DEPARTMENT OF TRANSPORTATION

Alternative Deicer Performance Characterization: Know Before the Snow

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MnDOT has been using alternative deicers (potassium chloride, magnesium chloride, and calcium chloride) to melt roadway ice at temperatures colder than sodium chloride can melt it alone. Using alternative deicers in brine form has been a way to leverage treatment techniques at temperatures below 15 degrees F. However, these alternative deicers have not yet had the "phase diagram" or "ice melt capacity relationship" developed to characterize their melting ability (potential and performance) by temperature and deicer concentration. Without these tools, MnDOT operators have been working on past observations, hunches and vendor recommendations, without the benefit of the science that guides their use of sodium chloride in rock salt brine. In colder regions of the state, the lack of scientific determination can be particularly troublesome as operators fight refreeze when either temperatures drop or deicer concentrations dilute down, which can result in either unsafe conditions or significantly extra material expense and environmental degradation.

This project developed a phase diagram and assessed the ice melt capacity of the alternative deicer most in use by MnDOT, specifically:

1. Quantified the freeze point curve for each of ten mixtures at temperatures down to -34 degrees F.
2. Quantified the ice melting capacity for each of six mixtures at temperatures down to -20 degrees F.
3. Field tested and compared melt behavior of five mixtures, comparing performance and assessing synergies under actual winter maintenance operations.

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Alternative Deicer Performance Characterization: Know Before The Snow

Final Report

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Anne Ludwick at Minnesota State Mankato ably shepherded this project through the contracts process every step of the way. Chandler Holland is the safety officer for Minnesota State who guided our field work to a safe experience; his care and professionalism is much appreciated.

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Executive Summary

The goal of this project was to develop a phase diagram and assess the ice melt capacity of the alternative deicer most in use by MnDOT, then to evaluate the alternative deicer in the field under conditions modeling actual highway conditions.

Characterization of BEET HEET®, the alternative deicer selected for study by the project's Technical Assistance Panel, was found to consistently have a specific gravity averaging 1.28, around 550 g/L total dissolved solids, and to average 37% organic content of the whole solids within the material. The samples showed moderate variability typically between 10 and 20% for most aggregate characteristics. BEET HEET® samples seem consistent particularly in total dissolved solids (TDS), inorganic content and specific gravity, likely a function of the high chloride content of the mixture. Greater but moderate variability appears to exist with the organic components of the mixture.

The freeze point curve of BEET HEET® and 23.3% salt brine mixtures was developed using concentrations from 0% (wholly salt brine) to 100% BEET HEET® and at temperatures from 0 °F to -34 °F. The ice melt capacity (IMC) of BEET HEET® and 23.3% salt brine mixtures at temperatures from 0 to -21° F was done also at concentrations from 0% (wholly salt brine) to 100% BEET HEET® and at temperatures from 26 °F to -21 °F. IMC, representing the volume of liquid measured/volume of deicer applied that was observed at levels ranging from 5.2 (at 26 °F) to 0.0 (at subzero temperatures). An IMC of 0.0 was interpreted as the deicer either froze or was wholly absorbed into the ice matrix. Values of IMC of 1.0 or less were consistently measured at temperatures of -10 °F or colder. "Ice softening" was reported by laboratory staff performing the IMC experiments at the colder temperatures of the study, even though the IMC measured less than 1.0 at those temperatures. It appears the deicer absorbs into the ice and disrupts the ice crystal matrix, not enough to create liquid and influencce IMC measurement, but enough to reduce the strength and firmness of the ice. When ice was melted by the applied deicer, most of the melting occurred within the first 30 minutes after application. When the applied deicer froze or was wholly absorbed into the ice matrix, the change occurred within the first hour after application.

In the field evaluation, deicing performance of BEET HEET® and salt brine mixtures was evaluated at an ambient temperature of 9° F with actual conditions of pavement, traffic, precipitation, sun and wind. On-pavement treatment comparisons allowed for performance of the alternative deicer to be compared across times and rates of application and co-treatment with rock salt. Traffic was systematically applied to the test locations after deicer treatment. The evaluation showed that rock salt amounts made little difference in deicing effect, and that traffic and pavement orientation appeared to have more effect. The amount of melted snowpack and open or opening pavement appeared to increase with additional amounts of liquid deicers, with the affected width estimated at about double for the higher amounts of liquid application. Differing liquid mixtures applied showed subtle but significant differences on deicing, ranging from a moistened snowpack under the treatment line, with no change over time for either additional melting or softening to a snow structure too slushy and wet to hold shape or form.

Chapter 1. Introduction

MnDOT has been using alternative deicers (potassium chloride, magnesium chloride, and calcium chloride) to melt roadway ice at temperatures colder than sodium chloride can melt alone. Using alternative deicers in brine form, a technique called direct liquid application (DLA), has been a way to leverage treatment techniques at temperatures below 15 degrees F. However, these alternative deicers for DLA have not yet had the "phase diagram" or "ice melt capacity relationship" developed to characterize the melting ability (potential and performance) by temperature and deicer concentration. Without these tools, MnDOT operators are working on past observations, hunches and vendor recommendations, without the benefit of the science that guides their use of sodium chloride in rock salt brine.

In colder regions, the lack of scientific determination can be particularly troublesome as snowplow operators fight refreeze when either temperatures drop or deicer concentrations dilute down, which can result in either unsafe conditions or significantly extra material expense and environmental degradation.

The goal of this project was to develop a phase diagram and assess the ice melt capacity of the alternative deicer most in use by MnDOT. With these tools, prediction of alternative deicer performance can be more scientific than just a "hunch" or similar situation comparison. Improved deicer performance would have several benefits, including potential reduction in costs, labor, and environmental impact.

1.1 Background

Clearing snow from roadways is an effort as old as roadways themselves, at least in cold climates. Truck mounted plows came into wide use by the 1920s. Abrasives such as sand, coal bottom ash or clinker were used to increase friction on icy roadways, once plowed. During the winter of 1941-42, New Hampshire became the first state to establish a systematic use of salt for deicing (TRB Special Report 235, 1991). About 1 million tons per year of salt were used for deicing in 1950; by 1970, 10 million tons per year were being used, an amount that has remained consistent though adjusted by winter-to-winter variation (Bolen, 2014). The rapid increase of salt use from 1950 to 1970 coincides with the rise of driver expectations for bare pavements during winter conditions, excepting storm events (TRB Special Report 235, 1991).

While awareness of environmental degradation caused by salt release from roadways into surface and ground water has trimmed amounts, winter driving conditions still require salt use: USGS (2019) reports about 27 million tons of road salt was used in 2018 in the United States. For the state highway and interstate system in Minnesota, MnDOT (2023) reports 260,000 tons of solid salt was used in the winter of 2022-23, plus approximately 13,500 tons more was used for brine application. Given that MnDOT maintains over 30,000 lane miles of highway, the rate averages over 18,000 pounds per lane mile for the whole winter season, or about 3 pounds per foot of lane. The total plowing and materials costs, as a statewide average, is reported by MnDOT (2023) for the winter of 2022-23 as $5,793 per lane mile.

Distribution of deicer on roadways has progressed from basic to quite advanced techniques as noted below (TRB Special Report 235, 1991, and author observation):

- 1940s: stationing of a shoveler in the back of a dump truck;
- 1950s: installation of a spinner plate below gravity fed chute for full roadway broadcast;
- 1970s: distribution through a smaller spinner plate or line drop onto the high side of travel lane, to encourage undercutting of ice through brine drainage;
- 1980s: incorporation of pre-wetting treatment onto granular deicer to improve roadway adherence and resistance to bounce or blow off;
- 1990s: introduction of pre-storm chemical treatment of pavements to anti-ice;
- 2000s: matching deicer spreading technologies with "smart vehicle" techniques such as maintenance decision support system (MDSS), automated vehicle location (AVL) and road weather information systems (RWIS);
- 2010s: introduction of brine blending systems and multi-component liquid chemical systems. Awareness of salt runoff as cause of environmental degradation; rise of "Smart Salting" programs, snow plow operator training and certification; and,
- 2020s: targeting of unique- and extreme-condition deicing associated with blizzards and "polar vortex" occurrence.

Alternatives in deicing material selection have been considered since the introduction of deicing as a technique, as cost-benefit analyses have accompanied the use of rock salt (bulk mined sodium chloride), solar salt (evaporated remains of solution mined or sea water-originated salt), magnesium chloride, calcium chloride, acetates, alcohols, carbohydrates and any other product available in bulk that can reduce the freeze point of water (Druschel, 2012). Many studies have been done since the 1980s of deicing and anti-icing performance addressing different materials, including:

- Chollar (1988) summarizes field studies done during the winter of 1986 – 87 comparing the performance of calcium magnesium acetate (CMA) and rock salt at four locations: Wisconsin, Massachusetts, Ontario and California.
- Hamilton et al. (1989) describes field trials of CMA and sodium formate (NaFo) against the performance of sodium chloride done during the winter of 1987 – 88 in Ottawa, Ontario.
- Raukola et al. (1993) describes an anti-icing program evaluation in Finland that used a residual chloride measurement to assess anti-icing persistence on pavement in a medium-duty roadway with 6,100 average daily traffic.
- Manning and Perchanok (1993) evaluates the use of CMA at two locations in Ontario using a comparison with rock salt for performance measures.
- Stotterud and Reitan (1993) discuss the findings of an anti-icing evaluation in Norway that considered weather factors on ice prevention, with performance assessed by friction measurements.
- Woodham (1994) describes a testing program that used a single storm event in 1991 with twelve roadway sections of 0.1 mile each in a single community in Colorado using four different materials/material preparations.
- Blackburn et al. (1994) presents a large and comprehensive study of anti-icing, consisting of liquid, solid and prewet solid anti-icing materials and techniques tested at fourteen locations in nine states (CA, CO, MD, MN, MO, NV, NY, OH and WA) during the winters of 1991 – 92 and 1992 – 93. Note: Blackburn et al. (1993) presented preliminary observations of techniques.

- Ketcham et al. (1998) is a follow-on study to Blackburn, et al. (1994) using eight of the sites previously studied and adding eight new sites to evaluate new techniques of anti-icing in comparison with conventional practices, with performance measured by friction tests and pavement observations, plus perceptions of passenger vehicle handling after treatment.
- Highway Innovative Technology Evaluation Center (1999) presents an evaluation of applications and techniques using Ice Ban Magic liquid deicer product, involving seven state highway agencies (AK, CO, IN, NE, NY, WA and WI) and one county.

Ice melting and compaction mechanics and the physical chemistry changes brought on by deicers have involved studies in primarily in laboratory setting, although some studies have had significant field verification aspects:

- Trost et al. (1987) is a laboratory study that evaluates deicing in the context of being fundamentally controlled by undercutting, allowing traffic to break up delaminated ice. Undercutting was further described as a two-phased behavior, first being controlled by ice melt capacity in a thermodynamic process and second being controlled by diffusion and density gradients in a kinetic process.
- Shi et al. (2013) connects the undercutting of Trost et al. (1987)'s two-phase behavior to observations of time being a highly significant factor in roadway ice melting.
- Blomqvist et al. (2011) shows that anti-icing and deicing operations could be negatively affected by the roadway wetness as traffic removes salt through splash and spray as well as run off, though first and foremost traffic appears to reduce deicer persistence.
- Muthumani et al. (2014) explores the differences between lab and field tests for evaluation of deicing and anti-icing chemicals, and suggested approaches for reducing the discrepancies in test conditions to improve the applicability for actual traffic conditions.
- Wåhlin and Klein-Paste (2015) evaluates the effects of deicing chemicals on the hardness of compacted snow and whether deicers cause an increase in snow compaction bonded to the pavement.

Fay, et al. (2022), in a work for Clear Roads Pooled Fund Program, presents the seminal work regarding the salt phase diagram, defined as the graphical representation of the physical states of a salt, ice and brine at varying temperatures and concentration (also known as a "ternary phase diagram" in physical chemistry). This work involves only sodium chloride but has set the standard by which snowplow operators are trained, as roadway deicing moves from "gut feel" to science-based approaches where application rates are determined based on pavement temperature, ice thickness, desired melting speed and configuration, and environmental protection. A one-page phase diagram fact sheet is presented in the Fay, et al (2022) report; this fact sheet is designed to be a "table top" and "break room" graphic for use by winter maintenance crews.

Fay, et al. (2022) presents the laboratory test results that contributed to the salt phase diagram development, including freeze point and solubility amount determinations across a range of temperatures (-6° F to +32° F) and sodium chloride (salt) concentrations (0 to 28% NaCl by weight). Further, friction testing was done of surfaces treated at the tested conditions, in a bench-scale approximation of field performance. Determination was done of the eutectic temperature, defined as the lowest temperature at which melting can be achieved, and the eutectic point, defined by the

concentration of sodium chloride required to achieve melting at the eutectic temperature, using the methods of Chappelow et al. (1992).

Discussion and determination of eutectic points, including consideration of the physical chemistry involved, are presented in several additional studies: Guthrie and Thomas (2014); Wåhlin et al. (2017); Klein-Paste and Wåhlin (2013); Du et al (2019); Farnham et al (2014), and Salt Institute (2016). Phase diagram development for salt was done with experiments presented by: El Kadi and Janajreh (2017), Luker et al. (2004), and Ketcham et al. (1996).

The speed of ice melting is evaluated by Wåhlin and Klein-Paste (2016). Dan et al. (2020) develops a "Water, Ice and Salt (WIS)" model to describe the time change of salt solution temperatures for the interaction of water, ice and salt on roadways during deicing. Druschel (2012) develops the concept of Ice Melt Capacity (IMC) regarding the amount of ice melted per the amount of deicer applied, using the methods of Chappelow, et al. (1992). Using the freezing curve to estimate Ice Melt Potential is described by Nilssen et al (2016). Fay et al (2022) notes that IMCs may vary between labs and research groups because of slight differences in materials and methods; however, comparisons in a single lab/research group of IMC between materials and application methods may provide critical comparisons within a given context.

Chapter 2: Sample Collection and Characterization

The goal of this task was to gain insight into aggregate characteristics and the variability of one chosen alternative deicer across two delivery years and across a geographic spread of delivery points within MnDOT's winter maintenance operations.

2.1 Materials and Methods

For this task, BEET HEET® (K-Tech Specialty Coatings, Inc., Ashley, Indiana) (K-Tech) was selected for study from available deicing brines used for direct liquid application (DLA) by the Technical Assistance Panel of this project. Eight BEET HEET® samples, each contained in a separate 5-gallon bucket, were obtained from different sources within MnDOT (Table 1 and Figure 1). Bucket samples were collected and transported to Mankato, Minnesota by MnDOT personnel where upon the research Project Investigator took custody.

Table 1. BEET HEET samples.

Sample Designation	Source Location (MnDOT Truck Station)	Season of Delivery to MnDOT (as reported)
BH Baxter July 2024	Baxter, MN	Summer 2024
BH Baxter Oct 2023	Baxter, MN	Fall 2023
BH Mankato Dec 2023 CL	Mankato, MN	Winter 2023
BH Mankato June 2024 MK	Mankato, MN	Summer 2024
BH Bemidji	Bemidji, MN	unknown
Roseau Old Fall 2023	Roseau, MN	Fall 2023
New BH Walker 7/29/24	Walker, MN	Summer 2024 *
Old Walker 7/18/24	Walker, MN	Fall 2023 *

Note: * assumed season based on description from sample collection or transport personnel.

Figure 1. Samples of BEET HEET®.

BEET HEET® is a brown, slightly odorous, liquid with a viscosity that appears to be similar to the viscosity of water; it is not "thick" but quite "loose", like water. The odor is faint and sweet as in sugar or molasses-like sometimes with a fragrance of alcohol and fermentation, particularly in the older samples (Standard Methods 2170). According to K-Tech Specialty Coatings (2023), BEET HEET® contains four chlorides and four carbohydrates (listed in the order listed by K-Tech):

- Calcium chloride, magnesium chloride, sodium chloride, and potassium chloride; and,
- Sucrose, glucose, fructose and raffinose sugars.

No effort was made to chemically "fingerprint" or define the constituents within the samples of BEET HEET® obtained for this project; per the project scope, analyses were done for aggregate properties, not individual component characterization. The aggregate property analyses were selected to evaluate and describe factors and variability related to the performance of the material in storage, handling, application, deicing and runoff aspects, with particular focus on deicing performance to be done in later project tasks. Analytical tests, generally done in conformance with methods described in (Rice, et al, 2012), hereafter referred to as Standard Methods, are listed in Table 2.

Specific gravity is a material identity, defined as the ratio of the material density to the density of water (1.00 g/mL). Determination of specific gravity was done using 100 mL Type A glass graduated cylinder with a precision of ±1.0 mL (1%). The graduated cylinder was filled to the 100 mL mark and a net mass of the 100 mL specimen obtained using a calibrated scale with 0.0001 g resolution.

Table 2. Analytical tests performed for this study.

Analysis	Method Reference
Specific Gravity (SG)	Identity
Conductivity (Sc)	Standard Methods 2510
Total Suspended Solids (TSS)	Standard Methods 2540 D
Total Dissolved Solids (TDS)	Standard Methods 2540 D
Inorganic Content	Standard Methods 2540 E
Organic Content	Standard Methods 2540 E
Acidity (pH)	Standard Methods 4500
Biological Oxygen Demand (BOD)	Standard Methods 5210
Chemical Oxygen Demand (COD)	Standard Methods 5200

Conductivity tests were done using an Environmental Express Oakton EC-100 portable conductivity meter (Environmental Express, Charleston, South Carolina), consisting of a twin-electrode probe connected to a readout device (Figures 2 and 3). Measurements were checked for calibration by testing of solutions of standard concentration (standards) before and after sample measurement. Checks for return to zero were done using measurement of deionized water between sample measurements. The probe was rinsed with deionized water between all sample and standard measurements. The probe was dried after rinsing using a laboratory-quality, lint free wipe (Kim wipe, Kimberly Clark Corporation, Neenah, Wisconsin).

According to Standard Methods: "Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends upon the presence of ions; on their total concentration, mobility, and valence; and on the temperature of the measurement." "Conductance of a solution is measured between two spatially fixed and chemically inert electrodes." Results are presented in units of milli-siemens per meter (mS/m).

As described by Standard Methods, pH value indicates the intensity of the acidic or basic character of a solution. It is measured using a standard hydrogen electrode and a reference electrode by correlation with the potentiometric or electromotive force between the electrodes when subjected to standard solutions (Standard Methods 4500). For this study, pH was measured by Minnesota Valley Testing Laboratories of New Ulm, Minnesota, using samples submitted for additional testing.

Solids refers to matter suspended or dissolved in water (Standard Methods 2540), and can be subdivided into several classifications:

- Total suspended solids (TSS), the portion of solids retained by a filter of 2.0 μm (0.002 mm) nominal pore size (Figure 4), expressed in units of mass per volume, typically mg/L or g/L;
- Total dissolved solids (TDS), the portion of solids passed through the filter (Figure 5), also expressed in units of mass per volume (mg/L or g/L);
- Organic content, the portion of TDS which is "volatile" (combustible) when heated to 550° C (1000° F), typically expressed as both mass per volume (g/L) and percentage of TDS; and,

Figure 2. Conductivity testing: measurement probe suspended in sample within bucket.

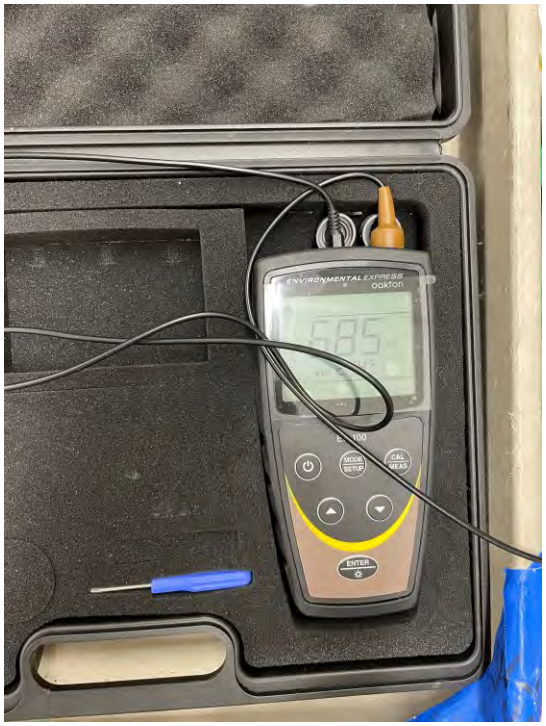

Figure 3. Conductivity testing meter readout.

Figure 4. Filters retaining suspended solids.

Figure 5. Dishes containing dissolved solids after combustion.

- Inorganic content, the portion of TDS which remains, likely as ash after combustion, when heated to 550° C (1000° F), also expressed as both mass per volume (g/L) and percentage of TDS. Organic and inorganic content will total 100% of TDS, by definition.

Organic characteristics of samples were also evaluated by the empirical methods Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) (Standard Methods 5210 and 5220, respectively). According to Standard Methods, the BOD test measures the molecular oxygen utilized during a specified incubation period for the biochemical degradation of organic material, also called carbonaceous demand. This demand is correlated with organic carbon content, as the oxygen demand is caused by bacterial respiration during consumption of the organic carbon as a food source. Results for the BOD test are reported as mg BOD/L or g BOD/L, often abbreviated to mg/L or g/L. BOD analyses for this project were measured by Minnesota Valley Testing Laboratories (MVTL) of New Ulm, Minnesota.

Chemical oxygen demand is defined by Standard Methods as the amount of a specified oxidant that reacts with the sample under controlled conditions, expressed in terms of its oxygen equivalence. The oxidant used for COD tests in this project was potassium dichromate. Like BOD, COD is correlated with organic carbon content, as the oxygen demand is caused by oxidation of the organic carbon in chemical reaction. Results for the COD test are reported as mg COD/L or g COD/L, often abbreviated to mg/L or g/L. COD analyses for this project were measured by MVTL.

Given the nature of BEET HEET®, there are likely to be interferences with the methods related to the unique composition of the material, particularly the high chloride levels, in some of the tests. Adjustments were not made at this time as it was concluded that the interferences were likely to be similar across the range of samples considered in this study. This conclusion was reached as the analyses were designed to evaluate the relative characteristic values ("order of magnitude" values) and particularly the variability of the results between samples, not exact values for comparison between materials.

2.2 Results

Appendix A presents full results of analyses performed by MVTL. Appendix B presents all analytical results, with bar graphs for comparison of key measurements. Appendix C presents analytical results evaluated by year in which delivery was received (either 2023 or 2024). Table 3 lists all analytical values determined, listed by sample and by analysis.

2.3 Evaluation

The eight BEET HEET® samples of this study were highly uniform in specific gravity and inorganic content, with RSDs of 5% or less. The samples were also uniform in pH, with a RSD of 8%. The BEET HEET® samples were fairly uniform in conductivity, TDS, inorganic content as percentage of TDS, organic content as percentage of TDS, and COD, all with RSDs of more than 10% but less than 20%.

Greater variability was measured in organic content with a RSD of 28%, BOD with a RSD of 38%, and TSS with a RSD of 57%.

The variation in TSS, even though wide, is considered insignificant as the suspended solids are a tiny fraction (0.03%) of the total solids, most of which are dissolved.

