capacities of chemical deicers to determine the effectiveness of different commercial deicing chemical products.

4. Apparatus

4.1 Mechanical Test Equipment:

4.1.1 Laboratory Freezer: The freezer must be large enough to hold at least three thermoses, one sieve, two ice trays, one funnel, a spatula, and tweezers (fig. 5.1). The freezer must be able to maintain a temperature of 0°F (-17.8°C) with an accuracy of ±1°F (±0.56°C).

4.1.2 Mechanical rocker: The mechanical rocker must be able to rock with a frequency range of 60 to 120 RPM. It must be capable of a tilt angle of ±10°. It must be able to hold the weight of at least 10 pounds.

4.1.3 A digital mass balance in a confined box with ± 0.001 gram accuracy. A confining glass box is important to eliminate the error caused by air flow within the room (see fig. 5.2).

4.1.4 Stop-watch: A digital stopwatch is required to record the rocking duration.

4.2 Sampling Equipment:

4.2.1 Latex gloves: A pair of latex gloves should be worn during the experiment.

4.2.2 Thermoses: Three stainless-steel vacuum-insulated thermoses (16 oz. each) labeled A, B, and C. It is important that the thermos be vacuum insulated to obtain the highest insulation possible. The thermos should also be stainless-steel to protect against corrosion from the deicer due to multiple uses.

4.2.3 No.4 Sieve, plastic spatula, and plastic tweezers: A No. 4 sieve allows particles no larger than ¼ inch (6.4 mm) to pass through its mesh. A sieve of a courser value may allow ice cubes to pass through, and a sieve of finer value may collect liquid on its mesh allowing for melting to continue. Using other sized sieves is not recommended. A plastic spatula and plastic tweezers will be used to collect the residual ice chunks on the sieve.

4.2.4 8 oz. coffee cups: A Styrofoam cup or dish must easily contain 33 ice cubes and also fit in the mass balance. Styrofoam as a material is important because of its insulation properties. Styrofoam was chosen as a material to eliminate the error caused by condensation when weighing the cup. If the reading of the mass balance increases significantly over time, the environment might be too humid such that the condensation on the cup or dish could cause significant error in the measurements.

4.2.5 Two ice cube trays: An ice cube tray must produce ice cubes that have a cross-section of 7/16 in × 7/16 in (1.1 cm × 1.1 cm) and a depth of 7/16 in (1.1 cm). The ice cube trays must be able to make 103 ice cubes total (33 ice cubes for 3 tests and at least 4 extra in case any are damaged or do not freeze properly).

4.2.6 Micropipette: The micropipette must be able to deliver 1.3 ml of water in a single delivery within the ±0.10 ml tolerance.

4.2.7 Pipette: A volumetric pipette must be able to deliver 30 ml of chemical deicer with a tolerance of ±0.03 ml.

4.2.8 Funnel: A working funnel must allow for the ice cubes to pass through the small-ended hole. The funnel's small end diameter must not be less than 1 in (2.5 cm).

4.2.9 Deicer Chemical: Any deicer liquid that can stay in liquid form at or below 0°F (-17.8°C).

5. Testing Procedures

5.1 Put on Latex gloves before testing.

5.2 Preparation:

5.2.1 Label six Styrofoam cups: A, B, C, AA, BB, and CC.

5.2.2 Label three thermoses: A, B, C.

5.2.3 Prepare ice cubes. Use the micropipette to dispense 1.3 mL of distilled/deionized water into the apertures of the ice cube trays to create 103 ice cubes (fig. 5.3). Thirty-three ice cubes are required for a single test, and three tests will be performed. Four extra ice cubes should be prepared in case some are damaged or do not freeze entirely.

5.2.3.1 After filling the ice cube trays, tap the sides of the tray gently to vibrate the liquid inside the tray. This breaks the surface tension of the water and ensures that all the ice cubes will freeze properly. Ice cubes that do not freeze properly will appear as unfrozen liquid or slush.

5.2.4 Prepare deicer sample. Use the pipette to dispense 30 mL of a given liquid chemical deicer into each of the three thermoses labeled A, B, and C. Make sure to shake or stir any container holding the liquid deicer chemical before dispensing it to the thermoses.

5.2.5 Measure and record the mass of the six pairs of 8 oz. Styrofoam cups labeled A, B, C, AA, BB, and CC using the digital mass balance.