The variation in BOD is likely related to a single result (New BH Walker 7/29/24) about 6% of the average BOD of the other seven samples. The low result was not mirrored by similarly low values in organic content or COD; therefore this low result is likely a spurious result for an undetermined reason. Removing the low value and assessing the BOD of the remaining seven samples provides a RSD of 8%, which would be considered uniform results.

The variation in organic content appears predominantly due to a single sample (BH Bemidji) about 40% of the average organic content of the other seven samples. Removing this value would result in a change of the RSD from 28% to 18%, interpreted as the one value causing greater variation but that the other samples also have noticeable variation, just less.

Table 3. Analytical results by sample.

Analysis	**BH Baxter July 2024**	**BH Baxter Oct. 2023**	**BH Mankato Dec. 2023 CL**	**BH Mankato June 2024 MK**	**BH Bemidji**	**Roseau Old Fall 2023**	**New BH Walker 7/29/24**	**Old Walker 7/18/24**	**x ± SD, and RSD (%)***
Specific Gravity (SG)	1.317	1.301	1.300	1.299	1.234	1.277	1.282	1.237	1.281 ± 0.031 2%
Conductivity (Sc, mS/m)	6.74	7.27	7.66	6.85	10.22	7.78	6.77	7.00	7.536 ± 1.154 15%
Total Suspended Solids (TSS, g/L)	0.104	0.086	0.302	0.288	0.078	0.322	0.120	0.162	0.183 ± 0.104 57 %
Total Dissolved Solids (TDS, g/L)	600	569	517	603	416	597	648	511	558 ± 73 13%

Inorganic Content (g/L)	336	347	309	331	312	299	346	323	325 18 5%
Inorganic Content (as % of TDS)	56%	61%	60%	55%	75%	50%	53%	63%	59% 8% 13%
Organic Content (g/L)	264	222	209	272	105	298	301	188	232 66 28%
Organic Content (as % of TDS)	44%	39%	40%	45%	25%	50%	47%	37%	41% 8% 19%
Acidity (pH)	5.33	5.96	6.26	5.20	6.17	6.13	5.46	6.25	5.85 0.44 8%
Biological Oxygen Demand (BOD, g/L)	52.4	52.5	59.5	64.6	57.4	54.6	3.9	54.6	49.9 19.0 38%
Chemical Oxygen Demand (COD, g/L)	223	208	202	218	125	192	224	209	200 32 16%

* Mean, standard deviation, and relative standard deviation.

The low organic content of the BH Bemidji sample is also reflected in the low TDS value for the sample; the inorganic content by mass does not significantly vary (less than 5%) from the average of all the other samples. The BH Bemidji sample also has an unusually high conductivity about 40% more than the average conductivity of the other seven samples.

Evaluating the results when organized by assumed delivery year (Appendix C) shows differences but without a discernable pattern that could be related to storage or age. Reasons for the greater variability between average values of different assumed delivery years in two analyses (TSS and BOD) have already been discussed in relation to the whole sample population; no further conclusion is drawn.

2.4 Conclusions

The analyses of the eight BEET HEET® samples obtained for this study found BEET HEET® to consistently have a specific gravity averaging 1.28, around 550 g/L total dissolved solids, and to average 37% organic content of the whole solids within the material.

The analyses of the eight BEET HEET® samples obtained for this study show moderate variability typically between 10 and 20% for most aggregate characteristics. BEET HEET® samples seem consistent particularly in TDS, inorganic content and specific gravity, likely a function of the high chloride content of the mixture. Greater but moderate variability appears to exist with the organic components of the mixture.

Chapter 3: Determination of Melting Potential by Phase Diagram Construction

3.1 Introduction

The goal of this task was to determine melting potential at a range of temperatures and alterative deicer concentrations through eutectic point, melting (freezing) curve, and solubility curve determinations. The alternative deicer was mixed with salt brine at concentrations ranging from 0 to 100% and evaluated for melting potential at temperatures ranging from 32 ºF down to -34 ºF. Because freezers typically operate at 0 ºF, not necessarily at the temperatures required, two special cold chambers were built and operated at the evaluation temperatures, using techniques previously developed for MnDOT research and described in Druschel (2012). Visual observations were made of ice formation or melting for a range of concentrations at a given temperature. One set of observations was made over a range of time to evaluate the rate of ice melting or crystal growth. A phase diagram for the alternative deicer has been developed, mapping conditions of ice-melting potential for any liquid mixture made with the alternative deicer and salt brine and showing the ranges of refreeze potential and oversaturation (wasted material).

3.2 Materials and Methods

For this task, BEET HEET® (K-Tech Specialty Coatings, Inc., Ashley, Indiana) (K-Tech) was selected for study from available deicing brines used for direct liquid application (DLA) by the MnDOT Technical Assistance Panel of this project. BEET HEET® is a brown, slightly odorous, liquid with a viscosity that appears to be similar to the viscosity of water; it is not "thick" but quite "loose", like water. The odor is faint and sweet as in sugar or molasses-like sometimes with a fragrance of alcohol and fermentation, particularly in the older samples (Standard Methods 2170; Rice, t al., 2012). According to K-Tech (2024), BEET HEET® contains four chlorides and four carbohydrates (listed in the order listed by K-Tech):

- Calcium chloride, magnesium chloride, sodium chloride, and potassium chloride; and,
- Sucrose, glucose, fructose and raffinose sugars.

Test specimens, including all blends, were comprised of BEET HEET® stock and salt brine mixtures.

BEET HEET® stock consisted of liquid taken from a 5-gallon bucket sample labeled as "BH Mankato June 2024 MK" and supplied by MnDOT to the Principal Investigator (Chapter 2). BEET HEET stock was collected from the bucket sample and contained in a capped 1 L Erlenmeyer flask.

Salt used in this study was obtained as Morton Pure and Natural Water Softener Salt (Morton Salt, Inc., Chicago, IL). This material is commonly referred to as a "solar salt" as it is produced from solution brine mine product that is evaporated under vacuum and dried to achieve crystal forms of approximately ¼ th inch in size. Salt prepared in this manner is characterized by high purity as clay and silt impurities are removed in the brine processing.

Water used in this study for brine makeup was obtained from Seven Mile Creek, a perennial stream at Seven Mile Creek Park, Saint Peter, Minnesota, owned and maintained by the Nicollet County Public Works Department. According to the trail map and park brochure (Nicollet County Public Works Department, 2024), Seven Mile Creek is a groundwater-dominated stream. This water source was selected to be a water of consistent composition that closely matches untreated groundwater typical of well water composition in Southern Minnesota.

Salt brine stock was made in a 1 L Erlenmeyer flask by weighing out solar salt and blending into a weighed-out amount of stream water such that the mixture comprised 23.3% salt. Mixing of salt brine stock was done rapidly until the granular salt crystals were fully dissolved. Salt brine stock was then capped and kept slowly mixing until use.

BEET HEET® mixtures of 120 mL volume were made using BEET HEET® stock and salt brine stock, measured using transfer pipettes with a precision of +/- 1 mL, and mixed in a 160 mL glass beaker. Ten mixtures were made up:

- 100% salt brine
- 10% BEET HEET® stock and 90% salt brine (called “90:10” by plow operators and supervisors, according to the Technical Assistance Panel of this project; nomenclature used similarly throughout this report)
- 20% BEET HEET® and 80% salt brine (called “80:20”)
- 30% BEET HEET® and 70% salt brine (called “70:30”)
- 40% BEET HEET® and 60% salt brine (called “60:40”)
- 50% BEET HEET® and 50% salt brine (called “50:50”)
- 60% BEET HEET® and 40% salt brine (called “40:60”)
- 70% BEET HEET® and 30% salt brine (called “30:70”)
- 85% BEET HEET® and 15% salt brine (called “15:85”)
- 100% BEET HEET®

Test specimens were made using 20 mL aliquots of BEET HEET® mixtures transferred using a transfer pipette with a precision of +/- 0.1 mL into 60 mL volatile organic analysis (VOA) glass vials and capped, leaving 40 mL of empty headspace. Approximately 0.6 g of sand was added to the mixture in the vial as an inert physical material upon which ice crystals could begin nucleation to limit potential supercooling (liquids being colder than freeze point not icing up as the crystals have no rough spot on which to begin forming). The inert sand was “sugar sand”, a poorly graded, medium sand which is composed primarily of quartz. Test specimens were stored in a 39 ºF refrigerator until use.

Ethylene glycol (glycol) is a liquid material that is commonly used as an antifreeze and corrosion inhibitor. Mixtures of glycol and water have highly predictable freeze points that are correlated with the specific gravity of the glycol-water mixture. In this study, proportions of glycol (Dynalene® EG; Dynalene, Inc., Whitehall, PA) and water were measured out and blended into mixtures that would freeze at target temperatures below 0 ºF. For identification of glycol and differentiation from water, glycol was dyed yellow florescent dye, in conformance with the coloration used for engine coolant fluids containing glycol.

Freeze point relationships to glycol weight proportion of glycol-water mixtures were taken from an ethylene glycol heat transfer fluid freeze point chart (CoreChem 2024). Temperatures targeted for study were created by freezing glycol-water mixtures in a -40 ºF laboratory freezer until the mixture was halfway frozen, then removing the mixture from the freezer and mixing the partially solid mixture into an ice slush of uniform consistency (Figure 6) to make an "ice bath". The slush was then put into one of two freeze chambers, depending upon volume of the ice slush being used:

- A 120-quart (114 L) Igloo Polar Cooler (Igloo Products Corp., Katy, Texas), if the ice slush volume was approximately 50 L, that was kept closed and positioned on a lab bench in an ambient air temperature of 69ºF; or,
- A 4 L High Density Polyethylene (HDPE) bucket, if the ice slush volume was approximately 2 L in volume, that was kept in a 0 ºF freezer to maintain temperature of the ice slush.

Figure 6. Ice slush composed of glycol – salt brine mixture.

Vials were placed in the bucket freeze chambers and were supported either using a grid of HDPE (commercially available snow fence), submerged in the ice slush to about half the depth of the slush (Figure 7), or using a brick for support (Figure 8). When used, bricks were pre-frozen at -40 ºF, inserted in the glycol mixture and allowed to equilibrate prior to placement of the sample vials.

Temperatures of slushes and fluids were measured using Jumbo Display Traceable Dial Thermometers (Traceable® Products, Webster, TX) with a range of –58 to 302 °F, a digital resolution of 0.1 °F, and an

accuracy of ±0.5 °F. The thermometers were calibrated and certified by the manufacture prior to use in this study. These thermometers use a stainless-steel probe for use in harsh liquids including salt brines, but are not protected from immersion. Thermometers were kept above liquid and slush surfaces either by using polystyrene foam for buoyancy (floating) or overhead support (suspended).

Figure 7. Bucket freeze chamber supporting grid.

Figure 8. Bucket freeze chambers with supporting brick and specimen vials; temporarily removed from 0 ºF to inspect and observe vial specimens.

To measure freeze point, BEET HEET® mixture specimens (20 mL liquid in a 60 mL VOA vial, as described above) were inserted into ice slushes of a known temperature and allowed to equilibrate for at least 1 hour. Figure 9 shows direct insertion of the specimen vials into the slush in a cooler freeze chamber. Figure 10 shows the bucket freeze chamber method of chilling specimens to a target temperature, with placement of the bucket freeze chamber in a 0 °F freezer to maintain ice slush temperature.

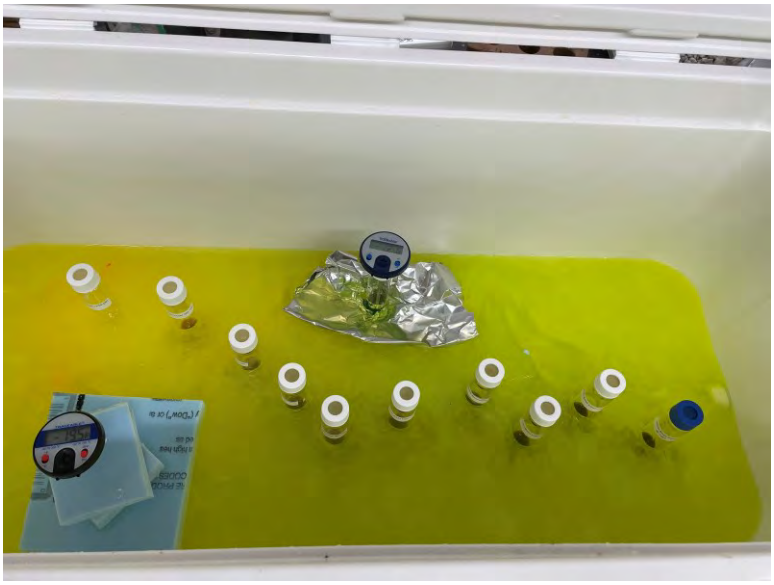

Figure 9. Direct insertion method of chilling specimens to a target temperature; placement in a cooler freeze chamber with floating thermometers.

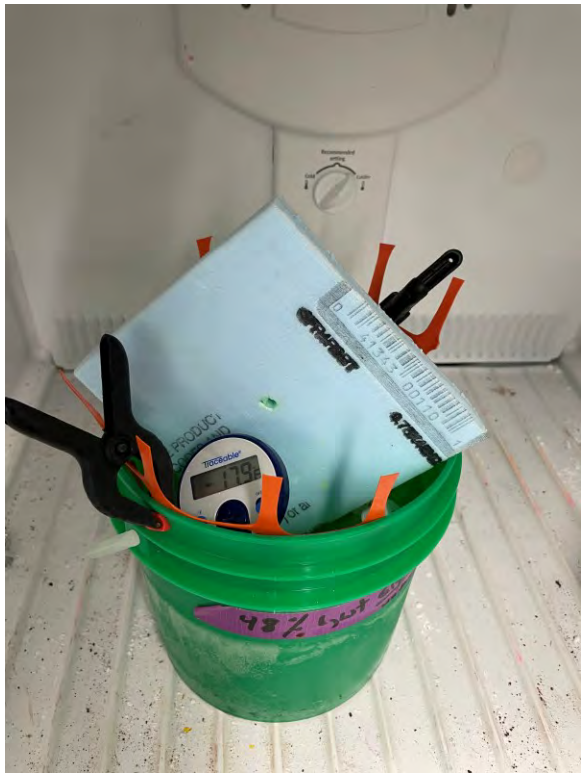

Figure 10. Bucket freeze chamber method of chilling specimens to a target temperature; placement of bucket freeze chamber in a 0 °F freezer with suspended thermometers.

Specimens were then inspected visually for presence of solid phase material (other than the included inert sand). Results were recorded as a descriptor word or phrase, ranging from:

- Unfrozen, i.e., no solid ice matrix observed;
- Half frozen, i.e., approximately equal volumes of solid ice matrix and liquid observed;
- Mostly frozen, i.e., some liquid observed within a mostly solid ice matrix; to,
- Wholly frozen, i.e., no free liquid observed (Figure 11).

Two other states were observed during the study:

- Bottom freezing, i.e., ice crystals (typically about 2 – 3 mL in volume) forming on the bottom of the specimen (Figure 12); and,
- Unfrozen (*supercooled*), i.e., salt brine being colder than the freeze point well established for the lowest freeze point of salt brine (-6 °F), a state in which ice crystals have not yet developed due to a lack of impurities within the fluid such that ice crystals have insufficient points on which to initiate.

Figure 11. Wholly frozen 90:10 specimen from -16.5 °F ice bath (originally at -17.9 °F).

Figure 12. Bottom freezing in 60:40 specimen.

3.3 Results

Appendix D presents full results of analyses performed. Three presentations of data are provided:

- Tabulation of all observations of tested deicer mixtures at test temperatures;
- Tabulation and graphing of freeze points by BEET HEET® concentration in tested deicer mixtures, with a best-fit line on the graph; and

- Tabulation and graphing of freeze points by BEET HEET® concentration in tested deicer mixtures, with a best-fit line on the graph, and adding the data and relationship for the freeze point by salt (sodium chloride) concentration (as shown in Fay, et al., 2022).

3.4 Evaluation

Physical chemistry defines freeze point as the temperature when a mixture is in balance between freezing and melting; both states exist in equilibrium (Helmenstine, 2020). To continue freezing, cold must be applied; to continue melting, warmth must be applied. If well mixed, the liquid:solid (ice) state will remain at the freeze point temperature until all of one or the other state is converted.

Freeze point depression is the lowering of the freeze temperature of a liquid by adding another substance to it (Helmenstine, 2021); the more the substance, the more the lowering. More substance is added by increasing the amount dissolved in the liquid. The Salts work particularly well in water at freeze point depression because salts dissolve completely into water. The greater the number of dissolving particles (ions) from a particular salt, the greater the freeze point lowering.

The chemical mechanism for freeze point depression is that the dissolved ions get in the way or disrupt the formation of the ice crystal lattice structure. To overcome the disruption, more cold is needed for the ice crystal lattice structure to form.

Particles of sodium chloride (NaCl) salt, commercially termed “rock salt”, split into two ions for every molecule. Two ions are a greater amount of dissolving particles than the amount that sugars and carbohydrates dissolve into, which is typically just one ion. Poly-ionic salts such as calcium chloride ($CaCl_2$) divide into three ions, therefore create greater freeze point depression than sodium chloride of equal amount.

As describe in the materials section, BEET HEET® contains multiple poly ionic and mono ionic substances. Each substance will contribute to lowering freeze point; the effect is additive, hence a great amount of freeze point lowering can be achieved by a given amount of BEET HEET®, much more than any of the components alone.

BEET HEET® was evaluated for freeze point in mixtures with 23.3% salt brine at concentrations from 0% (wholly salt brine) to 100% BEET HEET® and at temperatures from 0 °F to -34 °F. Freeze points were observed in mixtures up to 60% BEET HEET®, a level that would be termed “40:60” by MnDOT Winter Maintenance personnel. Freeze points were not observed at concentrations higher than 60% BEET HEET®. The eutectic temperature of BEET HEET® was not observed, as the freeze point curve of BEET HEET® appeared to be continuing to even colder levels when observed anecdotally at -40 °F, the limit of freezer ability in this study.

The freezing curve for BEET HEET® can be interpolated through use of a best fit line of the freeze points observed when graphed by BEET HEET® concentration. The freezing curve of BEET HEET® matches in well with the freezing curve for salt brine, but a flatter slope to the curve was observed, meaning that increases in BEET HEET® concentration have a lesser impact on freeze point than similar increases in salt

concentration. However, this slope flattening is likely due to the mixing of BEET HEET® as a liquid (the furnished state of BEET HEET®), not as a solid as is represented by the salt concentration.

3.5 Conclusions

BEET HEET® was evaluated for freeze point in mixtures with 23.3% salt brine at concentrations from 0% (wholly salt brine) to 100% BEET HEET® and at temperatures from 0 °F to -34 °F. Freeze points were observed in mixtures up to 60% BEET HEET®, a level that would be termed "40:60" by MnDOT Winter Maintenance personnel. Freeze points were not observed at concentrations higher than 60% BEET HEET®.

The freeze curve of BEET HEET® was interpolated through use of a best fit line of the freeze points observed when graphed by BEET HEET® concentration. This curve was developed to the limits for freezer capability in this study, -34 °F on a consistent and testable basis.

The eutectic temperature of BEET HEET® was not observed, as the freeze point curve of BEET HEET® appeared to be continuing to even colder levels when observed anecdotally at -40 °F, the limit of freezer ability in this study.

Chapter 4: Ice Melt Capacity Determination

The goal of this task was to determine melting potential at a range of temperatures and alterative deicer concentrations through eutectic point, melting (freezing) curve, and solubility curve determinations. The alternative deicer was mixed with salt brine at concentrations ranging from 0 to 100% and evaluated for melting potential at temperatures ranging from 32 ºF down to -34 ºF. Because freezers typically operate at 0 ºF, not necessarily at the temperatures required, special cold chambers were operated at the evaluation temperatures, using techniques previously developed for MnDOT research and described in Druschel (2012). Visual observations were made of ice formation or melting for a range of concentrations at a given temperature. Observations were made over a range of time to evaluate the rate of ice melting or crystal growth at each temperature and alternative deicer mixture application.

4.1 Materials

For this task, BEET HEET® (K-Tech Specialty Coatings, Inc., Ashley, Indiana) (K-Tech) was selected for study from available deicing brines used for direct liquid application (DLA) by the MnDOT Technical Assistance Panel of this project. BEET HEET® is a brown, slightly odorous, liquid with a viscosity that appears to be similar to the viscosity of water; it is not "thick" but quite "loose", like water. The odor is faint and sweet as in sugar or molasses-like sometimes with a fragrance of alcohol and fermentation, particularly in the older samples (Standard Methods 2170; Rice, t al., 2012). According to K-Tech (2024), BEET HEET® contains four chlorides and four carbohydrates (listed in the order listed by K-Tech):

- Calcium chloride, magnesium chloride, sodium chloride, and potassium chloride; and,
- Sucrose, glucose, fructose and raffinose sugars.

MnDOT has worked with K-Tech to have the magnesium chloride not in the mixture, due to difficult experiences in the past with magnesium chloride. K-Tech responded with Mn-BEET HEET®.

In this study, test specimens, including all blends, were comprised of Mn-BEET HEET® stock and salt brine mixtures, though referred to as just "BEET HEET®" to match the terminology of the winter maintenance operations staff.

BEET HEET® stock consisted of liquid taken from a 5-gallon bucket sample labeled as "BH Mankato June 2024 MK" and supplied by MnDOT to the Principal Investigator. For further characterization of this particular BEET HEET® sample, refer to the Chapter 2. BEET HEET stock was collected from the bucket sample and contained in a capped 1 L Erlenmeyer flask.

Salt used in this study was obtained as Morton Pure and Natural Water Softener Salt (Morton Salt, Inc., Chicago, IL). This material is commonly referred to as a "solar salt" as it is produced from solution brine mine product that is evaporated under vacuum and dried to achieve crystal forms of approximately ¼ th inch in size. Salt prepared in this manner is characterized by high purity as clay and silt impurities are removed in the brine processing.

Water used in this study for brine makeup was obtained from Seven Mile Creek, a perennial stream at Seven Mile Creek Park, Saint Peter, Minnesota, owned and maintained by the Nicollet County Public Works Department. According to the trail map and park brochure (Nicollet County Public Works Department, 2024), Seven Mile Creek is a groundwater-dominated stream. This water source was selected to be a water of consistent composition that closely matches untreated groundwater typical of well water composition in Southern Minnesota.

Ethylene glycol (glycol) is a liquid material that is commonly used as an antifreeze and corrosion inhibitor. Mixtures of glycol and water have highly predictable freeze points that are correlated with the specific gravity of the glycol-water mixture. In this study, proportions of glycol (Dynalene® EG; Dynalene, Inc., Whitehall, PA) and water were measured out and blended into mixtures that would freeze at target temperatures below 0 ºF. For identification of glycol and differentiation from water, glycol was dyed yellow florescent dye, in conformance with the coloration used for engine coolant fluids containing glycol.

4.2 Methods

4.2.1 Mixtures

Salt brine stock was made in a 1 L Erlenmeyer flask by weighing out solar salt and blending into a weighed-out amount of stream water such that the mixture comprised 23.3% salt. Mixing of salt brine stock was done rapidly until the granular salt crystals were fully dissolved. Salt brine stock was then capped and kept slowly mixing until use.

BEET HEET® mixtures of 120 mL volume were made using BEET HEET® stock and salt brine stock, measured using transfer pipettes with a precision of +/- 1 mL, and mixed in a 160 mL glass beaker. Ten mixtures were made up:

- 100% salt brine
- 10% BEET HEET® stock and 90% salt brine (called “90:10” by plow operators and supervisors, according to the Technical Assistance Panel of this project; nomenclature used similarly throughout this report)
- 20% BEET HEET® and 80% salt brine (called “80:20”)
- 30% BEET HEET® and 70% salt brine (called “70:30”)
- 40% BEET HEET® and 60% salt brine (called “60:40”)
- 50% BEET HEET® and 50% salt brine (called “50:50”)
- 60% BEET HEET® and 40% salt brine (called “40:60”; used in Phase I only)
- 70% BEET HEET® and 30% salt brine (called “30:70”)
- 85% BEET HEET® and 15% salt brine (called “15:85”; used in Phase I only)
- 100% BEET HEET®

The BEET HEET® mixtures were stored in capped 60 mL volatile organic analysis (VOA) glass vials in a 39 ºF refrigerator until use.

4.2.2 Ice Specimen Preparation

Ice specimens were prepared in 8 oz (240 mL) polyethylene beakers (cups) using 50.0 mL of stream water. Once loaded with water, beakers were covered with foil and placed in a thermal stabilization unit consisting of a 12-inch square, 3⁄4 inch-thick aluminum plate underlain by a 1-inch-thick polystyrene foam insulation with 3-inch-high walls made of 1-inch-thick polystyrene foam insulation/1/8th inch hardwood plywood composite. Up to 10 beakers were placed in each thermal stabilization unit, along with a spirit thermometer placed in 50 mL of BEET HEET® within a 120-mL Erlenmeyer flask. After being loaded with water, foil covered and loaded into the thermal stabilization units, beaker sets were placed in a laboratory freezer for a minimum of 16 hours at a 0 °F temperature to create ice specimens (Figure 13).

Figure 13. Thermal stabilization unit in 0 °F freezer with 10 prepared ice specimens and measurement thermometer.

4.2.3 Target Temperature Establishment

Temperatures targeted for study were created by freezing either glycol-water mixtures (used for temperatures below 0 ºF) or salt brine mixtures (used for temperatures above 0 ºF) in a -40 ºF laboratory freezer until the mixture was halfway frozen, then removing the mixture from the freezer and mixing the partially solid mixture into an ice slush of uniform consistency (Figure 14) to make an “ice

bath". The slush was then put into one of two freeze chambers, each consisting of 120-quart (114 L) Igloo Polar Cooler (Igloo Products Corp., Katy, Texas), that was kept closed and positioned on a lab bench in an ambient air temperature of 69ºF. Freeze point relationships for glycol-water mixtures were obtained from an ethylene glycol heat transfer fluid freeze point chart (CoreChem 2024). Freeze point relationships for salt brine mixtures were obtained from Druschel (2012).

Figure 14. Ice slush composed of glycol – water mixture being placed in a freeze chamber (cooler) at -26 °F.

Temperatures of slushes and fluids were measured using Jumbo Display Traceable Dial Thermometers (Traceable® Products, Webster, TX) with a range of –58 to 302 °F, a digital resolution of 0.1 °F, and an accuracy of ±0.5 °F. The thermometers were calibrated and certified by the manufacture prior to use in this study. These thermometers use a stainless-steel probe for use in harsh liquids including salt brines, but are not protected from immersion. Thermometers were kept above liquid and slush surfaces either by using polystyrene foam for buoyancy (floating) or overhead support (suspended). Additional temperature measurement was made using an armored spirit thermometers with a range of –30 to 120 °F and a resolution of 1 °F.

4.2.4 Deicer Application

To apply to ice specimens, BEET HEET® mixtures were measured using a 10.0 mL glass syringe with a precision of +/- 0.1 mL (Figure 15). Glass syringes were triple rinsed in DI water after each use. 3 mL of BEET HEET® mixture specimens were applied to the center of an ice specimen top surface after removal of

the foil cover (Figure 16). After 30 minutes, any melted brine that had been generated was pulled into a syringe, the brine volume recorded, and the brine returned to the ice specimen by a gentle spray across the exposed surface. Three cycles of brine measurement and return were done at 30-minute increments (30, 60 and 90 minutes after application of the deicer).

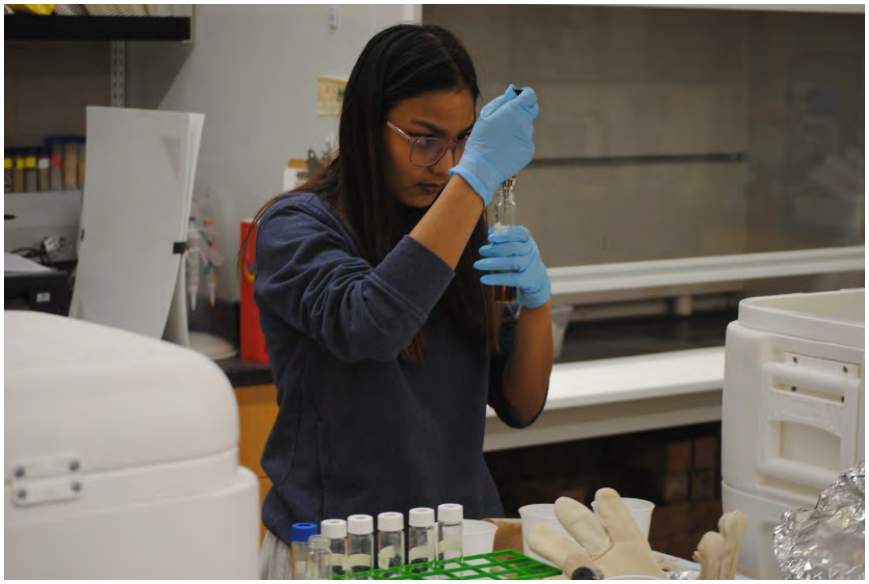

Figure 15. Measurement of BEET HEET mixture specimen prior to application to ice specimen.

Figure 16. Application of BEET HEET mixture specimen to ice specimen.

4.2.5 Melted Ice Brine Measurement

At 120 minutes after application of deicer, a beaker was removed from the freezer or cooler and a measurement made of melted ice brine (Figure 17) using a 10- or 25-mL glass syringe with a blunt point steel pipetting needle. The glass syringes have a precision of 0.1 mL or 0.25 mL for the 10- or 25-mL syringe, respectively. The steel needle allowed for collection of melted ice brine from depressions and cavities in the ice. Note that in Figure 17, the wetness around the specimen beaker is from liquid of ice bath in the cold chamber.

Figure 17. Melted ice brine on top of ice specimen (removed from cold chamber and placed on insulating foam for duration of measurement procedure).

4.3 Results

Appendix E presents full results of analyses performed. Results of two experimental sets are presented:

- The workbook "IMC Results 112524.xls", consisting of a table of results and ten graphs, representing mixtures:
  - 100% Salt Brine;
  - 10% BEET HEET® mixed with 90% Salt Brine (called "90:10");
  - 20% BEET HEET® (80:20);
  - 30% BEET HEET® (70:30);
  - 40% BEET HEET® (60:40);
  - 50% BEET HEET® (50:50);
  - 60% BEET HEET® (40:60);
  - 70% BEET HEET® (30:70);
  - 85% BEET HEET® (15:85); and,
  - 100% BEET HEET®.
- The workbook "IMC Results 022725.xls", consisting of a table of results and eight graphs:
  - 100% Salt Brine;
  - 10% BEET HEET® mixed with 90% Salt Brine (called "90:10");
  - 20% BEET HEET® (80:20);
  - 30% BEET HEET® (70:30);
  - 40% BEET HEET® (60:40);
  - 50% BEET HEET® (50:50);
  - 70% BEET HEET® (30:70); and,
  - 100% BEET HEET®.

The second experimental set (workbook "IMC Results 022725.xls") reflects several improvements made after evaluation of the first set of results. These improvements include:

- Reducing mixtures tested from 10 to 8 to allow more circulation of the cooling ice slush around the experimental units (beakers);
- Removing the foam side walls of the thermal test units, also to allow more circulation of the cooling ice slush around the experimental units;
- Continuing the use of the ¾ inch aluminum plate floor of the thermal test unit, but placing it deeper in the cooling ice slush; and,
- Adding ten ½ inch steel ball bearings into the bottom of each experimental unit to provide weight to steady and reduce the overtipping tendency of the units within the cooling ice slush, while increasing the composite heat capacity maintaining the ice specimen at the target temperature.

Each workbook presents results graphing three characteristics of the experimental results:

1. Overall, graphs are of results by deicer mixture;
2. Results are graphed as liquid (deicer and any ice melted) measured while at the temperature of the most representative experimental unit, taken as the beaker of 100% BEET HEET®), in the same thermal test unit; and,
3. Results are provided in series of measurements of the same experimental unit across a time sequence from 0 (initial deicer application), 30, 60, 90 and 120 minutes. Each series therefore allows characterization of the time required to produce the liquid after deicer application.

4.4 Evaluation

Evaluating the results, several trends may be identified and defined:

1. All time series show some temperature increase across the duration of the treatment (120 minutes)
    a. Temperature increases in all results are larger with analyses done at colder temperatures (e.g., below 0 °F);
    b. Temperature increases in the results of the IMC Results 112524.xls series show larger temperature increases of 10 to 30 °F during the duration of treatments; and,
    c. Temperature increases in the results of the IMC Results 022725.xls series show smaller temperature increases of 0 to 7 °F during the duration of treatments;
2. At colder temperatures, some mixtures lost liquid volume compared to the volume of the (liquid) deicer applied. These results are interpreted as the deicer applied in the experimental unit is freezing at the temperature of the ice specimen. The trend of these results generally matches the results presented in the Task 3 report of this project related to freeze point on the BEET HEET® phase diagram.
3. Variation between duplicate experimental units at similar temperatures is commonly seen:
    a. Typically variation is less than 1 mL of liquid measure when the temperature is less than 15 °F;
    b. Variation is less with increased proportions of BEET HEET® in a mixture;
    c. Variation is more with increased proportions of Salt Brine in a mixture, and is especially more with 100% Salt Brine.

4. Typically 80% (estimated value) of all melting observed occurred within the first 30 minutes after deicer application.
5. Freezing of deicer, when observed, typically was observed about 1 hour after deicer application.
6. Freezing of deicer, if it occurred, took longer for a mixture with greater proportions of BEET HEET® in a mixture.
7. The liquid measurement values, consisting of the amount of liquid deicer (if not frozen) and the amount of ice melted, for each mixture at each temperature was interpolated from the liquid measurement results of the IMC Results 022725.xls series. These values are shown in Table 4:

Table 4. Liquid amount measurements, average of two duplicates in mL, interpolated from the 60, 90 & 120-minute IMC Results 022725.xls series.

Temp.	100% Salt Brine	90:10 10% BEET HEET®	80:20 20% BEET HEET®	70:30 30% BEET HEET®	60:40 40% BEET HEET®	50:50 50% BEET HEET®	30:70 70% BEET HEET®	100% BEET HEET®
26 °F	13	15	15	15.5	15	14.5	15	14
13 °F	4.0	5.3	5.8	6.0	6.3	6.0	6.4	6.5
4 °F	1.5	3.4	3.8	3.5	4.0	3.9	4.3	4.8
-10 °F	1.3	3.1	3.1	3.0	2.9	2.5	3.1	3.8
-15 °F	1.5	3.9	2.8	2.8	2.6	2.4	2.5	3.1
-16 °F	0.8	2.0	2.9	3.0	2.6	2.4	2.6	2.5
-21 °F	0	0	0	0	0	1.4	1.8	1.9

8. Ice melt capacity (IMC), defined as the amount of ice melted per the amount of deicer applied, with units of mL brine created / mL of deicer brine applied, was developed from the results shown in Table 1, and are provided as Table 5. The IMC value necessarily includes any liquid measured that may actually be residual liquid deicer. For example:
    a. An IMC of 4.0 with a deicer application of 3 mL would mean that a liquid measurement of 4.0 x 3 mL = 12 mL was obtained;
    b. An IMC of 1.0 with a deicer application of 3 mL would mean that a liquid measurement of 1.0 x 3 mL = 3 mL was obtained, effectively suggesting that no melting has occurred, or that melting amount was equal to the deicer amount that absorbed into the ice matrix;
    c. An IMC of 0.0 with a deicer application of 3 mL would mean that no liquid measurement was obtained, interpreted as the deicer froze or penetrated the ice matrix without creating liquid.

Table 5. Ice melt capacity (IMC) by deicer blend (units of mL liquid / mL deicer applied) results developed from the liquid measurement interpreted values of Table 1.

Temp.	100% Salt Brine	90:10 10% BEET HEET®	80:20 20% BEET HEET®	70:30 30% BEET HEET®	60:40 40% BEET HEET®	50:50 50% BEET HEET®	30:70 70% BEET HEET®	100% BEET HEET®
26 °F	4.3	5.0	5.0	5.2	5.0	4.8	5.0	4.7
13 °F	1.3	1.8	1.9	2.0	2.1	2.0	2.1	2.2
4 °F	0.5	1.1	1.3	1.2	1.3	1.3	1.4	1.6
-10 °F	0.4	1.0	1.0	1.0	1.0	0.8	1.0	1.3
-15 °F	0.5	1.3	0.9	0.9	0.9	0.8	0.8	1.0
-16 °F	0.3	0.7	1.0	1.0	0.9	0.8	0.9	0.8
-21 °F	0.0	0.0	0.0	0.0	0.0	0.5	0.6	0.6

9. Trends observed within IMC results include:
    a. Temperature is a significant factor in the IMC value for every mixture tested.
    b. BEET HEET® proportion is a moderate factor in the IMC values, particularly when above or below but near the freeze point temperature of a mixture (defined in Chapter 3).
        i. Even 90:10 (90% salt brine, 10% BEET HEET®) had an IMC value nearly double the IMC of salt brine alone when at temperatures of +4 to -21°F (note: the freeze point of salt brine is -7 °F)
    c. An increase in BEET HEET® proportion resulted in an increased IMC (positively correlated), except at the warmest temperature evaluated.
    d. Only at the coldest temperature evaluated (-21°F) did mixtures have IMC values equal to zero, even though several temperatures evaluated were below the freeze points determined for the BEET HEET® mixtures.
10. Lastly, "ice softening" was reported by laboratory staff performing the IMC experiments at colder temperatures, even though the IMC measured less than 1.0 at those temperatures. This observation is interpreted as the deicer had absorbed into the ice and was disrupting the ice crystal matrix, a process called "solvation" (i.e., a material mixing into a solvent, even a solid phase solvent such as ice). This solvation is not enough to create liquid and therefore not influencing IMC measurement, but enough to reduce the strength and firmness of the ice.

4.5 Conclusions

BEET HEET® was tested for IMC in mixtures with 23.3% salt brine at concentrations from 0% (wholly salt brine) to 100% BEET HEET® and at temperatures from 26 °F to -21 °F. IMC, representing the volume of liquid measured / volume of deicer applied was observed at levels ranging from 5.2 (at 26 °F) to 0.0 (at subzero temperatures). An IMC of 0.0 was interpreted as the deicer either froze or was wholly absorbed into the ice matrix. Values of IMC of 1.0 or less were consistently measured at temperatures of -10 °F or colder.

"Ice softening" was reported by laboratory staff performing the IMC experiments at the colder temperatures of the study, even though the IMC measured less than 1.0 at those temperatures. It

appears the deicer absorbs into the ice and disrupts the ice crystal matrix, not enough to create liquid and therefore not influencing IMC measurement, but enough to reduce the strength and firmness of the ice.

When ice was melted by the applied deicer, most of the melting occurred within the first 30 minutes after deicer application. When the applied deicer froze or was wholly absorbed into the ice matrix, the change occurred within the first hour after deicer application.

Chapter 5: On-Pavement Field Comparison

The goal of this task was to develop an on-pavement treatment comparison, such that performance of the alternative deicer can be compared across times and rates of application and co-treatment with rock salt.

5.1 Materials

For this task, BEET HEET® (K-Tech Specialty Coatings, Inc., Ashley, Indiana) (K-Tech) was selected for study from available deicing brines used for direct liquid application (DLA) by the MnDOT Technical Assistance Panel of this project. BEET HEET® is a brown, slightly odorous, liquid with a viscosity that appears to be similar to the viscosity of water; it is not "thick" but quite "loose", like water. The odor is faint and sweet as in sugar or molasses-like sometimes with a fragrance of alcohol and fermentation, particularly in the older samples (Standard Methods 2170; Rice, et al., 2012). According to K-Tech (2024), BEET HEET® contains four chlorides and four carbohydrates (listed in the order listed by K-Tech):

- Calcium chloride, magnesium chloride, sodium chloride, and potassium chloride; and,
- Sucrose, glucose, fructose and raffinose sugars.

MnDOT has worked with K-Tech to have the magnesium chloride not in the mixture, due to difficult experiences in the past with magnesium chloride. K-Tech responded with Mn-BEET HEET®.

Rock salt and BEET HEET® were both provided by MnDOT from standard operational stockpiles and tankage working out of the Little Falls, Minnesota truck station.

5.2 Methods

5.2.1 Test Pavement Location and Facility Configuration

MnDOT arranged for the Emergence Vehicle Operator Course (EVOC) at the Minnesota National Guard Camp Ripley facility to be used for on-pavement testing, as MnDOT had used the course previously. The course consists of an approximately 2.5-mile paved perimeter track, several gravel road sections, and a paved 700 ft by 300 ft center pad called the Wet Skid Pad (Skid Pad). The perimeter track is configured with a two-lane highway geometry for about 2 miles and a four-lane divided highway geometry for about 1 mile. The EVOC was reserved and through Camp Ripley Range Control, who also managed the access through normally locked gates.

The Camp Ripley EVOC offered several advantages:

- Access is controlled, and can be reserved ahead during winter months within the window around weather forecasting of snow and temperature conditions;
- Post-storm traffic can be prevented until testing time;
- Pavement conditions are highly uniform;

- Camp Ripley is centrally located within Minnesota, allowing both support from MnDOT facilities and staff plus easy access to researchers; and,
- Camp Ripley's geographical position provides the potential for sub-zero temperatures and accompanying snow to support the targeted test conditions.

A sub-committee of the Technical Assistance Panel for this project met weekly with the project Principal Investigator during January and February to review upcoming forecasts and plan deployment and testing at the Camp Ripley EVOC (hereafter referred to as "the test track" for purposes of this report). The sub-committee consisted of Maintenance Engineers, Supervisors and technical staff from Districts 1 and 3 plus Central Office who could advise on application procedures, equipment, and EVOC use, and commit resources.

5.2.2 Test Track Proposed Application Areas

Test locations at the test track were planned out ahead and applications proposed for testing during work with the TAP sub-committee. Appendix F provides the Experimental Plan developed for the on-pavement field testing of the deicer blends. The plan included the following summary aspects:

- Base application amounts off a standard deicer treatment of 200 pounds per lane mile for rock salt with a 20 gallons per lane mile liquid co-application;
    - Note: A lane mile is a 12-foot width of pavement 1.0 mile (5,280 feet) long, or 63, 360 square feet, an area approximately 1.4 acres in size.
- On the skid pad, set up five parallel lanes of 12 feet wide by 300-feet long, separated by 32 feet to prevent cross-treatment possibilities.
    - Test five different salt brine:BEET HEET® mixtures including 100:0 (100% salt brine), 90:10, 70:30, 50:50, and 0:100 (100% BEET HEET®);
    - This number of lanes was later increased to seven.
    - Lanes were designated as SKID 1 to SKID 7.
    - Observations for the skid pad lanes were planned to include time lapse photography, using "game cameras" mounted on 5-foot-high stands, and hand-held photography taken with a Nikon D3000 single lens reflex digital camera, done on a fixed time interval basis after treatment application.
- On the perimeter roadway of the test track, set up 500-foot-long sections:
    - On four of the sections, evaluate effects of increased liquid co-treatment from 20 to 25 to 30 to 35 gallons per lane mile, holding the rock salt amount at 200 pounds per lane mile.
        - These lanes were designated WB for "west bound", representing their proposed locations on the four-lane divided highway section of the test track.
        - The sequence of application conditions was arranged such that the application amount increased with the driving direction, to limit extra application carry-through effects.
        - Note: The 70:30 salt brine:BEET HEET® mixture was proposed for the liquid as representing a typical mixture though on the high side, appropriate to severe cold conditions.
    - On four other 500-foot-long sections of the test track, evaluate effects of increased rock salt amount from 200 to 250 to 300 to 350 pounds per lane mile, holding the liquid co-treatment at 20 gallons per lane mile.

        - Again use 70:30 salt brine:BEET HEET® mixture to remain consistent with the test series addressing changing liquid deicer rate.
        - These lanes were designated EB for “east bound”, representing their proposed locations on the four-lane divided highway section of the test track.
        - The sequence of application conditions was again arranged such that the application amount increased with the driving direction.
    - Observations for the perimeter test track were planned to include time lapse photography, using “game cameras” mounted on 5-foot-high stands, and hand-held photography taken with a Nikon D3000 single lens reflex digital camera, done on a systematic basis associated with traffic looping in the directions of treatment.
- Overlapping treatment levels of 200 pounds per lane mile rock salt and 20 gallons a lane mile of 70:30 salt brine:BEET HEET® mixture would provide for comparisons of similar conditions, to be interpreted as controls between the three series of treatments.

The proposed test locations and applications are shown on Figure 18 as the locations indicated on the aerial photo by labels showing skid pad, west bound (WB) and east bound (EB) locations. Note that in-field adjustments to actual conditions for all WB and EB locations are shown in purple marker, with original locations indicated by labels with arrows and proposed applications.