5.2.5.1 A, B, and C will be used for the measurement of the mass of ice before testing.

5.2.5.2 AA, BB, and CC will be used to measure the mass of melted ice after rocking.

5.2.6 Place the thermoses and the ice cube trays into the freezer with the temperature set at 0°F (-17.8°C). Place the lids of the thermoses over the openings, but do not secure the lids. Allow all of the materials to acclimate and the ice to freeze for 24 hours. These materials include a #4 sieve with a bottom pan, a funnel, tweezers, and a spatula. Plastic tweezers and a plastic spatula are used for the separating of the ice from the deicer/melted ice. Place the Styrofoam cups labeled A, B, and C in the freezer.

5.3 Testing:

5.3.1 Working inside the freezer, place 33 ice cubes inside a single 8 oz. Styrofoam cup labeled *A.* The plastic funnel can be used to guide the ice cubes into the cup.

5.3.2 Remove Styrofoam cup A filled with the ice from the freezer and place it within the mass balance. Measure and record the mass of cup A and the ice, and place cup A and the ice back into the freezer. The reading on the mass balance should be recorded quickly within 30 seconds from the time the cup leaves the freezer.

5.3.3 Set the mechanical rocker's tilt angle to 10° and the frequency to 90 RPM.

5.3.4 Working within the confines of the freezer, remove the lid of the thermos and pour 33 ice cubes into thermos A using the funnel to guide the ice cube, and secure the lid. Thermos A should then be removed from the freezer, placed on the mechanical rocker perpendicular to the rocking axis, and the rocker started immediately afterwards (fig. 5.4). Start the rocker and the stopwatch simultaneously. Verify all of the ice cubes are in the thermos as the ice cubes may stick to the cup or the funnel. Also, make sure to tighten the lid securely to prevent leaking during the rocking motion. This step should not take more than 15 seconds.

5.3.5 Let the thermos rock for 15 minutes.

5.3.6 At the end of 15 minutes, remove the lid from thermos A and pour its contents onto the #4 sieve within the confines of the freezer. This step will separate the liquid from the remaining ice (fig. 5.5). Verify all the ice is dispensed from thermos A onto the sieve. Gently tap the sides of the thermos to remove excess ice and/or use the plastic tweezers and spatula to remove trapped ice, if necessary.

5.3.7 Place cup AA within the confines of the freezer and use the tweezers and/or spatula to move the ice from the #4 sieve into the cup. If the spatula is used to slide the ice into the cup, move no more than two ice cubes at a time to reduce the amount of liquid carried to the cup. In order to reduce ice melting, the ice cubes should be moved off of the sieve and into cup AA as quickly as possible. No more than 90 seconds should pass from the time the thermos is removed from the rocker in step 5.3.6 to the time the melted contents are moved from the sieve to cup AA. Cup AA should not have been allowed to acclimate with the rest of the testing materials in the freezer. Once inside cup AA, any melting that occurs will not affect the final mass of the ice.

5.3.8 Measure and record the mass of cup AA with the remaining ice in the digital mass balance. Although the effect of condensation is low, the reading on the mass balance will increase as the material remains on the balance. Cup AA should be removed from the freezer with its mass recorded in less than 30 seconds.

5.3.9 Repeat the test using cups B, BB, and thermos B, and then again using cup C, CC, and thermos C for a minimum set of 3 tests.

5.3.10 Calculate the mean and standard deviation of the ice melting capacity in grams (g) per milliliter (mL) of deicer and present the results as an estimate of the ice melting capacity of the liquid deicer.

6. Calculations

6.1 Use the following equations to calculate the ice melting capacity:

6.1.1 Mass of ice melted =

(cup A w/ ice – initial mass of cup A) – (cup AA w/ melted ice – initial mass of cup AA)

6.1.2 Ice melting capacity =

Mass of ice melted / 30 mL deicer liquid chemical (units are in grams of ice/mL of deicer)

7. Key Words

7.1 Ice melting capacity; deicer chemical; mechanical rocker

Figure 5.1 Freezer space

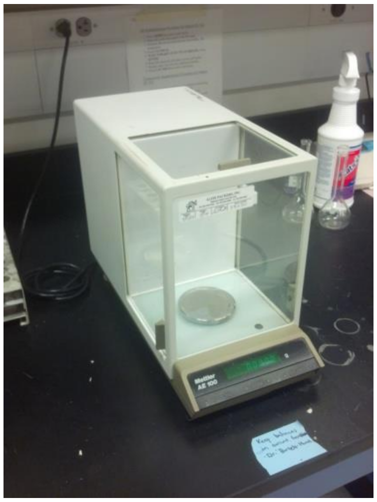

Figure 5.2 Digital mass balance in confining glass box

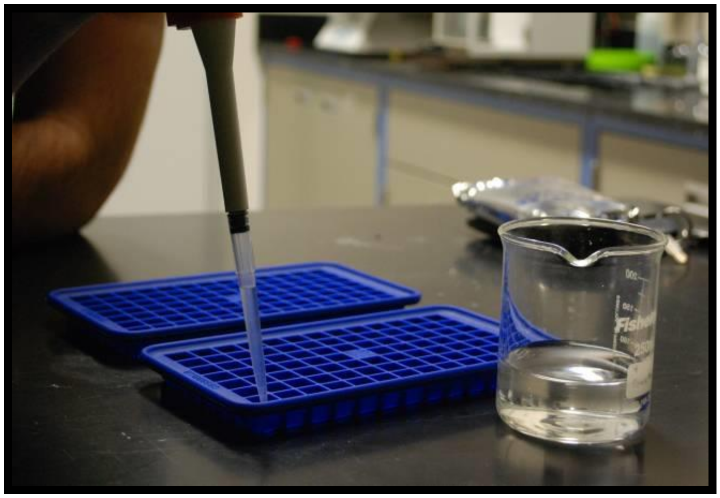

Figure 5.3 Filling ice trays

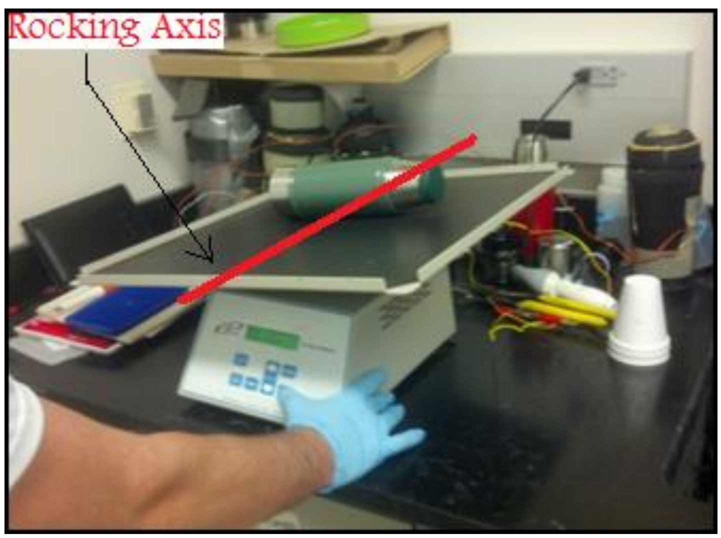

Figure 5.4 Rocking the thermos perpendicular to rocking axis

Figure 5.5 Separating the ice from the liquid

Chapter 6 Conclusions

The martini shaker test previously developed in research sponsored by MATC and NDOR has been significantly improved. The new testing procedure utilizes a mechanical rocker, and the new version is termed "The Mechanical Rocker Ice Melting Test." In this test, 33 ice cubes of 1.3-mL each and 30-mL of liquid chemical deicing are mixed in a vacuum sealed thermos on a mechanical rocking platform. The rocker is set to a frequency of 90 RPM with a tilt angle of ±10°. The time duration for rocking is set for 15 minutes. A Styrofoam dish or cup should be used for measuring the mass of ice. With these test parameters, it was shown that a standard deviation of 1.15% was achieved when testing with MeltDown Apex™.

This mechanical rocker ice melting test procedure will be submitted to Clear Roads and selected Departments of Transportation for parallel testing and feedback. The Mechanical Rocker Ice Melting Test can be used for screening new deicing products submitted by vendors each year. Once validated by other independent organizations, The Mechanical Rocker Ice Melting Test may be proposed to AASHTO for adoption regarding the ice melting capacity evaluation of liquid deicing chemicals.

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Appendix

The original test data that was accumulated during the entire development period of The Mechanical Rocker Ice Melting Test are given in this Appendix. The Mechanical Rocker Tests were repeated three times in each testing, which took approximately one day for the test preparation and experimentation. Each data set consisted of a total of 12 tests in 4 days. The test parameters used in the tests are given in the header of each data set. Ice melting capacities, standard deviations, and standard deviation percentages are calculated by an Excel spreadsheet. The concentrations of the deicers used in the tests are also given. Any highlighted data was thrown out for reasons such as experimentation contaminations, unusual outlier, or as noted otherwise.