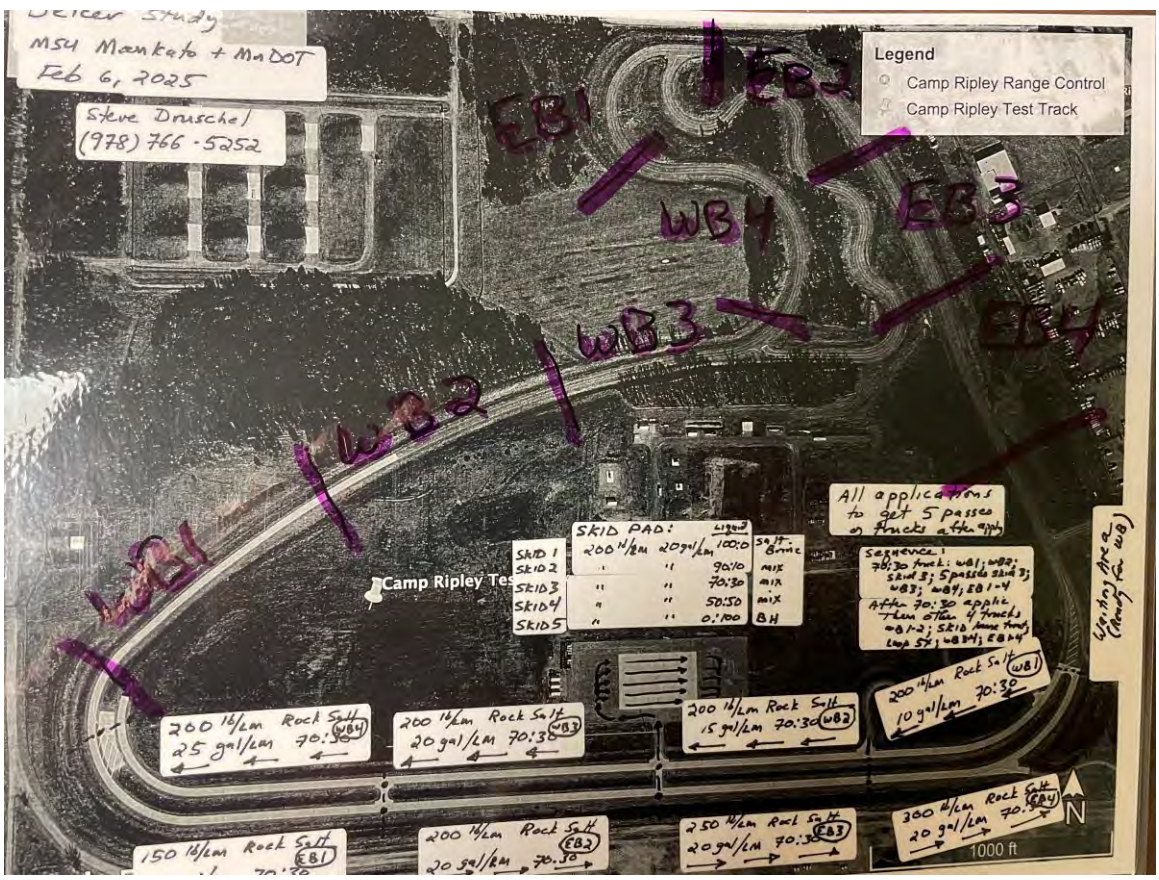

Figure 18. Test track experimental layout.

5.2.3 Test Track Weather Conditions

Snow of approximately 6 inches depth fell at the test track on February 2nd and 3rd, 2025; the sub-committee agreed conditions would suffice and testing was "go" for track reconnaissance and set up on February 5th and testing on February 6th. A weather summary of February 5th and 6th, 2025 for Brainard, Minnesota from Weatherunderground.com is provided in Appendix G. It includes hourly temperature, wind, and wind gust information plus minimum, maximum and daily average dew point information. Weather conditions at the test track may be summarized as:

- Temperatures: rising on February 5th from a morning low of 8° F to an afternoon high of 20° F, followed by an overnight decline to a morning low of 8° F which then held at 8 – 9 ° F for the daytime;
- Wind: daytime February 5th saw south-southeast winds from 5 – 10 mph, swinging to the west overnight and rising on February 6th to 15 – 30 mph with gusts to 45 mph;
- Dewpoint of 6° F on February 5th, dropping slightly to -1° F on February 6th.
- Cloudy and overcast conditions on February 5th, clearing overnight to February 6th with blue skies in the early and mid-morning followed by light overcast mostly sunny conditions for the late morning and afternoon.

5.2.4 Actual Test Track Snow Conditions

Upon arrival at the test track midafternoon on February 5th, conditions were found to be not very conducive to creation of compaction (snow and ice bonded to the pavement surface) because the snow was very dry on all sections of the test track. Snow had mostly blown off the four-lane divided highway section, leaving only finger and pillow drifts (Figure 19). Conditions on the two-lane highway section of the test track were better, having generally consistent snow presence and depth. The skid pad also had thin snow cover, but more than the divided highway section. After conferring with the members of the TAP sub-committee, it was decided to proceed with testing, as no better conditions were likely to occur for the remainder of the winter season. However, the WB and EB test sections were to be relocated to sections of the perimeter track, as shown by the purple marker marks on Figure 18. Other actions were decided upon to manipulate the snow to create testable conditions including:

- Adding moisture to the perimeter track snowpack using salt brine (23% concentration);
- Compacting the moistened perimeter track snowpack using vehicle traffic;
- Plowing snow onto the skid pad from the flanking drifts;
- Adding moisture to the skid pad snow using salt brine; and,
- Spreading and rough grading moistened skid pad snow onto the skid pad center area (area proposed for testing) using a plow truck.

The consensus judgement was that the additional moisture, even with dissolved salt, would freeze up the snowpack overnight with the forecasted falling temperatures dropping to 8° F. Salt brine also would be most likely to flow through the liquid application system without freezing in the supply lines. A MnDOT tanker truck loaded with 4000 gallons of salt brine was dispatched to the test track from the Little Falls truck station. Moisture was added to the snow of the perimeter test track by the tanker truck from a centerline application position by spraying left, center and right, each at a rate of 65 gallons per

lane mile (Figure 20) for a total of 195 gallons per lane mile. Three complete circuits of the perimeter test track were done by the tanker truck in this application mode. The tanker truck then continued for five additional circuits with no liquid application, joined by approximately ten light vehicles light duty vehicles (sports utility vehicles and pickup trucks), to mix and compact the moist snow; no plowing was done at this time. Test section starting points were then marked out using pin flags just beyond the roadway shoulders. Three locations within each section were marked for monitoring positions, designated by A, B and C; some test sections had monitoring location amounts that differed from as low as two to as many as five. Lane configurations using forward and backward (directions oriented to the traffic direction) photographs at each location are provided in Appendix H.

Figure 19. Conditions on four-lane divided highway section, originally proposed for WB and EB test locations, found upon arrival February 5, 2025.

Figure 20. Adding moisture to the snowpack by tanker truck spray application to snow cover of perimeter track.

Snow was plowed from the drifts flanking the skid pad (Figure 21) and arranged around the central area proposed for testing in a perimeter windrow. Moisture was added to the snow in and near the windrow by salt brine spray from the tanker truck using 65 gallons per lane mile in left side spray for two circuits around the skid pad (Figure 22). Snow was then distributed onto the skid pad center (Figure 23). Morning conditions showed distributed snow with frozen crust (Figure 24).

Figure 21. Plowing snow onto the skid pad center from perimeter drifts.

Snow was plowed from skid pad test lanes without concurrent deicer application (Figure 25), which was done independently. Truck speeds during both plowing and application runs were kept to about 10 mph to support the goal of uniformity in conditions. Plow trucks were lined up to the plowed lanes (Figure 26) in order of increasing BEET HEET® concentration from SKID 1 to SKID 5 (Table 6). Application of deicer was done one truck at a time (Figure 27) to aid in collection of photographs for documentation. Research staff acting as ground observers noticed that two application lanes appeared to suffer malfunction; photographs were checked and the malfunctions confirmed, as described in Table 6 and shown in Figures 28 and 29. Two additional lanes (SKID 6 and SKID 7) were then plowed and deicer applied with replacing the treatments of the lanes with application malfunctions (SKID 3 and SKID 4).

Figure 22. Adding moisture to the snowpack by tanker truck spray application onto snow being moved onto the skid pad center.

Figure 23. Distribution of moistened snow onto skid pad center.

Figure 24. Morning conditions at skid pad, showing distributed snow with frozen crust.

Traffic consisting of one plow truck pass (no plowing, no additional deicer application) (Figure 30) followed by one light vehicle (a sports utility vehicle) pass was then applied every 10 minutes (Figure 31). Photography of each lane was done from a set mid-lane location at 17, 27, 37, 49 and 71 minutes after deicer application, with photographs oriented in a pattern of: back long, back pavement, forward long, forward pavement, additional pavement photographs as needed, and lastly of a marker object to denote end of the specific lane photographs of that time interval. Lane configuration using the "back long" and "forward long" photographs is provided in Appendix H.

The planned approach of using time lapse photography failed on the day of testing due to high winds knocking over the equipment. Anchoring attempts were done but proved to take too long and were abandoned to keep the proposed testing schedule matched to the weather and the equipment and personnel availability.

Snow inspection was done between photographic documentation events, evaluating compacted snow strength and consistency at the pavement level (Figures 32 and 33).

Table 6. Test sections and deicer applications.

Test Section	Solid Deicer Applied	Liquid Deicer Applied	Comments
SKID 1	200 lbs/LM rock salt	20 gal/LM of 100% salt brine	
SKID 2	200 lbs/LM rock salt	20 gal/LM of 90:10	
SKID 3	200 lbs/LM rock salt	20 gal/LM of 70:30	Distribution lines frozen or blocked; no deicer applied. Use lane as blank.
SKID 4	200 lbs/LM rock salt	20 gal/LM of 50:50	Distribution control frozen in wide open position; excessive amount applied.
SKID 5	200 lbs/LM rock salt	20 gal/LM of 100% BEET HEET	
SKID 6	200 lbs/LM rock salt	20 gal/LM of 70:30	
SKID 7	200 lbs/LM rock salt	20 gal/LM of 50:50	
WB 1	200 lbs/LM rock salt	20 gal/LM of 70:30	
WB 2	200 lbs/LM rock salt	25 gal/LM of 70:30	
WB 3	200 lbs/LM rock salt	30 gal/LM of 70:30	
WB 4	200 lbs/LM rock salt	35 gal/LM of 70:30	
EB 1	200 lbs/LM rock salt	20 gal/LM of 70:30	
EB 2	250 lbs/LM rock salt	20 gal/LM of 70:30	
EB 3	300 lbs/LM rock salt	20 gal/LM of 70:30	
EB 4	350 lbs/LM rock salt	20 gal/LM of 70:30	

Note: liquid deicer material, when a mixture of two components, is designated using the industry standard terminology of salt brine proportion: alternative deicer proportion. As discussed in the Materials section of this report, the alternative deicer selected for study was BEET HEET.

Figure 25. Plowing of skid pad treatment lane; no treatment at first.

Figure 26. Trucks lined up on treatment lanes SKID 1 to 5.

Figure 27. Treatment of skid pad treatment lane SKID 1.

Figure 28. Treatment attempt on SKID 3; note no application of material due to equipment freeze up.

Figure 29. Treatment on SKID 4; note overapplication of material due to equipment freeze up.

Figure 30. Typical truck traffic applied to skid lanes.

Figure 31. Typical automotive traffic applied to skid lanes.

Figure 32. Up close inspection of residual snow on skid lane after treatment.

Figure 33. Weak and moist condition of residual snow on skid lane after treatment.

Testing moved to the perimeter test track locations late morning; conditions showed compacted snow with frozen crust (Figure 34). Taking advantage of the two-lane highway geometry of the perimeter test track, the track was set as a one-way traffic direction (clockwise). Deicer application was done from the right lane in an approach typically followed by MnDOT winter maintenance operations for two-lane highways. Snow was first plowed off the left lane, casting left with no deicer application (Figure 35), then plowed off the right lane (Figure 36), casting right with a left wheel line deicer application (Figure 37), effectively treating both lanes. Traffic was then initiated using five tandem axle plow trucks and eight light duty vehicles (six sports utility vehicles and two pickup trucks), with each light duty vehicle alternating between the right lane about two-thirds of the time and the left (passing) lane one-third of the time, shifting back and forth in a manner typical of normal traffic of a single direction two-lane highway (Figure 38). The traffic pattern used is also associated with deicer mixing and spread, as seen during previous MnDOT on-pavement testing of deicers.

Photography of each test section was done from the previously selected monitoring locations (typically three per test section) using loop driving along the perimeter roadway. Four passes were made, approximately 30, 50, 75 and 95 minutes after treatment. As with the skid pad lanes, photographs were oriented in a pattern of: back long, back pavement, forward long, forward pavement, and then additional pavement photographs as needed; Figure 39 shows typical results. All pavements were then plowed clear at the completion of the testing (Figure 40).

Figure 34. Perimeter track on testing day with compacted, frozen snow on the pavement.

Figure 35. Plowing left on perimeter track; no treatment.

Figure 36. Plowing to right side on perimeter track.

Figure 37. Deicer application on perimeter track by truck plowing to right side.

Figure 38. Typical traffic applied to perimeter track.

Figure 39. Typical results (EB2 with 200 lbs/LM rock salt and 25 gal/LM 70:30 prewet). From top to bottom: 4 minutes, 34 minutes, and 57 minutes after application.

Figure 40. Cleaning off wet skid pad pavement after completion of testing.

5.3 Results

Appendix I presents full results of analyses performed using photograph comparison of test locations by time. Results of three experimental sets are presented (Table 6):

- SKID 1 to 7, in which different concentrations of BEET HEET® liquid deicer were spread at 20 gal/LM along with rock salt at 200 lbs/LM;
- WB 1 to 4, in which the rock salt amount spread was held constant at 200 lbs/LM and the liquid amount varied from 20 to 35 gal/LM using 70:30 (30% BEET HEET®); and,
- EB 1 to 4, in which the rock salt amount spread was varied from 200 to 350 lbs/LM while the liquid amount was held constant at 20 gal/LM using 70:30 (30% BEET HEET®).

5.4 Evaluation

Evaluating the results, several trends may be identified and defined:

1. All the time series, except SKID 3 which functions as a blank (location with no treatment) for the SKID lanes, show some effect from deicing under the left wheel line/under the drop location. Typically, effects are an initial “moistening” look directly on the drop line, then varying amounts

of effect widening, snow structure softening, and pavement opening. Initial apparent softening and pavement opening show as fully occurring by the first round of photographic observations for the treatment locations, ranging in time from 5 to 33 minutes, though some of the early observations are on the WB and EB locations and therefore likely to be as much from traffic interaction with the deicer as the deicer ice melt capacity alone.

2. SKID 3, functioning as a blank, shows consistent compacted snowpack on the pavement. No moistening appears to develop. Some snow coloration change is noted on the left wheel track, which may be track-through from the traffic vehicles transiting both the return lane which is used by all traffic from all skid pad lanes and SKID 6, the replacement lane for the 200 lbs/LM and 20 gal/LM of 70:30 treatment.
3. Comparing the three test locations (SKID 6, EB 1 and WB 1) all with the same treatment level of 200 lbs/LM and 20 gal/LM of 70:30, some similarity in deicing behavior is noted as all three locations showed initial moistening on the left wheel track followed by some widening. However, the increased traffic (five plow trucks and eight light vehicles passing every 6 minutes with lane changing versus one plow truck and one light vehicle passing every 10 minutes) appears to create much wider mixing and blending of the deicer into the snowpack. Additionally, orientation of the deicer drop line on pavement graded slightly more towards the sun appears to accelerate the pavement opening and deicing effect (pavement grading encompasses roadway crown and superelevation effects on the cross slope and longitudinal roadway grade).
4. With an ambient temperature of 9° F, no treatment area or deicer drop line shows any apparent icing up from time of treatment to the end of the monitoring period. Based on both literature and laboratory observations, freezing of the salt brine in the deicer liquid blends would not be expected until ambient temperatures are below at least -6° F.
5. Effects on deicing appear limited or nonexistent across the range of rock salt amount in EB 1 to 4 from 200 to 350 lbs/LM, all made with a consistent liquid amount of 20 gal/LM of 70:30. Traffic and pavement orientation appears to have more effect than any increase in rock salt amount, which would fit with the expectation for an ambient temperature of 9° F at which rock salt would have very limited ice melt capacity to support deicing. No difference could be identified that aligns with the increasing rock salt amount rather than other factors.
6. Effects on deicing appear slight to moderate across the range of liquid mixture amount in WB 1 to 4 from 20 to 35 gal/LM of 70:30, all made with a consistent rock salt amount of 200 lbs/LM. The amount of melted snowpack and open or opening pavement appears to increase with additional amount of liquid, with the affected width estimated at about double for the higher (nearly double) amount of liquid application.
7. Differing liquid mixtures applied across SKID 1, 2, 6, 7, and 5, in order from 100% salt brine to 90:10 to 70:30 to 50:50 to 100% BEET HEET®, all applied at 200 lbs/LM and 20 gal/LM, show subtle but significant effects on deicing (Table 5.2).
    a. 100% salt brine for the liquid treatment shows as a moistened snowpack under the treatment line, with no change over time for either additional melting or softening.

b. 90:10 for the liquid treatment shows with similar effects as 100% salt brine; no significant difference.
c. 70:30 for the liquid treatment shows a greater amount of moistening and softening than 90:10, suggesting about twice the effect magnitude as with 90:10.
d. 50:50 for the liquid treatment caused the treated snowpack to become very moist and mushy, formable into pack at a high moisture level colloquially known in some regions of the United States as “lake effect snowball” or as “snowman making snow” (Figure 5.14). This level of created moisture is significantly higher than for the 70:30 liquid treatment.
e. 100% BEET HEET® for the liquid treatment created snow structure too slushy and wet to hold shape or form. When lightly squeezed, free moisture was easily produced.

Table 7. Snow structure and consistency determination across the range of liquid mixture treatments at 37 minutes after treatment.

Treatment and Lane Designation	View Down Lane	Up Close View
No treatment (treatment blank) SKID 3		
100% salt brine SKID 1		
90:10		

SKID 2		
70:30 SKID 6		
50:50 SKID 7		
100% BEET HEET SKID 5		

Note: All deicer treatments at 20 gal/LM of selected liquid and 200 lb/LM rock salt

5.5 Conclusions

The alternative deicer BEET HEET® was tested in an on-pavement treatment comparison, allowing for performance of the alternative deicer to be compared across times and rates of application and co-treatment with rock salt. The Emergence Vehicle Operator Course at the Minnesota National Guard Camp Ripley facility was used for the on-pavement testing, where about 6 inches of dry snow had fallen 3 to 4 days before. Materials, equipment and personnel were supplied by MnDOT. Ambient weather on the day of testing was a temperature of 8 to 9° F and steady, skies were mostly sunny to lightly overcast, winds were from the west at 15 to 30 mph with gusts to 45 mph, and there was an average dew point of -1 °F.

During test location set up, snow was observed to have drifted significantly, in some cases off the proposed locations, and was assessed as very dry. Snow in the test locations was moistened and, in

some cases, added to by “plowing on” and then being redistributed. Compaction of snow was done after moistening by repeated applications of plow truck, tanker truck and light vehicle traffic.

Comparative tests were performed on selected locations using photograph documentation of test locations by time after deicer treatment. Three experimental sets were done:

- The skid pad series, in which different concentrations of BEET HEET® liquid deicer were spread at 20 gal/LM along with rock salt at 200 lbs/LM;
- The WB series, using locations on the perimeter track, in which the rock salt amount spread was held constant at 200 lbs/LM and the liquid amount varied from 20 to 35 gal/LM using 70:30 (30% BEET HEET®); and,
- The EB series, also using locations on the perimeter track, in which the rock salt amount spread was varied from 200 to 350 lbs/LM while the liquid amount was held constant at 20 gal/LM using 70:30 (30% BEET HEET®).

Traffic was systematically applied to the test locations after deicer treatment.

The evaluation showed that the deicer treatment effects are an initial “moistening” look directly on the deicer drop line, then varying amounts of effect widening, snow structure softening, and pavement opening.

Effects on deicing appeared limited or nonexistent across the range of rock salt amount tested with consistent amounts of the same liquid deicer. Traffic and pavement orientation appeared to have more effect than any increase in rock salt amount, which matched the expectation for an ambient temperature of 9° F at which rock salt would have very limited ice melt capacity to support deicing. No difference was identified that aligned with an increasing rock salt amount rather than other factors such as traffic or pavement surface orientation.

Effects on deicing appeared slight to moderate across the range of liquid mixture amounts made with a consistent rock salt amount. The amount of melted snowpack and open or opening pavement appeared to increase with additional amount of liquid, with the affected width estimated at about double for the higher amounts of liquid application.

Differing liquid mixtures applied showed subtle but significant effects on deicing, ranging from a moistened snowpack under the treatment line, with no change over time for either additional melting or softening to a snow structure too slushy and wet to hold shape or form.

Chapter 6: Conclusions

The goal of this project was to develop a phase diagram and assess the ice melt capacity of the alternative deicer most in use by MnDOT. Three laboratory evaluations and a field evaluation were done to accomplish this project.

Characterization of BEET HEET®, the alternative deicer selected for study by the project's Technical Assistance Panel, was done in the first laboratory phase. The analyses of the eight BEET HEET® samples obtained for this study found BEET HEET® to consistently have a specific gravity averaging 1.28, around 550 g/L total dissolved solids, and to average 37% organic content of the whole solids within the material. The samples showed moderate variability typically between 10 and 20% for most aggregate characteristics. BEET HEET® samples seem consistent particularly in TDS, inorganic content and specific gravity, likely a function of the high chloride content of the mixture. Greater but moderate variability appears to exist with the organic components of the mixture.

The second laboratory phase developed the freeze point curve of BEET HEET® and 23.3% salt brine mixtures were at concentrations from 0% (wholly salt brine) to 100% BEET HEET® and at temperatures from 0 °F to -34 °F. Freeze points were observed in mixtures up to 60% BEET HEET®, a level that would be termed "40:60" by MnDOT Winter Maintenance personnel. Freeze points were not observed at concentrations higher than 60% BEET HEET®. The freeze curve of BEET HEET® was interpolated through use of a best fit line of the freeze points observed when graphed by BEET HEET® concentration. This curve was developed to the limits for freezer capability in this study, -34 °F on a consistent and testable basis. The eutectic temperature of BEET HEET® was not observed, as the freeze point curve of BEET HEET® appeared to be continuing to even colder levels when observed anecdotally at -40 °F, the limit of freezer ability in this study.

The third laboratory phase characterized the ice melt capacity (IMC) of BEET HEET® and 23.3% salt brine mixtures at temperatures from 0 to -21° F was done at concentrations from 0% (wholly salt brine) to 100% BEET HEET® and at temperatures from 26 °F to -21 °F. IMC, representing the volume of liquid measured/volume of deicer applied was observed at levels ranging from 5.2 (at 26 °F) to 0.0 (at subzero temperatures). An IMC of 0.0 was interpreted as the deicer either froze or was wholly absorbed into the ice matrix. Values of IMC of 1.0 or less were consistently measured at temperatures of -10 °F or colder. "Ice softening" was reported by laboratory staff performing the IMC experiments at the colder temperatures of the study, even though the IMC measured less than 1.0 at those temperatures. It appears the deicer absorbs into the ice and disrupts the ice crystal matrix, not enough to create liquid and influence IMC measurement, but enough to reduce the strength and firmness of the ice. When ice was melted by the applied deicer, most of the melting occurred within the first 30 minutes after application. When the applied deicer froze or was wholly absorbed into the ice matrix, the change occurred within the first hour after application.

In the field evaluation, deicing performance of BEET HEET® and salt brine mixtures was evaluated with actual conditions of pavement, traffic, precipitation, sun and wind. The alternative deicer BEET HEET® was tested in an on-pavement treatment comparison, allowing for performance of the alternative deicer to be compared across times and rates of application and co-treatment with rock salt. The Emergency Vehicle Operator Course at the Minnesota National Guard Camp Ripley facility was used for the on-pavement testing, where about 6 inches of dry snow had fallen 3 to 4 days before. Materials, equipment and personnel were supplied by MnDOT. Ambient weather on the day of testing was a temperature of 8 to 9° F and steady, skies were mostly sunny to lightly overcast, winds were from the west at 15 to 30 mph with gusts to 45 mph, and there was an average dew point of -1 °F.