TEN 1 mL CUBES::7 mL DEICER::SYRINGE					
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	
10/9/2012	7	9.429	7.382	0.2924	
	7	9.573	7.448	0.3036	
	7	9.225	7.101	0.3034	
10/10/2012	7	9.583	7.474	0.3013	
	7	9.481	7.289	0.3131	
	7	9.704	7.417	0.3267	
10/11/2012	7	9.559	7.367	0.3131	
	7	9.663	7.631	0.2903	
	7	9.580	7.555	0.2893	
10/12/2012	7	9.676	7.625	0.2931	
	7	9.722	7.932	0.2558	
	7	9.572	7.618	0.2792	
10/23/2012	7	9.281	7.393	0.2696	
	7	9.720	7.897	0.2604	
	7	9.668	7.590	0.2968	
			AVERAGE	**0.2911**	
			STD DEV	**0.0196**	6.74%

FORTY 1 mL CUBES::28 mL DEICER::SYRINGE					
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	
10/24/2012	28	38.539	28.740	0.3500	
	28	38.571	28.471	0.3607	
	28	38.962	27.872	0.3961	
10/25/2012	28	38.749	28.450	0.3678	
	28	38.723	28.990	0.3476	
	28	38.875	29.127	0.3481	
10/26/2012	28	38.568	28.433	0.3620	
	28	38.737	28.996	0.3479	
	28	39.103	29.430	0.3454	
10/29/2012	28	37.803	28.836	0.3202	
	28	37.701	27.868	0.3512	
	28	38.408	28.445	0.3558	
			AVERAGE	**0.3506**	
			STD DEV	**0.0130**	3.71%

FIFTY 0.8 mL CUBES::28 mL DEICER::MICROPIPET					
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	
11/19/2012	28	37.461	27.864	0.343	
	28	37.858	28.260	0.343	
	28	37.557	27.356	0.364	
11/23/2012	28	37.523	27.800	0.347	
	28	37.545	27.680	0.352	
	28	37.061	27.822	0.330	
11/27/2012	28	39.084	28.990	0.360	
	28	39.395	29.949	0.337	
	28	39.662	30.362	0.332	
11/30/2012	28	39.468	29.952	0.340	
	28	39.035	28.849	0.364	
	28	39.255	29.682	0.342	
			AVERAGE	**0.3462**	
			STD DEV	**0.0117**	3.37%

31 x 1.3 mL CUBES--MICROPIPET::28 mL DEICER--BURETTE:: 60 RPM					*
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	
3/19/2013	28	36.789	27.458	0.333	
	28	36.580	27.481	0.325	
	28	37.818	29.213	0.307	
3/21/2013	28	36.615	27.085	0.340	
	28	36.513	26.928	0.342	
	28	37.522	28.960	0.306	
3/23/2012	28	38.020	28.924	0.325	
	28	36.590	27.240	0.334	
	28	37.832	28.937	0.318	
3/26/2013	28	35.752	27.191	0.306	
	28	35.471	25.840	0.344	
	28	37.070	28.347	0.312	
			AVERAGE	0.3243	
			STD DEV	0.0145	4.48%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE:: 60 RPM :: STANLEY :: 5 MIN					
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	
4/22/2013	30	41.291	31.106	0.339	
	30	41.743	32.018	0.324	
	30	40.943	31.774	0.306	
4/24/2013	30	41.371	31.864	0.317	
	30	42.703	32.949	0.325	
	30	40.990	31.835	0.305	
4/26/2013	30	41.755	31.867	0.330	
	30	41.699	32.365	0.311	
	30	40.960	31.476	0.316	
4/27/2013	30	41.427	32.105	0.311	
	30	41.749	31.889	0.329	
	30	40.950	31.787	0.305	
			AVERAGE	0.3182	
			STD DEV	0.0112	3.52%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE:: 60 RPM :: STANLEY :: 2.5 MIN					
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	
5/3/2013	30	39.260	32.376	0.229	
	30	39.312	33.024	0.210	
	30	40.612	33.891	0.224	
5/6/2013	30	39.202	30.262	0.298	
	30	40.234	31.078	0.305	
	30	40.695	32.888	0.260	
5/7/2013	30	42.025	34.713	0.244	
	30	41.133	33.461	0.256	
	30	41.263	34.900	0.212	
5/8/2013	30	42.130	33.568	0.285	
	30	42.326	35.183	0.238	
	30	42.231	35.038	0.240	
			AVERAGE	**0.2375**	
			STD DEV	**0.0233**	9.81%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE:: 60 RPM :: STANLEY :: 10 MIN					
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	
5/10/2013	30	39.990	25.542	0.482	
	30	42.357	28.712	0.455	
	30	41.493	28.044	0.448	
5/11/2013	30	40.900	27.535	0.445	
	30	41.473	29.500	0.399	
	30	39.836	26.358	0.449	
5/13/2013	30	40.947	28.011	0.431	
	30	41.143	27.753	0.446	
	30	41.496	27.984	0.450	
5/14/2013	30	41.450	27.493	0.465	**MgCl2 %:**
	30	41.835	28.839	0.433	**28.40%**
	30	41.783	29.280	0.417	
5/15/2013	30	41.107	28.303	0.427	
	30	41.542	29.049	0.416	
	30	41.981	29.547	0.414	
			AVERAGE	**0.4288**	
			STD DEV	**0.0193**	4.49%

Note: Fields in orange and green were discarded because the concentration of the magnesium chloride used in the tests was unknown.