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- The EB series, also using locations on the perimeter track, in which the rock salt amount spread was varied from 200 to 350 lbs/LM while the liquid amount was held constant at 20 gal/LM using 70:30 (30% BEET HEET®).

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Differing liquid mixtures applied showed subtle but significant effects on deicing, ranging from a moistened snowpack under the treatment line, with no change over time for either additional melting or softening to a snow structure too slushy and wet to hold shape or form.

Project results were presented to maintenance supervisors at each MnDOT district in August and September 2025. Feedback received at these conversations included:

- Regional differences of the use of alternative deicer matter, are similar to winter storm differences, and include: whether snow is dry or wet, what wind conditions are occurring and where on a highway, and what traffic amount is likely during the treatment period;
- Distribution of the alternative deicer may have a significant effect, as the left wheel side appears to increase effectiveness and distribution of the deicer;
- Alternative deicer placement near the roadway crown or on the high side of the superelevation cross slope may significantly improve effectiveness and distribution of the deicer;
- Blending of the alternative deicer directly into rock salt such as within an auger may better the effectiveness of the deicer than a co-delivered alternative deicer and rock salt such as onto a spinner plate;
- Alternative deicer application to compacted snow bonded to pavement does indeed result in "softening" of the hard pack, as seen in actual highway conditions and matching observations from the research efforts;
- Patience with alternative deicer application during very cold (colder than 10° F) temperatures may mean waiting 90 minutes before additional plowing and deicer application, as actual highway conditions generally match results seen during research efforts;
- "Snotty roads" are a difficult to remove condition seen when too much of the alternative deicer is applied or it is too concentrated, and there seems to be residual sugar or organic material remaining on the pavement. Snotty roads attract moisture even after a storm event causing low friction conditions. The snotty road moisture can refreeze and cause significant troubles for traffic;
- Capacity of on-truck tankage and truck station tankage for alternative deicer storage and mixing may control application choices including treatment rate and blend composition;
- As with traditional deicer applications, alternative deicer application effectiveness will be significantly influenced by the trend of temperatures, traffic and sunshine at the time of application;
- Insufficient mixing of stock can result in plugging of fluid flow lines as the alternative deicer may separate into thinner and thicker components; and,
- Simple models for the demonstration of deicer chemistry can be highly effective.

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Appendix A
Laboratory Test Reports

MINNESOTA VALLEY TESTING LABORATORIES, INC.
1126 North Front St. ~ New Ulm, MN 56073 ~ 800-782-3557 ~ Fax 507-359-2890
2616 East Broadway Ave. ~ Bismarck, ND 58501 ~ 800-279-6885 ~ Fax 701-258-9724
1201 Lincoln Hwy. ~ Nevada, IA 50201 ~ 800-362-0855 ~ Fax 515-382-3885
www.MVTL.com

Account #: 99991 **Client:** Cash Sales - New Ulm
Workorder: MN State University Mankato (67323)

Steve Druschel
205 Trafton Science Center E
Mankato, MN 56001

Certificate of Analysis

Approval

All data reported has been reviewed and approved by:

Dan O'Connell, Organic Chemistry Lab Manager New Ulm, MN

Analyses performed under Minnesota Department of Health Accreditation conforms to the current TNI standards.

NEW ULM LAB CERTIFICATIONS:
MN LAB # 027-015-125 ND WW/DW # R-040

BISMARCK LAB CERTIFICATIONS:
MN LAB # 038-999-267 ND W/DW # ND-016 SD SDWA

Workorder Comments

All analytes with dilution factors greater than 1 (displayed in DF column) required dilution due to matrix or high concentration of target analyte unless otherwise noted and reporting limits (RDL column) have been adjusted accordingly.

MVTL guarantees the accuracy of the analysis done on the sample submitted for testing. It is not possible for MVTL to guarantee that a test result obtained on a particular sample will be the same on any other sample unless all conditions affecting the sample are the same, including sampling by MVTL. As a mutual protection to clients, the public and ourselves, all reports are submitted as the confidential property of clients, and authorization for publication of statements, conclusions or extracts from or regarding our reports is reserved pending our written approval.

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Member ACIL

Account #: 99991 **Client:** Cash Sales - New Ulm

Analytical Results

Lab ID: 67323001 **Date Collected:** No Date Sampled Supplied **Matrix:** Wastewater
Sample ID: BH Oct 2023 **Date Received:** 10/10/2024 09:15
Sample Desc: Winter Roadway Deicer (Note: 30%r)
Temp @ Receipt (C): 18.1 **Received on Ice:** No

Parameter	Results	Units	RDL	DF	Prepared	Analyzed	Qual
Method: EPA 410.4							
Chemical Oxygen Demand	**208000**	mg/L	5000	500		10/14/2024 16:36	
Method: SM4500 H+ B-2011							
pH	**5.96**	units	0.01	1		10/10/2024 12:55	*
Method: SM5210B-2016							
Biochemical Oxygen Demand	>6000	mg/L	0.500	1		10/10/2024 13:55	*
Biochemical Oxygen Demand	**52500**	mg/L	0.500	1		10/15/2024 15:39	*

Sample Comments

Sample containers were supplied by the customer, therefore, MVTL cannot determine if the containers meet all the requirements for appropriateness as required in TNI 2016 Standard, Volume 1, Module 2, section 5.8.6.c.

Time sampled was not supplied by the client.

Temperature received outside of the 0 - 6 °C range specified by EPA requirements. Client has authorized MVTL to proceed with analysis through direct communication or authorization letter retained on file with customer service.

Analysis Results Comments

Biochemical Oxygen Demand

Sample analyzed beyond holding time.

BOD result was outside of the estimated dilution range determined during initial sample set-up.

pH

Sample analyzed beyond holding time.

MVTL guarantees the accuracy of the analysis done on the sample submitted for testing. It is not possible for MVTL to guarantee that a test result obtained on a particular sample will be the same on any other sample unless all conditions affecting the sample are the same, including sampling by MVTL. As a mutual protection to clients, the public and ourselves, all reports are submitted as the confidential property of clients, and authorization for publication of statements, conclusions or extracts from or regarding our reports is reserved pending our written approval.

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www.MVTL.com

Member ACIL

Account #: 99991 **Client:** Cash Sales - New Ulm

Analytical Results

Lab ID: 67323002 **Date Collected:** No Date Sampled Supplied **Matrix:** Wastewater
Sample ID: BH July 2024 **Date Received:** 10/10/2024 09:15
Sample Desc: Winter Roadway Deicer (Note: 30%r)
Temp @ Receipt (C): 18.1 **Received on Ice:** No

Parameter	Results	Units	RDL	DF	Prepared	Analyzed	Qual
Method: EPA 410.4							
Chemical Oxygen Demand	**223000**	mg/L	5000	500		10/14/2024 16:36	
Method: SM4500 H+ B-2011							
pH	**5.33**	units	0.01	1		10/10/2024 12:55	*
Method: SM5210B-2016							
Biochemical Oxygen Demand	>6000	mg/L	0.500	1		10/10/2024 13:57	*
Biochemical Oxygen Demand	**52400**	mg/L	0.500	1		10/15/2024 15:41	*

Sample Comments

Sample containers were supplied by the customer, therefore, MVTL cannot determine if the containers meet all the requirements for appropriateness as required in TNI 2016 Standard, Volume 1, Module 2, section 5.8.6.c.

Time sampled was not supplied by the client.

Temperature received outside of the 0 - 6 °C range specified by EPA requirements. Client has authorized MVTL to proceed with analysis through direct communication or authorization letter retained on file with customer service.

Analysis Results Comments

Biochemical Oxygen Demand

Sample analyzed beyond holding time.

BOD result was outside of the estimated dilution range determined during initial sample set-up.

pH

Sample analyzed beyond holding time.

MVTL guarantees the accuracy of the analysis done on the sample submitted for testing. It is not possible for MVTL to guarantee that a test result obtained on a particular sample will be the same on any other sample unless all conditions affecting the sample are the same, including sampling by MVTL. As a mutual protection to clients, the public and ourselves, all reports are submitted as the confidential property of clients, and authorization for publication of statements, conclusions or extracts from or regarding our reports is reserved pending our written approval.

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www.MVTL.com

Account #: 99991 **Client:** Cash Sales - New Ulm

Analytical Results

Lab ID: 67323003 **Date Collected:** No Date Sampled Supplied **Matrix:** Wastewater
Sample ID: New BH Walker 7.29.24 **Date Received:** 10/10/2024 09:15
Sample Desc: Winter Roadway Deicer (Note: 30%r)
Temp @ Receipt (C): 18.1 **Received on Ice:** No

Parameter	Results	Units	RDL	DF	Prepared	Analyzed	Qual
Method: EPA 410.4							
Chemical Oxygen Demand	**224000**	mg/L	5000	500		10/14/2024 16:36	
Method: SM4500 H+ B-2011							
pH	**5.46**	units	0.01	1		10/10/2024 12:55	*
Method: SM5210B-2016							
Biochemical Oxygen Demand	**3900**	mg/L	0.500	1		10/10/2024 14:40	

Sample Comments

Sample containers were supplied by the customer, therefore, MVTL cannot determine if the containers meet all the requirements for appropriateness as required in TNI 2016 Standard, Volume 1, Module 2, section 5.8.6.c.

Time sampled was not supplied by the client.

Temperature received outside of the 0 - 6 °C range specified by EPA requirements. Client has authorized MVTL to proceed with analysis through direct communication or authorization letter retained on file with customer service.

Analysis Results Comments

pH

Sample analyzed beyond holding time.

MVTL guarantees the accuracy of the analysis done on the sample submitted for testing. It is not possible for MVTL to guarantee that a test result obtained on a particular sample will be the same on any other sample unless all conditions affecting the sample are the same, including sampling by MVTL. As a mutual protection to clients, the public and ourselves, all reports are submitted as the confidential property of clients, and authorization for publication of statements, conclusions or extracts from or regarding our reports is reserved pending our written approval.

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www.MVTL.com

Account #: 99991 **Client:** Cash Sales - New Ulm

Analytical Results

Lab ID: 67323004 **Date Collected:** No Date Sampled Supplied **Matrix:** Wastewater
Sample ID: Roseau Old Fall 2023 **Date Received:** 10/10/2024 09:15
Sample Desc: Winter Roadway Deicer (Note: 30%r)
Temp @ Receipt (C): 18.1 **Received on Ice:** No

Parameter	Results	Units	RDL	DF	Prepared	Analyzed	Qual
Method: EPA 410.4							
Chemical Oxygen Demand	**192000**	mg/L	5000	500		10/14/2024 16:36	
Method: SM4500 H+ B-2011							
pH	**6.13**	units	0.01	1		10/10/2024 12:55	*
Method: SM5210B-2016							
Biochemical Oxygen Demand	>6000	mg/L	0.500	1		10/10/2024 14:43	*
Biochemical Oxygen Demand	**54600**	mg/L	0.500	1		10/15/2024 15:40	*

Sample Comments

Sample containers were supplied by the customer, therefore, MVTL cannot determine if the containers meet all the requirements for appropriateness as required in TNI 2016 Standard, Volume 1, Module 2, section 5.8.6.c.

Time sampled was not supplied by the client.

Temperature received outside of the 0 - 6 °C range specified by EPA requirements. Client has authorized MVTL to proceed with analysis through direct communication or authorization letter retained on file with customer service.

Analysis Results Comments

Biochemical Oxygen Demand

Sample analyzed beyond holding time.

BOD result was outside of the estimated dilution range determined during initial sample set-up.

pH

Sample analyzed beyond holding time.

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1201 Lincoln Hwy. ~ Nevada, IA 50201 ~ 800-362-0855 ~ Fax 515-382-3885
www.MVTL.com

Account #: 99991 **Client:** Cash Sales - New Ulm

Analytical Results

Lab ID: 67323005 **Date Collected:** No Date Sampled Supplied **Matrix:** Wastewater
Sample ID: Old Walker 7.18.24 **Date Received:** 10/10/2024 09:15
Sample Desc: Winter Roadway Deicer (Note: 30%r)
Temp @ Receipt (C): 18.1 **Received on Ice:** No

Parameter	Results	Units	RDL	DF	Prepared	Analyzed	Qual
Method: EPA 410.4							
Chemical Oxygen Demand	**209000**	mg/L	5000	500		10/14/2024 16:36	
Method: SM4500 H+ B-2011							
pH	**6.25**	units	0.01	1		10/10/2024 12:55	*
Method: SM5210B-2016							
Biochemical Oxygen Demand	>6000	mg/L	0.500	1		10/10/2024 14:44	*
Biochemical Oxygen Demand	**60600**	mg/L	0.500	1		10/15/2024 15:42	*

Sample Comments

Sample containers were supplied by the customer, therefore, MVTL cannot determine if the containers meet all the requirements for appropriateness as required in TNI 2016 Standard, Volume 1, Module 2, section 5.8.6.c.

Time sampled was not supplied by the client.

Temperature received outside of the 0 - 6 °C range specified by EPA requirements. Client has authorized MVTL to proceed with analysis through direct communication or authorization letter retained on file with customer service.

Analysis Results Comments

Biochemical Oxygen Demand

Sample analyzed beyond holding time.

BOD result was outside of the estimated dilution range determined during initial sample set-up.

pH

Sample analyzed beyond holding time.

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Account #: 99991 **Client:** Cash Sales - New Ulm

Analytical Results

Lab ID: 67323006 **Date Collected:** No Date Sampled Supplied **Matrix:** Wastewater
Sample ID: BH Dec 2023 CL **Date Received:** 10/10/2024 09:15
Sample Desc: Winter Roadway Deicer (Note: 30%r)
Temp @ Receipt (C): 18.1 **Received on Ice:** No

Parameter	Results	Units	RDL	DF	Prepared	Analyzed	Qual
Method: EPA 410.4							
Chemical Oxygen Demand	**202000**	mg/L	5000	500		10/14/2024 16:36	
Method: SM4500 H+ B-2011							
pH	**6.26**	units	0.01	1		10/10/2024 12:55	*
Method: SM5210B-2016							
Biochemical Oxygen Demand	>6000	mg/L	0.500	1		10/10/2024 14:45	*
Biochemical Oxygen Demand	**59500**	mg/L	0.500	1		10/15/2024 15:43	*

Sample Comments

Sample containers were supplied by the customer, therefore, MVTL cannot determine if the containers meet all the requirements for appropriateness as required in TNI 2016 Standard, Volume 1, Module 2, section 5.8.6.c.

Time sampled was not supplied by the client.

Temperature received outside of the 0 - 6 °C range specified by EPA requirements. Client has authorized MVTL to proceed with analysis through direct communication or authorization letter retained on file with customer service.

Analysis Results Comments

Biochemical Oxygen Demand

BOD result was outside of the estimated dilution range determined during initial sample set-up.

Sample analyzed beyond holding time.

pH

Sample analyzed beyond holding time.

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www.MVTL.com

Account #: 99991 **Client:** Cash Sales - New Ulm

Analytical Results

Lab ID: 67323007 **Date Collected:** No Date Sampled Supplied **Matrix:** Wastewater
Sample ID: BH June 2024 MK **Date Received:** 10/10/2024 09:15
Sample Desc: Winter Roadway Deicer (Note: 30%r)
Temp @ Receipt (C): 18.1 **Received on Ice:** No

Parameter	Results	Units	RDL	DF	Prepared	Analyzed	Qual
Method: EPA 410.4							
Chemical Oxygen Demand	**218000**	mg/L	5000	500		10/14/2024 16:36	
Method: SM4500 H+ B-2011							
pH	**5.20**	units	0.01	1		10/10/2024 13:11	*
Method: SM5210B-2016							
Biochemical Oxygen Demand	>6000	mg/L	0.500	1		10/10/2024 14:47	*
Biochemical Oxygen Demand	**64600**	mg/L	0.500	1		10/15/2024 15:45	*

Sample Comments

Sample containers were supplied by the customer, therefore, MVTL cannot determine if the containers meet all the requirements for appropriateness as required in TNI 2016 Standard, Volume 1, Module 2, section 5.8.6.c.

Time sampled was not supplied by the client.

Temperature received outside of the 0 - 6 °C range specified by EPA requirements. Client has authorized MVTL to proceed with analysis through direct communication or authorization letter retained on file with customer service.

Analysis Results Comments

Biochemical Oxygen Demand

Sample analyzed beyond holding time.

BOD result was outside of the estimated dilution range determined during initial sample set-up.

pH

Sample analyzed beyond holding time.

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Account #: 99991 **Client:** Cash Sales - New Ulm

Analytical Results

Lab ID: 67323008 **Date Collected:** No Date Sampled Supplied **Matrix:** Wastewater
Sample ID: BH Bemedji **Date Received:** 10/10/2024 09:15
Sample Desc: Winter Roadway Deicer (Note: 30%r)
Temp @ Receipt (C): 18.1 **Received on Ice:** No

Parameter	Results	Units	RDL	DF	Prepared	Analyzed	Qual
Method: EPA 410.4							
Chemical Oxygen Demand	**125000**	mg/L	5000	500		10/14/2024 16:36	
Method: SM4500 H+ B-2011							
pH	**6.17**	units	0.01	1		10/10/2024 13:11	*
Method: SM5210B-2016							
Biochemical Oxygen Demand	>6000	mg/L	0.500	1		10/10/2024 14:48	*
Biochemical Oxygen Demand	**57400**	mg/L	0.500	1		10/15/2024 15:45	*

Sample Comments

Sample containers were supplied by the customer, therefore, MVTL cannot determine if the containers meet all the requirements for appropriateness as required in TNI 2016 Standard, Volume 1, Module 2, section 5.8.6.c.

Time sampled was not supplied by the client.

Temperature received outside of the 0 - 6 °C range specified by EPA requirements. Client has authorized MVTL to proceed with analysis through direct communication or authorization letter retained on file with customer service.

Analysis Results Comments

Biochemical Oxygen Demand

Sample analyzed beyond holding time.

BOD result was outside of the estimated dilution range determined during initial sample set-up.

pH

Sample analyzed beyond holding time.

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Member ACIL

Account #: 99991 **Client:** Cash Sales - New Ulm

MVTL
Minnesota Valley Testing Laboratories, Inc.
1126 North Front Street, Building 2
New Ulm, MN 56073
Phone: (507) 354-8517
Toll Free: (800) 782-3557 Fax: (507) 359-2890

Cash Sales – New Ulm
WO: 67323

Chain of Custody Record
Page ____ of ____

Work Order #

Company Name and Address: Minnesota State University Mankato 205 Trafton Sci Center East Mankato MN 56001

Email: Stephen.drusche@mnsu.edu

Contact (Report to):

Account #: Salt IV | Phone #: 928 766 5252

Name of Samplers:

Billing Address (indicate if different from above):

Quote Number | Date Submitted: 10/10/24

Project Name/Number: | Purchase Order #:

Transferred by:	Date:	Time:	Sample Condition:	Received by:	Date:	Time:	Temp:
1. Steve Drusche			AMB	BZ	10/oct/24	9:15	18.1 TM941
2.							

Comments: AMB CM 10 Oct 24 0915 18.1 C TM941 Pd CC Total $ 634.00

Sample Information

Lab Use Only Lab #	Sample ID	Sample Type	Date Sampled	Time Sampled	Number of Bottles	32.25 Analysis	34.00 Analysis	13.00 Analysis
01	BH Oct 2023	Winter			1	BOD	COD	pH
02	BH July 2024	Runway			1			
03	New BH Walker 7.29.24	Deicer			1			
04	Roseau old Fall 2023	Note:			1			
05	old Walker 7.18.24	30% E			1			
06	BH DEC 2023 CL	TDS			1			
07	BH June 2024 WK				1			
08	BH Benedjs				1			

Enclosed are your containers for your sampling event. Completely fill and label containers appropriately for the analyses to be conducted. Complete chain of custody and submit with samples. For questions regarding individual parameter holding times, chemical and thermal preservation and sample volumes please refer to our sample preservation guide on our website at www.mvtl.com or by contacting customer service at 1-800-782-3557. If samples show signs of contamination, inadequate preservation or are in any way compromised you will be contacted as to whether to proceed with analysis or submit a new sample.

Please submit the top two copies with your samples.

Form # 10-90008-5 See above for page number Effective Date: 25 Jan 2021

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Account #: 99991 **Client:** Cash Sales - New Ulm

Paid CC - log as Cash Sale

Minnesota State University, Mankato
Big ideas. Redwoild thinking.
Stephen J. Druschel, PhD, PE, F. ASCE
Professor
Department of Mechanical and Civil Engineering
205 Trafton Science Center E
Mankato, MN 56001
Phone: 507-389-2115 (V)
800-627-3529 or 711 (MRS/TTY)
Email: stephen.druschel@mnsu.edu
www.mnsu.edu

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Account #: 99991 **Client:** Cash Sales - New Ulm

Sample Condition Checklist

Date: 10 Oct24 Time: 0915 ☑ AM ☐ PM By: CM

Account Name: Minnesota State University Mankato Account #:

Bill of Lading #: Cooler #:

Temp: 18.0 °C ROI ☐ Ambient ☑ Tracking #:

TM#: 941 Ice Crystals Present in Sample ☐

MVTL Courier: Other:

MVTL Route: Walk-In ☑ UPS Air ☐ FedEx Air ☐ SpeeDee ☐

Mail ☐ UPS Ground ☐ Fed Ex Ground ☐

Containers Supplied by MVTL: Yes ☐ No ☑ Designate customer supplied containers as "Other" in container size column

Comments:

Number	Containers Size (mL)	Container Type	Preservation	pH
8	(100) (120) (125) (250) (290) (500) (1000) Other	(G) (P) (AG) (AP)	$NaHSO_4$ $Na_2O_3S_2$ NONE HNO_3 H_2SO_4 NaOH HCl SUB*	<2 >9 >12 N/A Add
	(100) (120) (125) (250) (290) (500) (1000) Other	(G) (P) (AG) (AP)	$NaHSO_4$ $Na_2O_3S_2$ NONE HNO_3 H_2SO_4 NaOH HCl SUB*	<2 >9 >12 N/A Add
	(100) (120) (125) (250) (290) (500) (1000) Other	(G) (P) (AG) (AP)	$NaHSO_4$ $Na_2O_3S_2$ NONE HNO_3 H_2SO_4 NaOH HCl SUB*	<2 >9 >12 N/A Add
	(100) (120) (125) (250) (290) (500) (1000) Other	(G) (P) (AG) (AP)	$NaHSO_4$ $Na_2O_3S_2$ NONE HNO_3 H_2SO_4 NaOH HCl SUB*	<2 >9 >12 N/A Add
	(100) (120) (125) (250) (290) (500) (1000) Other	(G) (P) (AG) (AP)	$NaHSO_4$ $Na_2O_3S_2$ NONE HNO_3 H_2SO_4 NaOH HCl SUB*	<2 >9 >12 N/A Add
	(100) (120) (125) (250) (290) (500) (1000) Other	(G) (P) (AG) (AP)	$NaHSO_4$ $Na_2O_3S_2$ NONE HNO_3 H_2SO_4 NaOH HCl SUB*	<2 >9 >12 N/A Add
	(100) (120) (125) (250) (290) (500) (1000) Other	(G) (P) (AG) (AP)	$NaHSO_4$ $Na_2O_3S_2$ NONE HNO_3 H_2SO_4 NaOH HCl SUB*	<2 >9 >12 N/A Add
	Low Level Mercury Kit	****DO NOT OPEN THE PLASTIC BAGS HOLDING THE SAMPLE BOTTLES!!****		
	4 oz Jar	Clear Amber	MeOH None	n/a
	2 oz Jar	Clear Amber	MeOH None	n/a
	Vials Individual Set of 2 Set of 3	Clear Amber	HCl H_3PO_4 H_2SO_4 None	n/a
	Vials Individual Set of 2 Set of 3	Clear Amber	HCl H_3PO_4 H_2SO_4 None	n/a
	Trip Blank Individual Set of 2 Set of 3	n/a		
	Moisture Vial	n/a		
	Manure Bottle	n/a		

***ANY CONTAINER SENT TO A SUBCONTRACT LABORATORY WILL NOT BE CHECKED FOR PRESERVATION!**

Form # 30-911001-0 Page 1 of 1 Effective Date: 29 September 2021

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Appendix B
Analytical Results

Salt IV - Know Before the Snow

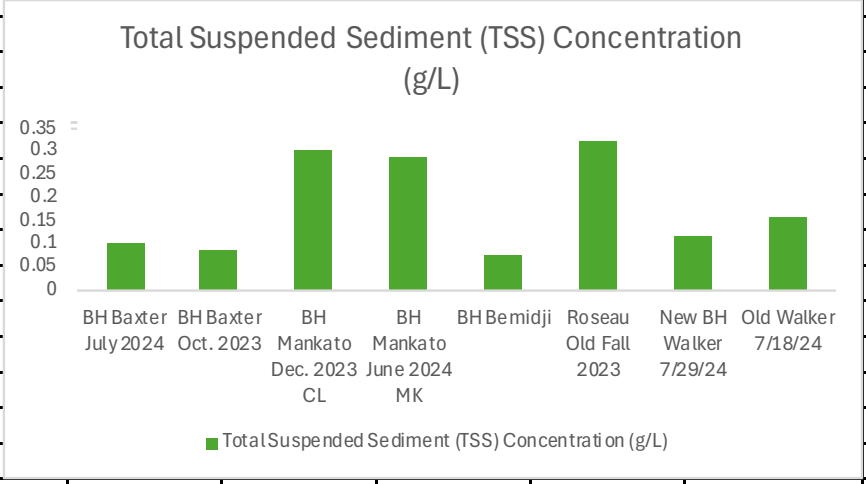
B. Suwal and M. Marshmann | S. Druschel

October 7, 2024 | November 9, 2024

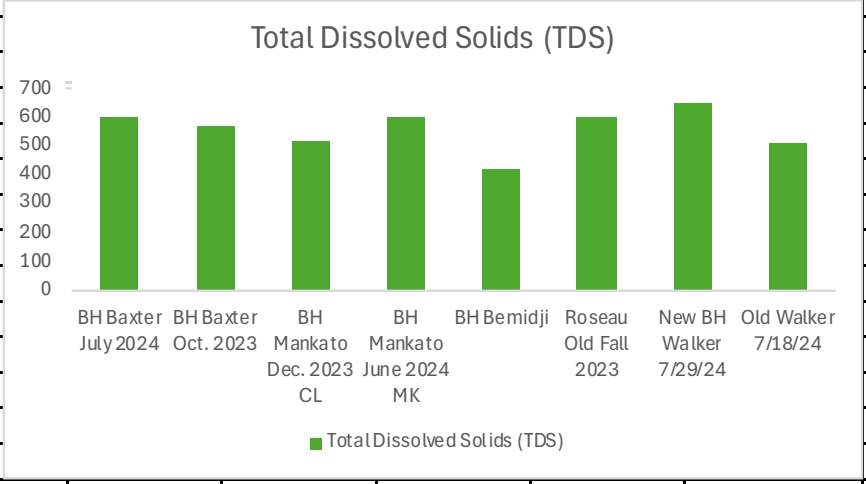
Testing of Beet Heet Samples for Total Suspended Solids (TSS) and Total Dissolved Solids (TDS), Inorganic Content and Organic Content

Total Suspended Solids (TSS)

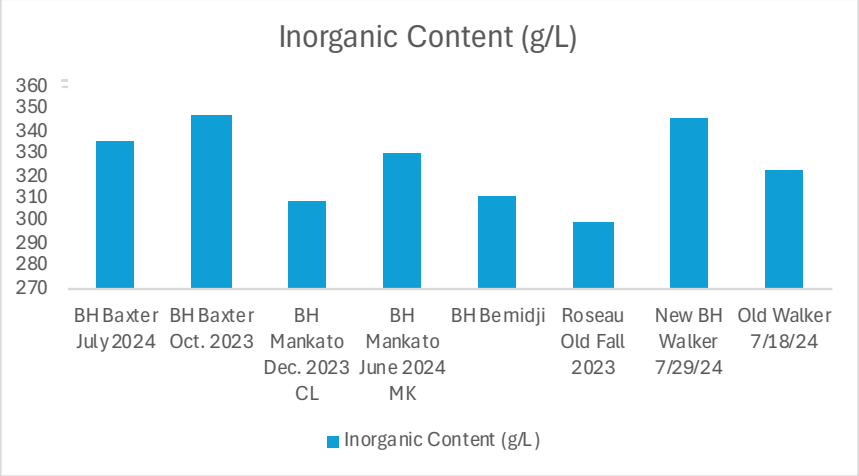
Sample Material (as labeled by source)	Volume of Specimen (mL)	Mass of Dish and Filter Before Drying (g)	Mass of Sediment, Dish and Filter After Drying & Cooling (g)	Sediment on Filter (g)	Total Suspended Sediment (TSS) Concentration (mg/L)	Total Suspended Sediment (TSS) Concentration (g/L)
BH Baxter July 2024	50.0	36.446	36.4512	0.0052	104	0.104
BH Baxter Oct. 2023	50.0	32.8505	32.8548	0.0043	86	0.086
BH Mankato Dec. 2023 CL	50.0	33.1567	33.1718	0.0151	302	0.302
BH Mankato June 2024 MK	50.0	36.4656	36.4800	0.0144	288	0.288
BH Bemidji	50.0	34.4293	34.4332	0.0039	78	0.078
Roseau Old Fall 2023	50.0	32.9220	32.9381	0.0161	322	0.322
New BH Walker 7/29/24	50.0	33.7473	33.7533	0.0060	120	0.120
Old Walker 7/18/24	50.0	33.7983	33.8064	0.0081	162	0.162
				Average	183	0.183
				Standard Deviation	104	0.104
				RSD (%)	57%	57%

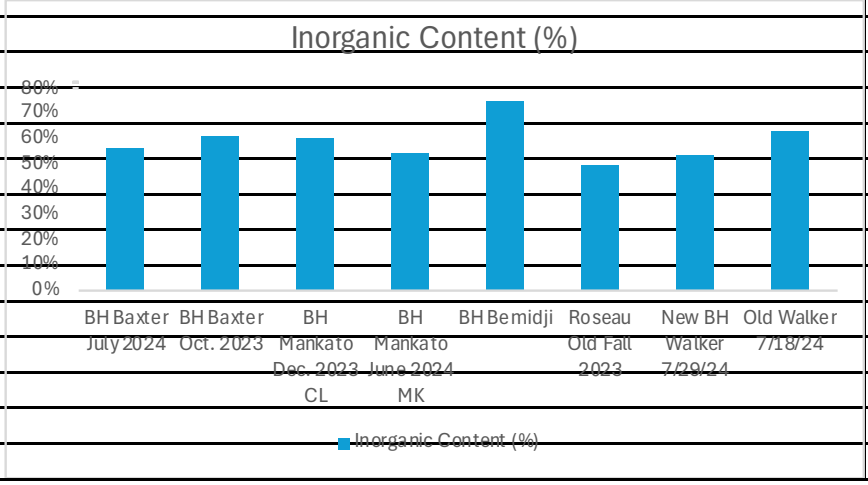


		Total Dissolved Solids (TDS)					
Sample Material (as labeled by source)	Volume of Specimen (mL)	Mass of Dish Empty (g)	Mass of Dish & Filtered Liquid After Heating and Drying in 104 deg C oven (g)	Mass of Dry Filtrate (Filtered Liquid Dry Remains) (g)	Total Dissolved Solids Concentration (mg/L)	Total Dissolved Solids (TDS) Concentration (g/L)	
BH Baxter July 2024	50.0	81.4275	111.4452	30.0177	600,354	600	
BH Baxter Oct. 2023	50.0	78.8504	107.2757	28.4253	568,506	569	
BH Mankato Dec. 2023 CL	50.0	80.4080	106.2823	25.8743	517,486	517	
BH Mankato June 2024 MK	50.0	82.1635	112.2910	30.1275	602,550	603	
BH Bemidji	50.0	75.3252	96.1355	20.8103	416,206	416	
Roseau Old Fall 2023	50.0	77.2833	107.1464	29.8631	597,262	597	
New BH Walker 7/29/24	50.0	77.3744	109.7656	32.3912	647,824	648	
Old Walker 7/18/24	50.0	76.3068	101.8793	25.5725	511,450	511	
				Average	557,705	558	
				Standard Deviation	73,107	73	
				RSD (%)	13%	13%	

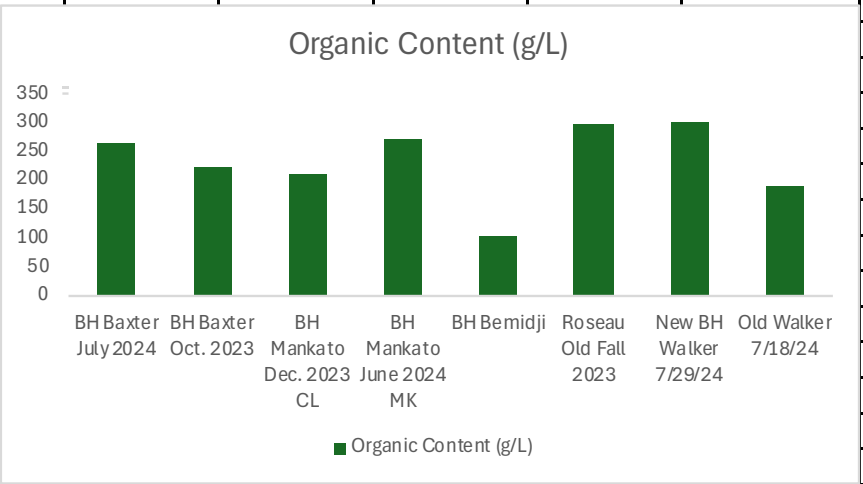


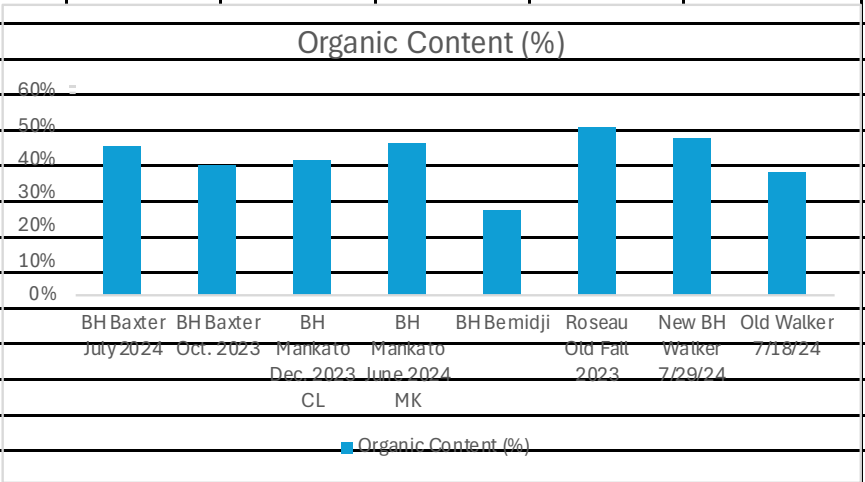
		Inorganic Content					
Sample Material (as labeled by source)	Volume of Specimen (mL)	Mass of Dish & Dry Filterate After Heating in 500 deg C Muffle Furnace (g)	Inorganic Mass (g)	Inorganic Content (g/L)	Inorganic Content (%)		
BH Baxter July 2024	50.0	98.2334	16.8059	336	56%		
BH Baxter Oct. 2023	50.0	96.1900	17.3396	347	61%		
BH Mankato Dec. 2023 CL	50.0	95.8536	15.4456	309	60%		
BH Mankato June 2024 MK	50.0	98.6920	16.5285	331	55%		
BH Bemidji	50.0	90.9002	15.575	312	75%		
Roseau Old Fall 2023	50.0	92.2555	14.9722	299	50%		
New BH Walker 7/29/24	50.0	94.6993	17.3249	346	53%		
Old Walker 7/18/24	50.0	92.4660	16.1592	323	63%		
			Average	325	59%		
			Standard Deviation	18	8%		
			RSD (%)	5%	13%		



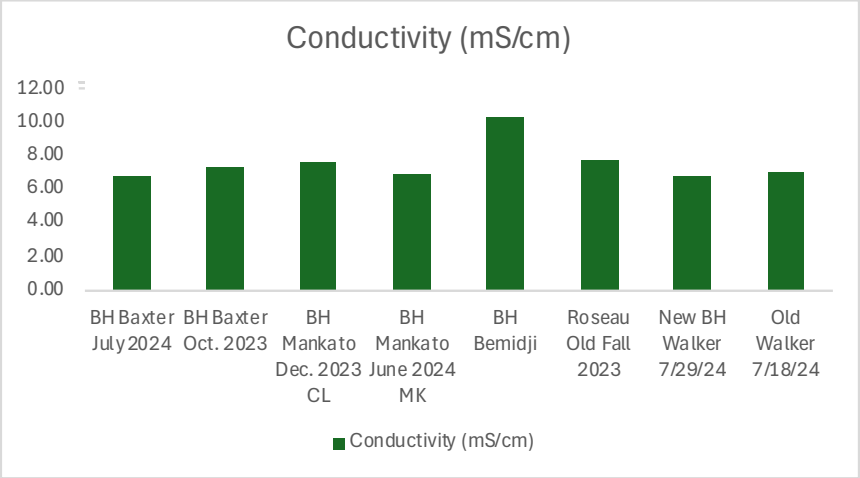


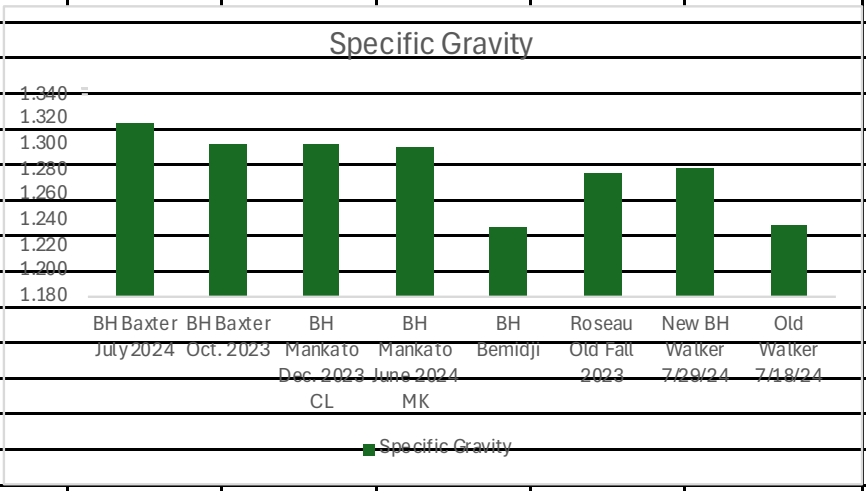
		Organic Content					
Sample Material (as labeled by source)	Volume of Specimen (mL)	Organic Mass (g)	Organic Content (g/L)	Organic Content (%)			
BH Baxter July 2024	50.0	13.2118	264	44%			
BH Baxter Oct. 2023	50.0	11.0857	222	39%			
BH Mankato Dec. 2023 CL	50.0	10.4287	209	40%			
BH Mankato June 2024 MK	50.0	13.5990	272	45%			
BH Bemidji	50.0	5.2353	105	25%			
Roseau Old Fall 2023	50.0	14.8909	298	50%			
New BH Walker 7/29/24	50.0	15.0663	301	47%			
Old Walker 7/18/24	50.0	9.4133	188	37%			
		Average	232	41%			
		Standard Deviation	66	8%			
		RSD (%)	28%	19%			



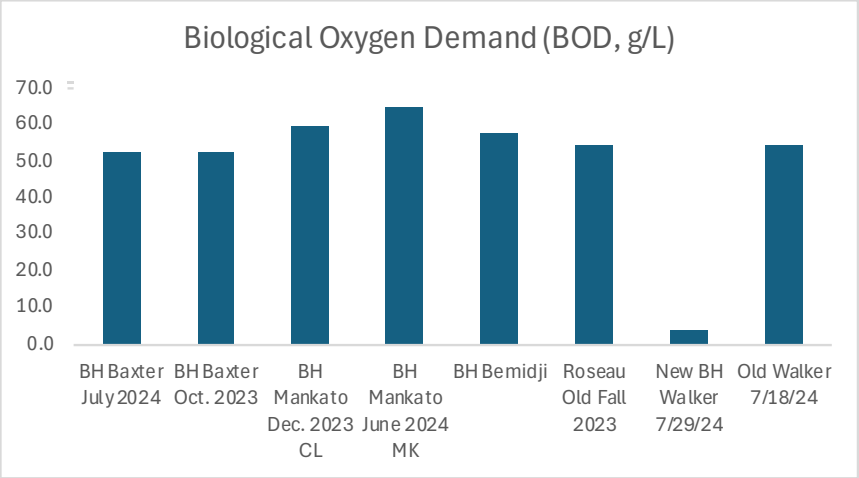


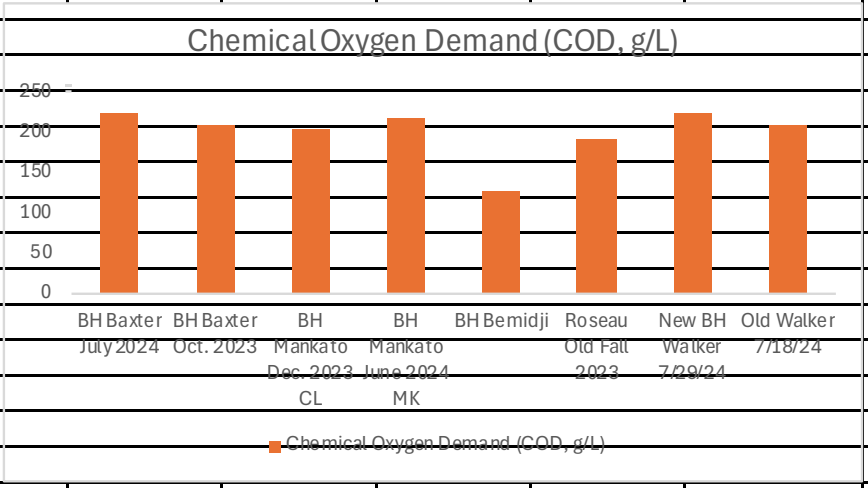
		Specific Gravity and Conductivity					
Sample Material (as labeled by source)	Specific Gravity		Conductivity (mS/cm)				
BH Baxter July 2024	1.317		6.74				
BH Baxter Oct. 2023	1.301		7.27				
BH Mankato Dec. 2023 CL	1.300		7.66				
BH Mankato June 2024 MK	1.299		6.85				
BH Bemidji	1.234		10.22				
Roseau Old Fall 2023	1.277		7.78				
New BH Walker 7/29/24	1.282		6.77				
Old Walker 7/18/24	1.237		7.00				
Average	1.281		7.536				
Standard Deviation	0.031		1.154				
RSD (%)	2%		15%				





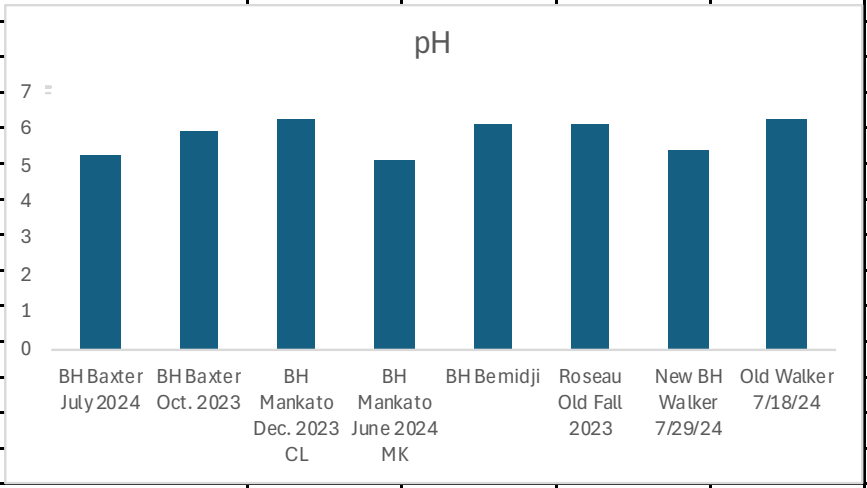
Sample Material (as labeled by source)	Biological Oxygen Demand (BOD, g/L)	Chemical Oxygen Demand (COD, g/L)					
BH Baxter July 2024	52.4	223		Minnesota Valley Testing Laboratory			
BH Baxter Oct. 2023	52.5	208		New Ulm, Minnesota			
BH Mankato Dec. 2023 CL	59.5	202					
BH Mankato June 2024 MK	64.6	218					
BH Bemidji	57.4	125					
Roseau Old Fall 2023	54.6	192					
New BH Walker 7/29/24	3.9	224					
Old Walker 7/18/24	54.6	209					
Average	49.9	200					
Standard Deviation	19.0	32					
RSD (%)	38%	16%					





Sample Material (as labeled by source)	pH
BH Baxter July 2024	5.33
BH Baxter Oct. 2023	5.96
BH Mankato Dec. 2023 CL	6.26
BH Mankato June 2024 MK	5.20
BH Bemidji	6.17
Roseau Old Fall 2023	6.13
New BH Walker 7/29/24	5.46
Old Walker 7/18/24	6.25
Average	5.85
Standard Deviation	0.44
RSD (%)	8%