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE:: 60 RPM :: STANLEY :: 15 MIN					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.40%
5/23/2013	30	38.458	24.211	0.475	
	30	39.027	25.580	0.448	
	30	40.071	25.643	0.481	
5/24/2013	30	41.414	27.212	0.473	
	30	42.083	28.773	0.444	
	30	41.660	27.221	0.481	
5/25/2013	30	39.863	25.555	0.477	
	30	40.974	26.546	0.481	
	30	40.614	25.753	0.495	
5/28/2013	30	40.787	25.538	0.508	
	30	41.655	28.120	0.451	
	30	41.401	27.507	0.463	
			AVERAGE	0.4732	
			STD DEV	0.0191	4.03%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE:: 60 RPM :: STANLEY :: 30 MIN					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.40%
5/30/2013	30	41.412	24.170	0.575	
	30	41.169	24.196	0.566	
	30	41.491	24.657	0.561	
5/31/2013	30	40.224	24.556	0.522	
	30	41.353	24.923	0.548	
	30	41.407	24.699	0.557	
6/2/2013	30	41.457	23.963	0.583	
	30	41.491	24.915	0.553	
	30	41.804	24.471	0.578	
5/28/2013	30	-	-	#VALUE!	
	30	-	-	#VALUE!	
	30	-	-	#VALUE!	
			AVERAGE	0.5602	
			STD DEV	0.0185	3.31%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE:: 60 RPM :: THERMOS :: 30 MIN					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.40%
6/6/2013	30	35.866	23.563	0.410	
	30	39.949	23.034	0.564	
	30	39.294	22.709	0.553	
6/7/2013	30	39.021	21.451	0.586	
	30	40.741	22.137	0.620	
	30	38.289	21.434	0.562	
6/10/2013	30	39.829	22.742	0.570	
	30	39.624	22.747	0.563	
	30	38.261	21.615	0.555	
6/11/2013	30	40.144	22.734	0.580	
	30	38.660	22.747	0.530	
	30	40.112	21.615	0.617	
			AVERAGE	**0.5726**	
			STD DEV	**0.0268**	4.69%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE:: 60 RPM :: THERMOS :: 15 MIN					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.40%
6/12/2013	30	39.846	25.495	0.478	
	30	40.643	26.252	0.480	
	30	39.441	25.027	0.480	
6/13/2013	30	40.836	26.246	0.486	
	30	40.474	26.334	0.471	
	30	39.660	25.287	0.479	
6/14/2013	30	40.711	26.077	0.488	
	30	41.986	26.534	0.515	
	30	40.335	26.461	0.462	
6/17/2013	30	39.287	25.752	0.451	
	30	39.506	25.819	0.456	
	30	40.661	27.510	0.438	
			AVERAGE	**0.4739**	
			STD DEV	**0.0200**	4.22%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE:: 60 RPM :: THERMOS :: 10 MIN					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.40%
6/18/2013	30	39.952	27.376	0.419	
	30	40.847	28.912	0.398	
	30	41.463	29.955	0.384	
6/19/2013	30	40.475	28.328	0.405	
	30	40.699	29.727	0.366	
	30	40.287	28.689	0.387	
6/20/2013	30	40.509	26.930	0.453	
	30	41.370	29.428	0.398	
	30	40.521	28.143	0.413	
6/21/2013	30	39.605	26.632	0.432	
	30	40.642	27.920	0.424	
	30	42.273	29.735	0.418	
			AVERAGE	0.4080	
			STD DEV	0.0236	5.79%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE:: 60 RPM :: THERMOS :: 5 MIN					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	29.00%
6/24/2013	30	39.662	29.588	0.336	
	30	41.069	30.928	0.338	
	30	39.913	30.192	0.324	
6/25/2013	30	41.121	#VALUE!	#VALUE!	
	30	41.535	31.457	0.336	
	30	41.118	30.924	0.340	
6/26/2013	30	40.480	30.057	0.347	
	30	41.355	31.457	0.330	
	30	41.545	30.825	0.357	
6/27/2013	30	41.132	32.063	0.302	
	30	40.478	30.025	0.348	
	30	41.031	29.613	0.381	
			AVERAGE	0.3400	
			STD DEV	0.0197	5.80%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE:: 60 RPM :: THERMOS :: 2.5 MIN					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	29.00%