Minnesota Valley Testing Laboratory
New Ulm, Minnesota



Appendix C
Analytical Results by Delivery Year

Salt IV - Know Before the Snow					
S. Druschel					
November 8, 2024					
Testing of Beet Heet Samples for Total Suspended Solids (TSS) and Total Dissolved Solids (TDS), Inorganic Content and Organic Content					
Total Suspended Solids (TSS) Concentration (g/L)					
Assumed as 2024 Delivery		Assumed as 2023 Delivery			
BH Baxter July 2024	0.104	BH Baxter Oct. 2023	0.086		
BH Mankato June 2024 MK	0.288	BH Mankato Dec. 2023 CL	0.302		
New BH Walker 7/29/24	0.12	Roseau Old Fall 2023	0.322		
		Old Walker 7/18/24	0.162		
Average	0.171	Average	0.218	-0.047	Difference
Standard Deviation	0.102	Standard Deviation	0.113	-28%	Relative Difference (%)
RSD (%)	60%	RSD (%)	52%		
Total Dissolved Solids (TSS) Concentration (g/L)					
Assumed as 2024 Delivery		Assumed as 2023 Delivery			
BH Baxter July 2024	600	BH Baxter Oct. 2023	569		
BH Mankato June 2024 MK	603	BH Mankato Dec. 2023 CL	517		
New BH Walker 7/29/24	648	Roseau Old Fall 2023	597		
		Old Walker 7/18/24	511		
Average	617.000	Average	548.5	69	Difference
Standard Deviation	26.889	Standard Deviation	41.517	11%	Relative Difference (%)
RSD (%)	4%	RSD (%)	8%		
Inorganic Content					
Assumed as 2024 Delivery		Assumed as 2023 Delivery			
BH Baxter July 2024	336	BH Baxter Oct. 2023	347		
BH Mankato June 2024 MK	331	BH Mankato Dec. 2023 CL	309		
New BH Walker 7/29/24	346	Roseau Old Fall 2023	299		
		Old Walker 7/18/24	323		
Average	338	Average	320	18	Difference
Standard Deviation	8	Standard Deviation	21	5%	Relative Difference (%)
RSD (%)	2%	RSD (%)	6%		
Organic Content					
Assumed as 2024 Delivery		Assumed as 2023 Delivery			
BH Baxter July 2024	264	BH Baxter Oct. 2023	222		
BH Mankato June 2024 MK	272	BH Mankato Dec. 2023 CL	209		
New BH Walker 7/29/24	301	Roseau Old Fall 2023	298		
		Old Walker 7/18/24	188		
Average	279	Average	229	50	Difference
Standard Deviation	19	Standard Deviation	48	18%	Relative Difference (%)
RSD (%)	7%	RSD (%)	21%		

Specific Gravity					
Assumed as 2024 Delivery		Assumed as 2023 Delivery			
BH Baxter July 2024	1.317	BH Baxter Oct. 2023	1.301		
BH Mankato June 2024 MK	1.299	BH Mankato Dec. 2023 CL	1.3		
New BH Walker 7/29/24	1.282	Roseau Old Fall 2023	1.277		
		Old Walker 7/18/24	1.24		
Average	1.30	Average	1.28	0.02	Difference
Standard Deviation	0.02	Standard Deviation	0.03	2%	Relative Difference (%)
RSD (%)	1%	RSD (%)	2%		
Conductivity (mS/cm)					
Assumed as 2024 Delivery		Assumed as 2023 Delivery			
BH Baxter July 2024	6.74	BH Baxter Oct. 2023	7.27		
BH Mankato June 2024 MK	6.85	BH Mankato Dec. 2023 CL	7.66		
New BH Walker 7/29/24	6.77	Roseau Old Fall 2023	7.78		
		Old Walker 7/18/24	7.00		
Average	6.79	Average	7.43	-0.64	Difference
Standard Deviation	0.06	Standard Deviation	0.36	-9%	Relative Difference (%)
RSD (%)	1%	RSD (%)	5%		
pH					
Assumed as 2024 Delivery		Assumed as 2023 Delivery			
BH Baxter July 2024	5.33	BH Baxter Oct. 2023	5.96		
BH Mankato June 2024 MK	5.20	BH Mankato Dec. 2023 CL	6.26		
New BH Walker 7/29/24	5.46	Roseau Old Fall 2023	6.13		
		Old Walker 7/18/24	6.25		
Average	5.33	Average	6.15	-0.82	Difference
Standard Deviation	0.13	Standard Deviation	0.14	-15%	Relative Difference (%)
RSD (%)	2%	RSD (%)	2%		
Biological Oxygen Demand (BOD, g/L)					
Assumed as 2024 Delivery		Assumed as 2023 Delivery			
BH Baxter July 2024	52.4	BH Baxter Oct. 2023	52.5		
BH Mankato June 2024 MK	64.6	BH Mankato Dec. 2023 CL	59.5		
New BH Walker 7/29/24	3.9	Roseau Old Fall 2023	54.6		
		Old Walker 7/18/24	54.6		
Average	40.3	Average	55.3	-15.0	Difference
Standard Deviation	32.1	Standard Deviation	3.0	-37%	Relative Difference (%)
RSD (%)	80%	RSD (%)	5%		
Chemical Oxygen Demand (COD, g/L)					
Assumed as 2024 Delivery		Assumed as 2023 Delivery			
BH Baxter July 2024	223	BH Baxter Oct. 2023	208		
BH Mankato June 2024 MK	218	BH Mankato Dec. 2023 CL	202		
New BH Walker 7/29/24	224	Roseau Old Fall 2023	192		
		Old Walker 7/18/24	209		
Average	222	Average	203	19	Difference
Standard Deviation	3	Standard Deviation	8	9%	Relative Difference (%)
RSD (%)	1%	RSD (%)	4%		

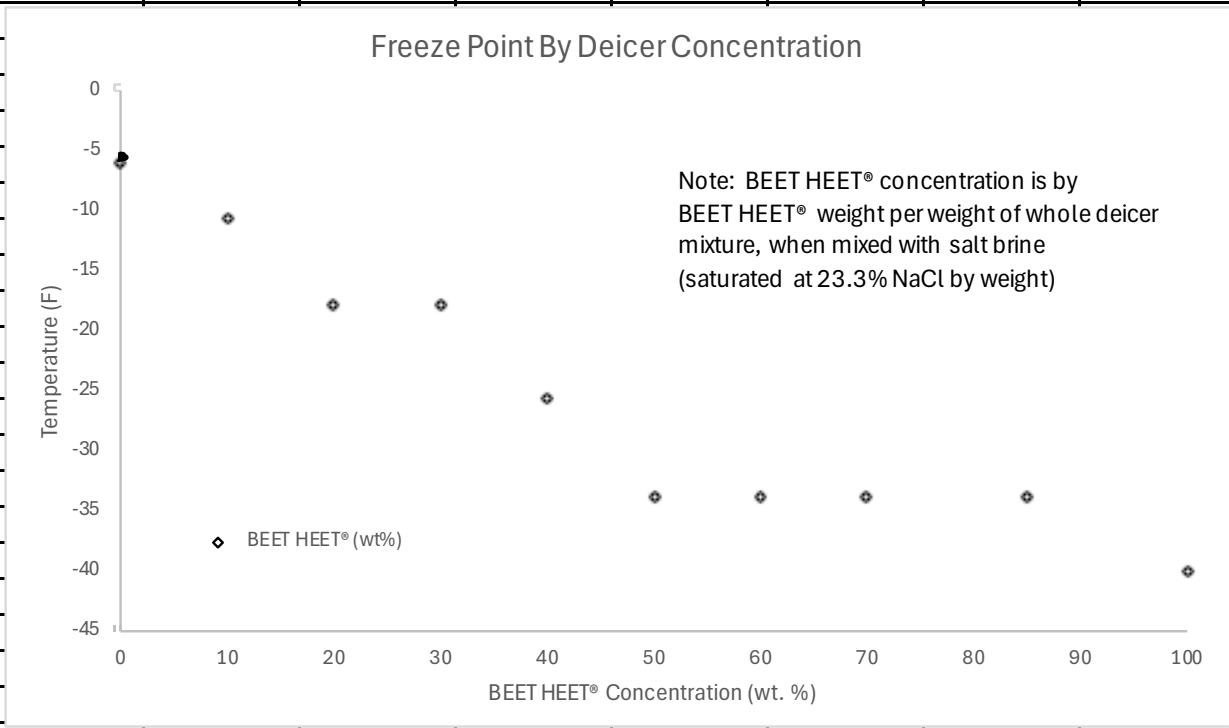
Appendix D
Freeze Point Evaluation Results

Salt IV: Know Before the Snow
MSU Mankato
S. Druschel
January 23, 2025

Freeze Point Experiments

Temperature (ºF)	Elapsed Time at	Ice Bath Setting	0%BH Salt Brine	10%BH 90:10	20%BH 80:20	30%BH 70:30	40%BH 60:40	50%BH 50:50	60%BH 40:60	70%BH 30:70	85%BH 15:85	100%BH 0:100
0	20 hrs	2 L in Freezer	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen
-3.5	1 hr	2 L in Freezer	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen
-4.0	120 hr	2 L in Freezer	unfrozen	unfrozen	unfrozen	bottom freezing	bottom freezing	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen
-6.0	128 hr	2 L in Freezer	unfrozen	unfrozen	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	unfrozen	unfrozen
-7.1	1 hr	2 L in Freezer	unfrozen *supercooled*	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	unfrozen
-8.0	120 hr	2 L in Freezer	unfrozen *supercooled*	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	unfrozen
-9.0	128 hr	2 L in Freezer	unfrozen *supercooled*	unfrozen	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	unfrozen	unfrozen
-10.7	1 hr	2 L in Freezer	wholly frozen	wholly frozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen
-12.0	1.5 hr	2 L in Freezer	wholly frozen	wholly frozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen
-13.0	1 hr	2 L in Freezer	wholly frozen	wholly frozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen
-17.9	1 hr	2 L in Freezer	wholly frozen	wholly frozen	wholly frozen	wholly frozen	bottom freezing	bottom freezing	bottom freezing	bottom freezing	bottom freezing	unfrozen
-25.6	2 hrs	50 L in Cooler	wholly frozen	wholly frozen	wholly frozen	mostly frozen	mostly frozen	mostly frozen	half frozen	unfrozen	unfrozen	unfrozen
-33.8	2 hrs	50 L in Cooler	wholly frozen	wholly frozen	wholly frozen	wholly frozen	bottom freezing	unfrozen	unfrozen	unfrozen	unfrozen	unfrozen
-33.8	4 hrs	50 L in Cooler	wholly frozen	wholly frozen	wholly frozen	wholly frozen	mostly frozen	unfrozen	unfrozen	bottom freezing	unfrozen	unfrozen
-33.8	16 hrs	50 L in Cooler	wholly frozen	wholly frozen	wholly frozen	wholly frozen	wholly frozen	wholly frozen	wholly frozen	wholly frozen	wholly frozen	unfrozen

Salt IV: Know Before the Snow						S. Druschel	
MSU Mankato		**Freeze Point Experiments**				January 23, 2025	
Reference: Fay et al (2022). Clear Roads Final Report CR 20-02							
NaCl (wt%)	BEET HEET® (wt%)	Freeze Point (°F)					
0		32		characteristic property			
2		30		scaled from graph			
5		27		scaled from graph			
10		20.5		scaled from graph			
10.5		20		scaled from graph			
15		11.5		scaled from graph			
16		10		scaled from graph			
20		0.5		scaled from graph			
20.5		0		scaled from graph			
23.3		-6		characteristic property			
	0	-6		characteristic property			
	10	-10.7		observed			
	20	-17.9		observed			
	30	-17.9		observed			
	40	-25.6		observed			
	50	-33.8		observed			
	60	-33.8		observed			
	70	-33.8		observed			
	85	-33.8		observed			
	100	-40	less than	observed			



Appendix E
Ice Melt Capacity Evaluation Results

10% Salt Brine Ice Slush Mixture

Time	Temperatures (Fahrenheit)			Measured Amounts of Liquid on Ice Surface (3ml Deicer Initially Applied)															
Min-utes	Temp. of BH (In Tray)		Temp of Center	100% BH		70% BH		50% BH		40% BH		30% BH		20% BH		10% BH		0% BH	
	Tray 1	Tray 2	(In Cooler)	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2
0	11.8	12	12	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
30	12.5	13.1	11	6.0	5.8	5.6	6.0	5.8	5.8	5.6	5.8	5.6	5.6	5.2	5.8	5.0	5.4	4.8	5.0
60	12.7	13.6	11.5	6.4	6.2	6.2	6.4	6.0	6.0	6.0	6.4	5.8	6.0	5.6	5.8	5.2	5.8	4.0	4.4
90	13.2	13.8	12	6.6	6.4	6.2	6.6	6.0	6.0	6.0	6.6	6.0	6.0	5.8	6.0	5.0	5.6	4.8	2.6
120	13.4	14.1	12	6.6	6.6	6.0	6.6	6.2	6.4	6.0	6.4	6.0	6.0	5.6	6.0	4.6	5.6	4.2	1.4

37.5% Glycol Ice Slush Mixture

Time	Temperatures (Fahrenheit)			Measured Amounts of Liquid on Ice Surface (3ml Deicer Initially Applied)															
Min-utes	Temp. of BH (In Tray)		Temp of Center	100% BH		70% BH		50% BH		40% BH		30% BH		20% BH		10% BH		0% BH	
	Tray 1	Tray 2	In Cooler	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2
0	-11.1	-10.7	-11	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
30	-10.3	-10.5	-10.5	3.4	4.0	3.0	2.1	2.9	3.2	2.8	3.0	2.7	2.8	2.6	2.7	2.8	2.8	1.9	2.2
60	-8.7	-9.6	-9	3.4	3.8	3.0	3.2	2.0	3.2	3.0	2.9	3.0	2.8	2.8	2.9	3.0	2.9	0.8	1.9
90	-7.1		-8	2.4	2.2	3.0	3.2	2.1	2.1	3.0	2.2	3.0	3.0	3.1	3.0	3.1	3,2	0.7	1.8
120	-5.5		-6	4.0	3.8	3.1	3.4	3.4	3.2	3.2	3.2	3.4	3.2	3.3	3.0	3.3	3.3	0.6	1.4

16% Salt Brine Ice Slush Mixture

Time	Temperatures (Fahrenheit)			Measured Amounts of Liquid on Ice Surface (3ml Deicer Initially Applied)															
Min-utes	Temp. of BH (In Tray)		Temp of Center	100% BH		70% BH		50% BH		40% BH		30% BH		20% BH		10% BH		0% BH	
	Tray 1	Tray 2	In Cooler	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2
0	3.5	3.5	1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
30	3.5	3.9	1	4.0	4.4	4.0	4.3	3.6	4.1	3.6	4.1	3.4	4.1	3.6	4.0	3.8	3.9	3.8	2.4
60	3.9	4.1	1	4.4	4.8	4.0	4.5	3.8	4.4	4.0	4.2	3.2	4.1	3.4	4.1	4.0	4.1	3.0	2.2
90	4.2	4.4	1.5	4.6	5.0	4.0	4.7	3.6	4.2	4.0	4.2	3.4	3.9	3.6	4.0	3.4	3.5	2.0	1.0
120	4.4	4.6	2	4.6	5.0	3.8	4.6	3.6	4.2	3.8	4.2	3.0	3.9	3.0	3.8	3.0	2.4	1.0	0.6

41% Glycol Ice Slush Mixture

Time	Temperatures (Fahrenheit)			Measured Amounts of Liquid on Ice Surface (3ml Deicer Initially Applied)															
Min-utes	Temp. of BH (In Tray)		Temp of Center	100% BH		70% BH		50% BH		40% BH		30% BH		20% BH		10% BH		0% BH	
	Tray 1	Tray 2	In Cooler	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2
0	-22.9	-21.7	-24	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
30	-22	-20.8	-24.5	2.0	2.0	2.2	2.1	2.2	2.2	2.1	2.1	2.0	2.0	1.6	2.0	0.0	0.3	0.0	0.0
60	-21.1	-20.1	-24	1.8	1.8	2.0	2.0	2.6	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	-20.1	-19.2	-23	1.9	1.9	1.9	2.0	0.6	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
120	-19.5	-18.3	-22	2.0	1.9	1.6	1.8	0.6	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

45% Glycol Ice Slush Mixture

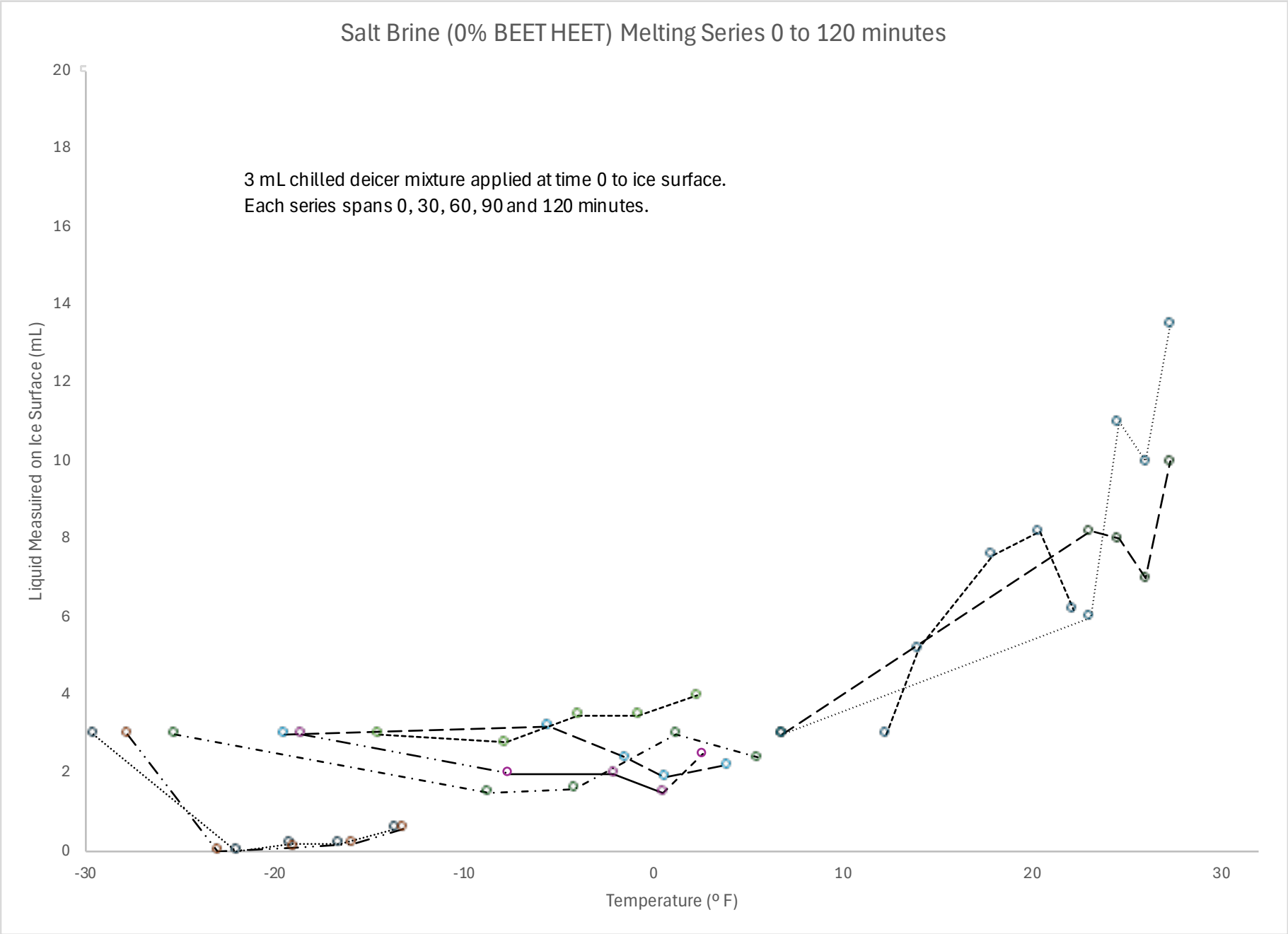
Time	Temperatures (Fahrenheit)			Measured Amounts of Liquid on Ice Surface (3ml Deicer Initially Applied)															
Min-utes	Temp. of BH (In Tray)		Temp of Center	100% BH		70% BH		50% BH		40% BH		30% BH		20% BH		10% BH		0% BH	
	Tray 1	Tray 2	In Cooler	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 1	Tray 2	In Cooler	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2
0	-16.6	-17.2	-18	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
30	-14.5	-15.2	-15	2.8	3.0	2.4	2.4	2.0	2.4	2.2	2.6	2.8	2.4	2.6	2.6	3.2	3.4	2.4	3.2
60	-12.9	-13.4	-15	2.8	3.2	2.6	2.6	2.4	2.2	2.2	2.6	2.8	2.6	3.0	2.8	3.6	3.8	1.4	3.0
90	-11.2	-11.8	-13	3.0	3.2	2.6	2.4	2.4	2.4	2.4	2.8	3.0	2.6	3.0	2.6	3.6	3.8	1.0	2.8
120	-9.6	-10.3	-11	3.0	3.4	2.4	2.4	2.6	2.4	2.6	28.0	3.0	2.8	3.0	2.6	4.0	4.2	1.0	2.0