7/1/2013	30	40.909	33.041	0.262	
	30	41.486	34.084	0.247	
	30	39.368	32.263	0.237	
7/2/2013	30	40.834	33.493	0.245	
	30	40.799	33.939	0.229	
	30	40.210	32.427	0.259	
7/3/2013	30	41.519	34.134	0.246	
	30	42.056	30.367	0.390	
	30	41.792	33.817	0.266	
7/5/2013	30	40.253	32.259	0.266	
	30	40.529	32.512	0.267	
	30	41.472	32.960	0.284	
			AVERAGE	0.2553	
			STD DEV	0.0160	6.28%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE:: 90 RPM :: THERMOS :: 15 MIN					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	29.00%
7/9/2013	30	39.011	24.278	0.491	
	30	38.854	24.530	0.477	
	30	38.761	24.213	0.485	
7/10/2013	30	41.084	26.072	0.500	
	30	40.947	25.830	0.504	
	30	40.894	26.097	0.493	
7/11/2013	30	39.927	25.049	0.496	
	30	39.109	24.223	0.496	
	30	39.329	24.640	0.490	
7/12/2013	30	39.871	25.325	0.485	
	30	40.317	25.335	0.499	
	30	40.000	25.910	0.470	
			AVERAGE	0.4925	
			STD DEV	0.0079	1.60%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE:: 90 RPM :: THERMOS :: 10 MIN					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	29.00%
7/13/2013	30	41.570	27.907	0.455	
	30	41.777	28.196	0.453	
	30	41.539	28.309	0.441	
7/15/2013	30	38.362	25.009	0.445	
	30	39.482	25.689	0.460	
	30	40.272	26.454	0.461	
7/16/2013	30	41.911	28.504	0.447	
	30	40.709	27.905	0.427	
	30	41.369	28.230	0.438	
7/17/2013	30	40.045	26.230	0.460	
	30	39.357	26.144	0.440	
	30	39.749	25.973	0.459	
			AVERAGE	0.4489	
			STD DEV	0.0109	2.43%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::120 RPM :: THERMOS :: 10 MIN					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	29.00%
7/19/2013	30	41.073	28.575	0.417	
	30	40.378	27.462	0.431	
	30	41.156	27.932	0.441	
7/21/2013	30	40.665	27.146	0.451	
	30	40.842	27.523	0.444	
	30	41.278	27.916	0.445	
7/24/2013	30	39.792	27.681	0.404	
	30	40.404	27.340	0.435	
	30	41.277	27.871	0.447	
7/25/2013	30	41.324	28.216	0.437	
	30	41.678	28.483	0.440	
	30	40.830	27.282	0.452	
			AVERAGE	0.4399	
			STD DEV	0.0100	2.28%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::120 RPM :: THERMOS :: 15 MIN					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	27.60%
7/26/2013	30	41.614	27.162	0.482	
	30	41.652	27.344	0.477	
	30	41.886	28.002	0.463	
7/28/2013	30	41.101	27.259	0.461	
	30	40.790	26.560	0.474	
	30	41.578	27.529	0.468	
7/29/2013	30	41.492	26.856	0.488	
	30	41.452	27.246	0.474	
	30	42.155	27.808	0.478	
7/30/2013	30	42.017	27.379	0.488	
	30	42.159	27.947	0.474	
	30	41.971	27.145	0.494	
			AVERAGE	0.4767	
			STD DEV	0.0100	2.10%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::120 RPM :: THERMOS :: 20 MIN:STYROFOAM					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	27.60%
7/31/2013	30	41.852	26.767	0.503	
	30	41.307	25.880	0.514	
	30	41.980	26.992	0.500	
8/1/2013	30	41.776	26.613	0.505	
	30	42.086	26.673	0.514	
	30	41.791	26.733	0.502	
8/2/2013	30	41.540	27.125	0.480	
	30	42.055	27.484	0.486	
	30	#VALUE!	#VALUE!	#VALUE!	
8/5/2013	30	41.360	27.338	0.467	
	30	41.171	25.999	0.506	
	30	41.808	27.345	0.482	
			AVERAGE	0.4963	
			STD DEV	0.0151	3.04%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::90 RPM :: THERMOS :: 20 MIN:STYROFOAM					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	27.60%
8/6/2013	30	41.780	27.389	0.480	
	30	41.791	27.165	0.488	
	30	40.870	25.694	0.506	
8/7/2013	30	40.683	25.681	0.500	
	30	40.748	25.841	0.497	
	30	40.864	25.384	0.516	
8/8/2013	30	41.939	26.690	0.508	
	30	40.729	25.561	0.506	
	30	40.688	25.658	0.501	
8/9/2013	30	40.374	25.840	0.484	
	30	41.260	26.433	0.494	
	30	41.158	26.022	0.505	
			AVERAGE	0.4987	
			STD DEV	0.0106	2.13%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::60 RPM :: THERMOS :: 20 MIN:STYROFOAM					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	27.60%
8/13/2013	30	40.786	26.183	0.487	
	30	39.989	24.393	0.520	
	30	40.541	24.953	0.520	
8/14/2013	30	41.281	25.917	0.512	
	30	41.471	25.652	0.527	
	30	41.495	26.012	0.516	
8/15/2013	30	41.216	25.480	0.525	
	30	41.598	25.556	0.535	
	30	41.509	26.509	0.500	
8/16/2013	30	41.022	26.158	0.495	
	30	41.325	26.493	0.494	
	30	41.339	26.366	0.499	
			AVERAGE	0.5108	
			STD DEV	0.0153	2.99%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::60 RPM :: THERMOS :: 15 MIN:STYROFOAM:18^TILT					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.70%
11/12/2013	30	41.626	26.011	0.520	
	30	42.042	26.184	0.529	
	30	41.883	26.251	0.521	
11/13/2013	30	41.968	26.304	0.522	
	30	42.042	26.222	0.527	
	30	42.278	26.628	0.522	
11/14/2013	30	41.646	25.364	0.543	
	30	41.965	27.175	0.493	
	30	41.909	26.097	0.527	
11/15/2013	30	42.533	27.230	0.510	
	30	42.668	26.864	0.527	
	30	42.380	26.442	0.531	
			AVERAGE	**0.5227**	
			STD DEV	**0.0121**	2.32%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::60 RPM :: THERMOS :: 20 MIN:STYROFOAM:18^TILT					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.70%
11/20/2013	30	41.228	24.756	0.549	
	30	41.689	24.504	0.573	
	30	41.180	23.746	0.581	
11/21/2013	30	42.050	25.297	0.558	
	30	42.487	24.855	0.588	
	30	42.159	25.518	0.555	
11/25/2013	30	41.696	25.278	0.547	
	30	42.034	25.129	0.564	
	30	41.725	24.549	0.573	
11/26/2013	30	42.058	25.088	0.566	
	30	42.162	25.220	0.565	
	30	42.031	24.953	0.569	
			AVERAGE	**0.5656**	
			STD DEV	**0.0128**	2.26%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::60 RPM :: THERMOS :: 10 MIN:STYROFOAM:18^TILT					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.70%
12/17/2013	30	42.136	27.629	0.484	
	30	42.171	27.612	0.485	
	30	42.469	27.302	0.506	
12/20/2013	30	41.444	27.060	0.479	
	30	42.143	27.230	0.497	
	30	41.519	27.098	0.481	
1/7/2014	30	41.420	27.435	0.466	
	30	41.832	27.304	0.484	
	30	41.386	26.741	0.488	
1/8/2014	30	40.698	26.202	0.483	
	30	40.977	26.573	0.480	
	30	41.388	27.054	0.478	
			AVERAGE	**0.4843**	
			STD DEV	**0.0098**	2.02%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::80 RPM :: THERMOS :: 15 MIN:STYROFOAM:18^TILT					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.70%
1/14/2014	30	40.673	24.860	0.527	
	30	41.124	24.612	0.550	
	30	39.736	23.210	0.551	
1/15/2014	30	41.862	25.486	0.546	
	30	41.893	25.838	0.535	
	30	42.364	25.666	0.557	
1/16/2014	30	41.050	24.946	0.537	
	30	42.194	25.740	0.548	
	30	41.846	25.484	0.545	
1/17/2014	30	41.332	24.691	0.555	
	30	41.766	24.780	0.566	
	30	41.942	24.827	0.570	
			AVERAGE	**0.5510**	
			STD DEV	**0.0108**	1.97%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::80 RPM :: THERMOS :: 10 MIN:STYROFOAM:18^TILT					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.70%
1/22/2014	30	39.963	25.459	0.483	
	30	39.893	25.051	0.495	
	30	40.632	25.636	0.500	
1/23/2014	30	42.044	27.562	0.483	
	30	42.241	26.993	0.508	
	30	41.707	26.456	0.508	
1/24/2014	30	42.133	26.717	0.514	
	30	42.371	27.263	0.504	
	30	41.857	26.871	0.500	
1/26/2014	30	42.001	27.341	0.489	
	30	41.699	26.599	0.503	
	30	41.951	26.541	0.514	
			AVERAGE	**0.5000**	
			STD DEV	**0.0107**	2.15%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::80 RPM :: THERMOS :: 20 MIN:STYROFOAM:18^TILT					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.70%
1/28/2014	30	41.577	24.414	0.572	
	30	41.324	24.438	0.563	
	30	42.199	25.376	0.561	
2/3/2014	30	42.584	25.209	0.579	
	30	42.680	25.560	0.571	
	30	42.261	24.990	0.576	
2/5/2014	30	41.448	24.296	0.572	
	30	42.203	24.533	0.589	
	30	41.889	24.384	0.583	
2/6/2014	30	41.913	24.509	0.580	
	30	42.042	24.364	0.589	
	30	42.028	24.473	0.585	
			AVERAGE	**0.5767**	
			STD DEV	**0.0094**	1.63%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::90 RPM :: THERMOS :: 15 MIN:STYROFOAM:8^TILT					MgCl2 %:
DATE	**VOLUME OF DEICER (mL)**	**INITIAL MASS OF ICE (g)**	**FINAL MASS OF ICE (g)**	**ICE MELTING CAPACITY (grams of ice / mL of deicer**	**28.00%**
3/4/2014	30	41.908	28.798	0.437	
	30	41.750	27.808	0.465	
	30	42.065	28.040	0.468	
3/5/2014	30	41.639	27.927	0.457	
	30	41.954	27.904	0.468	
	30	41.878	27.938	0.465	
3/6/2014	30	41.999	28.031	0.466	
	30	42.074	28.289	0.460	
	30	42.274	28.514	0.459	
3/11/2014	30	41.946	27.838	0.470	
	30	42.013	27.756	0.475	
	30	42.165	28.277	0.463	
			AVERAGE	**0.4650**	
			STD DEV	**0.0054**	1.15%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::90 RPM :: THERMOS :: 10 MIN:STYROFOAM:8^TILT					MgCl2 %:
DATE	**VOLUME OF DEICER (mL)**	**INITIAL MASS OF ICE (g)**	**FINAL MASS OF ICE (g)**	**ICE MELTING CAPACITY (grams of ice / mL of deicer**	**28.00%**
4/8/2014	30	41.876	29.133	0.425	
	30	41.779	29.146	0.421	
	30	41.963	29.467	0.417	
4/9/2014	30	41.971	28.970	0.433	
	30	42.264	28.994	0.442	
	30	42.319	29.637	0.423	
4/11/2014	30	41.664	29.070	0.420	
	30	42.160	29.542	0.421	
	30	41.532	28.719	0.427	
4/13/2014	30	41.693	29.010	0.423	
	30	42.043	29.331	0.424	
	30	41.892	29.562	0.411	
			AVERAGE	**0.4238**	
			STD DEV	**0.0080**	1.88%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::60 RPM :: THERMOS :: 10 MIN:STYROFOAM:8°TILT					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.00%
4/14/2014	30	42.200	30.143	0.402	
	30	41.665	28.723	0.431	
	30	42.101	29.845	0.409	
4/16/2014	30	#VALUE!	#VALUE!	#VALUE!	
	30	41.962	28.802	0.439	
	30	42.313	29.450	0.429	
4/18/2014	30	41.446	28.915	0.418	
	30	41.696	29.672	0.401	
	30	41.412	28.987	0.414	
4/21/2014	30	41.722	29.495	0.408	
	30	41.230	29.099	0.404	
	30	41.848	29.815	0.401	
			AVERAGE	0.4141	
			STD DEV	0.0134	3.23%

33 x 1.3 mL CUBES--MICROPIPET::30 mL DEICER--PIPPETTE::60 RPM :: THERMOS :: 15 MIN:STYROFOAM:8°TILT					MgCl2 %:
DATE	VOLUME OF DEICER (mL)	INITIAL MASS OF ICE (g)	FINAL MASS OF ICE (g)	ICE MELTING CAPACITY (grams of ice / mL of deicer	28.00%
4/24/2014	30	40.842	26.824	0.467	
	30	40.838	26.866	0.466	
	30	41.328	26.704	0.487	
4/28/2014	30	40.368	26.058	0.477	
	30	41.857	28.090	0.459	
	30	40.781	26.649	0.471	
5/2/2014	30	40.420	27.133	0.443	
	30	41.477	27.405	0.469	
	30	40.165	26.288	0.463	
5/6/2014	30	40.677	27.636	0.435	
	30	40.834	27.418	0.447	
	30	41.992	28.217	0.459	
			AVERAGE	0.4619	
			STD DEV	0.0148	3.19%