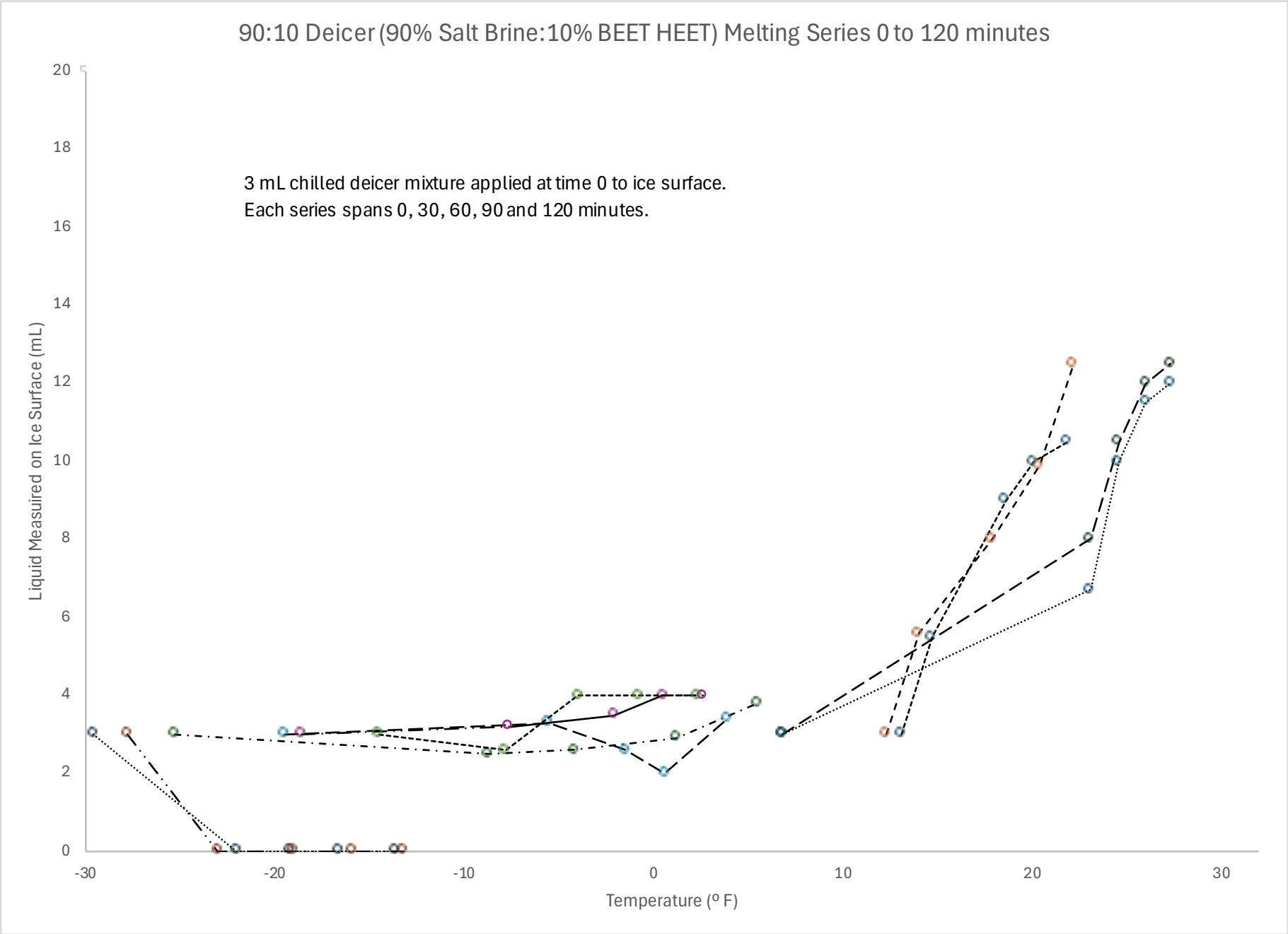
4% Salt Brine Ice Slush Mixture

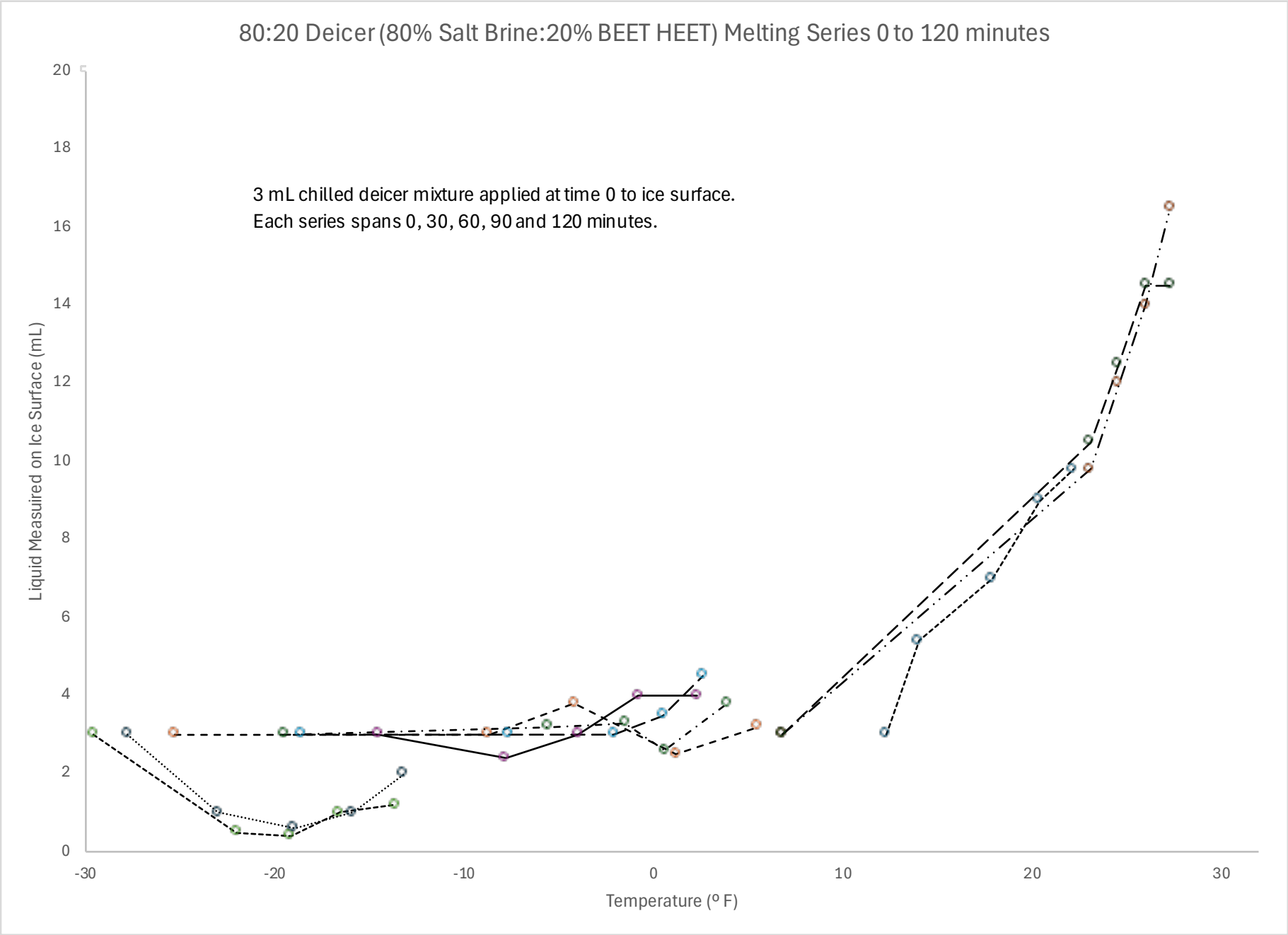
Time	Temperatures (Fahrenheit)			Measured Amounts of Liquid on Ice Surface (3ml Deicer Initially Applied)															
Min-utes	Temp. of BH (In Tray)		Temp of Center	100% BH		70% BH		50% BH		40% BH		30% BH		20% BH		10% BH		0% BH	
	Tray 1	Tray 2	In Cooler	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	In Cooler	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1
0	25.7	25.7	25	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
30	25.7	25.7	25	11.0	11.2	10.5	10.9	11.1	10.8	11.0	11.8	11.5	12.6	12.1	12.0	12.1	12.2	11.0	12.4
60	25.7	25.7	25	13.0	13.0	13.5	13.0	15.0	13.0	14.0	14.0	14.0	14.5	14.0	14.0	12.5	13.5	11.5	12.5
90	25.8	25.7	25	14.0	15.0	15.0	14.5	15.5	13.5	15.0	15.0	15.5	15.5	15.0	15.0	15.5	14.0	12.5	14.0
120	26	25.8	25	15.0	13.0	15.0	15.0	16.0	14.0	15.5	15.0	16.0	16.0	17.5	16.0	18.0	15.0	11.0	15.0

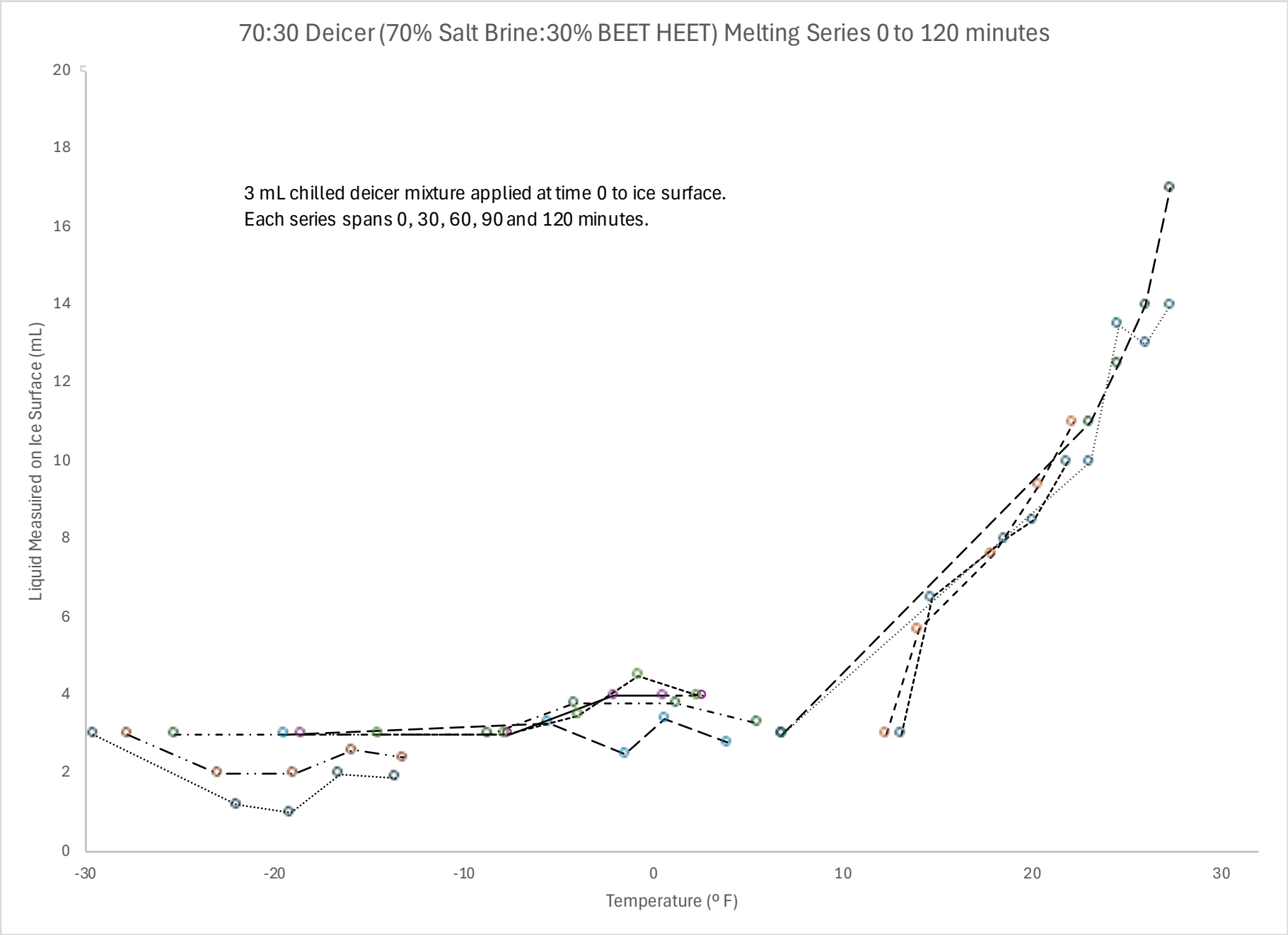
48% Glycol Ice Slush Mixture

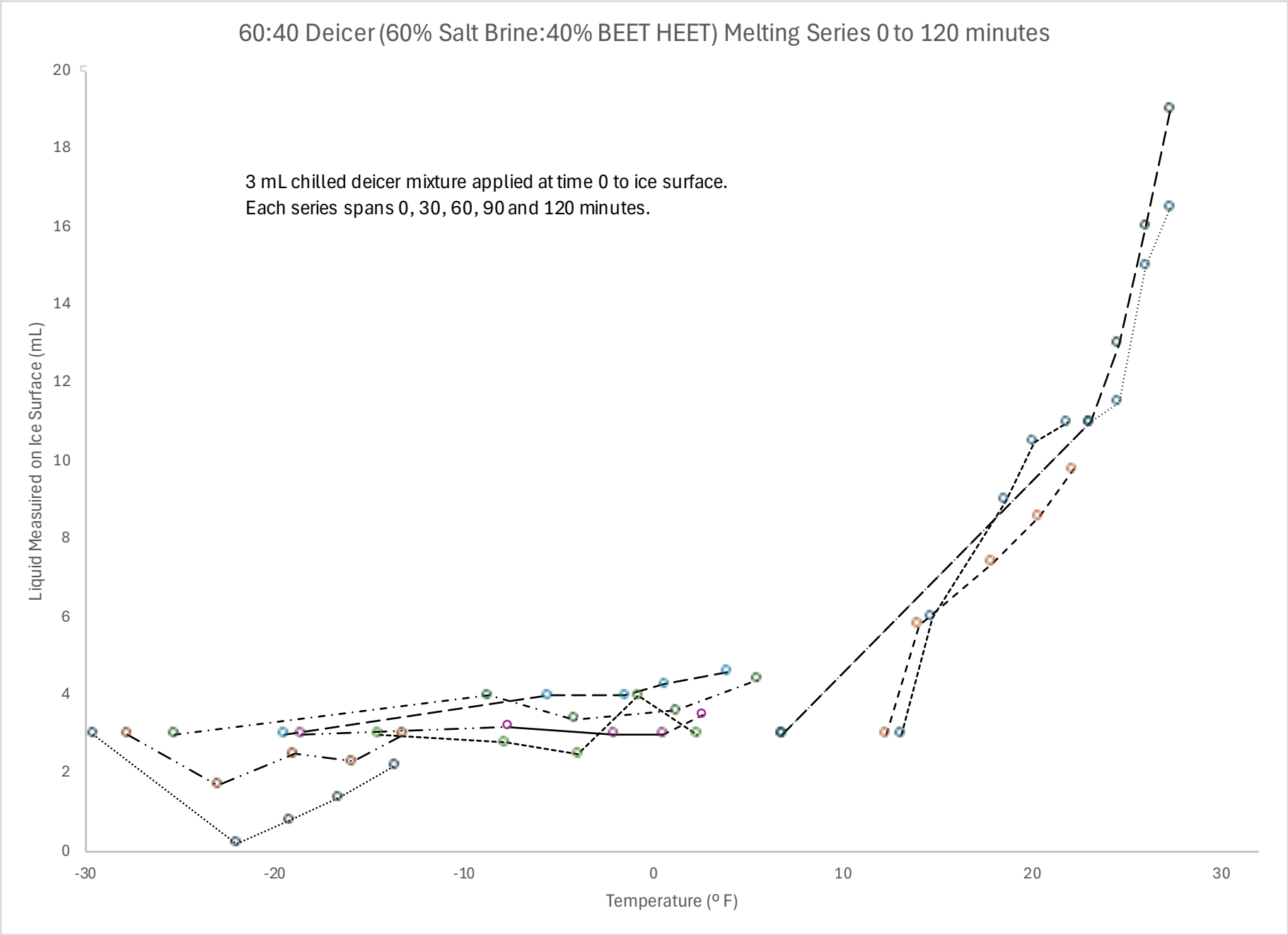
Time	Temperatures (Fahrenheit)			Measured Amounts of Liquid on Ice Surface (3ml Deicer Initially Applied)															
Min-utes	Temp. of BH (In Tray)		Temp of Center	100% BH		70% BH		50% BH		40% BH		30% BH		20% BH		10% BH		0% BH	
	Tray 1	Tray 2	In Cooler	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	In Cooler	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1
0	-18.1	-17.9	-19	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
30	-16.3	-16.1	-20	2.4	2.2	2.6	2.4	2.4	2.6	2.8	3.0	2.8	2.9	2.6	2.8	3.0	2.7	1.8	2.6
60	-15.5	-14.3	-19	2.6	2.4	2.5	2.6	2.0	2.4	2.6	2.4	3.0	3.0	3.0	3.0	3.2	2.7	1.2	0.6
90	-12.9	-12.5	-16	2.7	2.4	2.6	2.4	2.2	2.5	2.8	2.6	3.0	3.0	3.0	3.4	3.0	2.8	1.0	0.2
120	-11.1	-10.9	-15	2.8	2.6	2.6	2.6	2.4	2.4	2.7	2.2	3.0	3.2	2.8	2.4	2.0	0.4	0.8	0.8

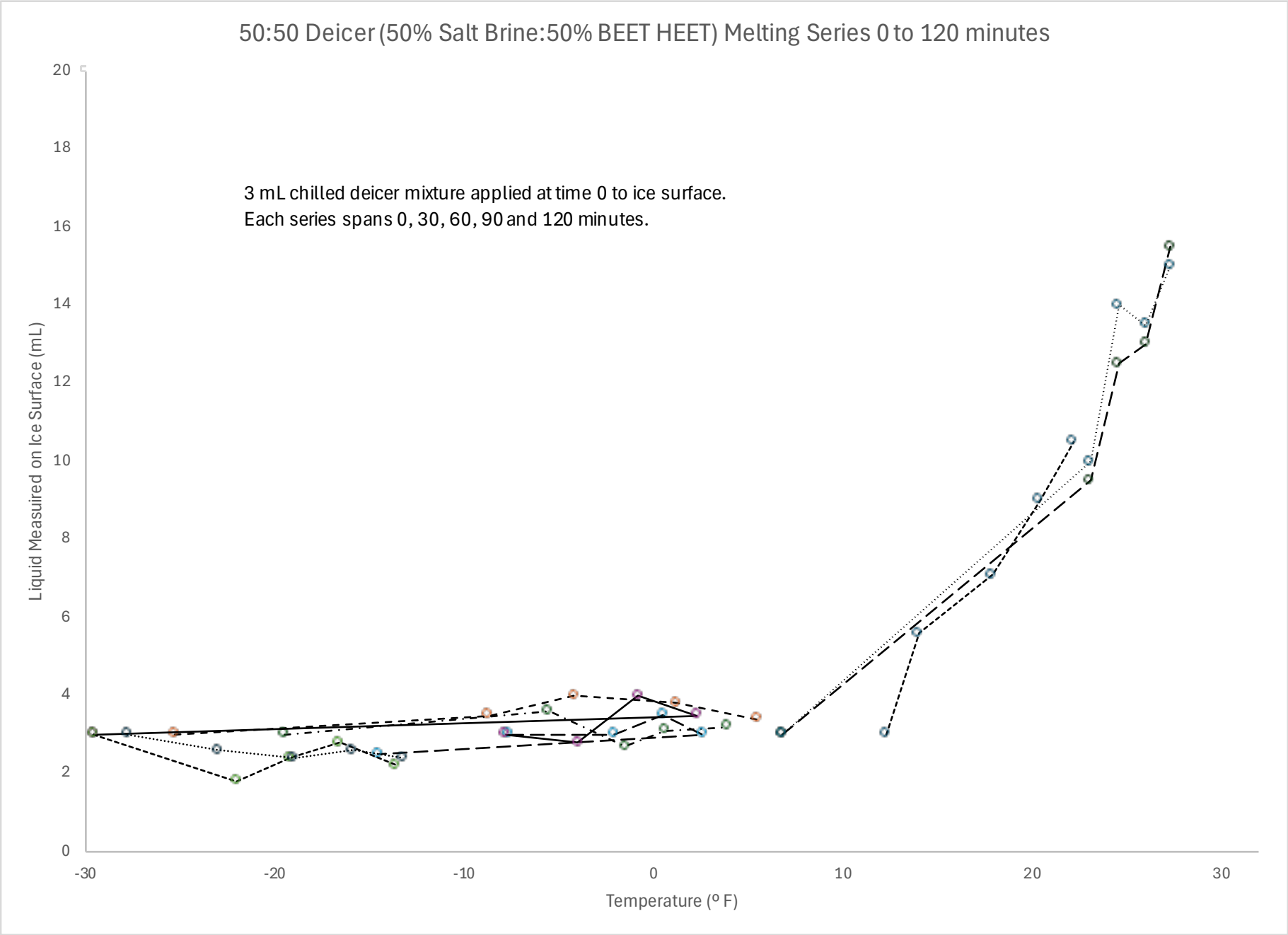

Salt Brine (0% BEET HEET) Melting Series 0 to 120 minutes
3 mL chilled deicer mixture applied at time 0 to ice surface.
Each series spans 0, 30, 60, 90 and 120 minutes.
Liquid Measuired on Ice Surface (mL)
Temperature (º F)
20
18
16
14
12
10
8
6
4
2
0
-30
-20
-10
0
10
20
30

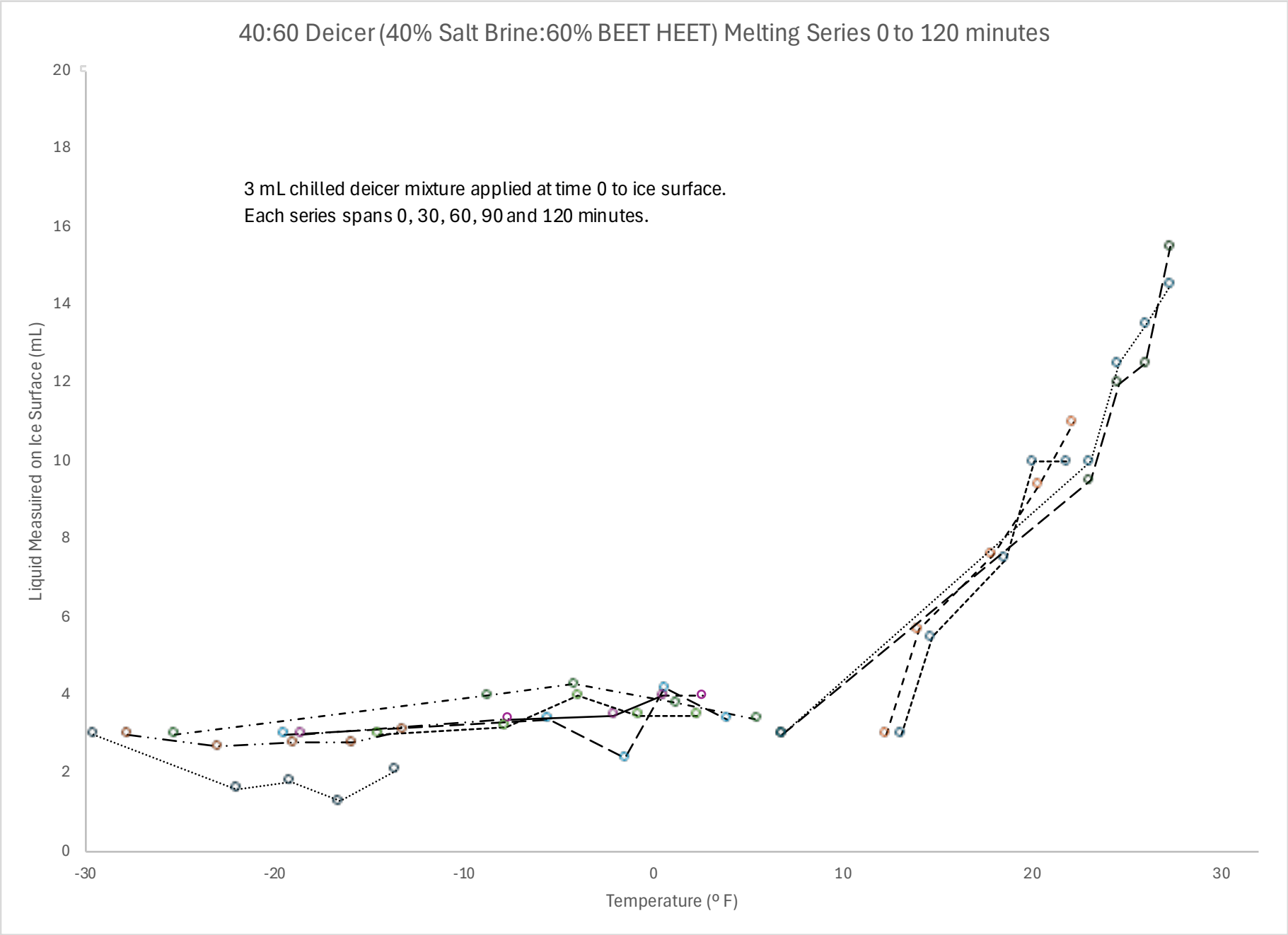

90:10 Deicer (90% Salt Brine:10% BEET HEET) Melting Series 0 to 120 minutes
3 mL chilled deicer mixture applied at time 0 to ice surface.
Each series spans 0, 30, 60, 90 and 120 minutes.
Liquid Measuired on Ice Surface (mL)
Temperature (º F)
20
18
16
14
12
10
8
6
4
2
0
-30
-20
-10
0
10
20
30

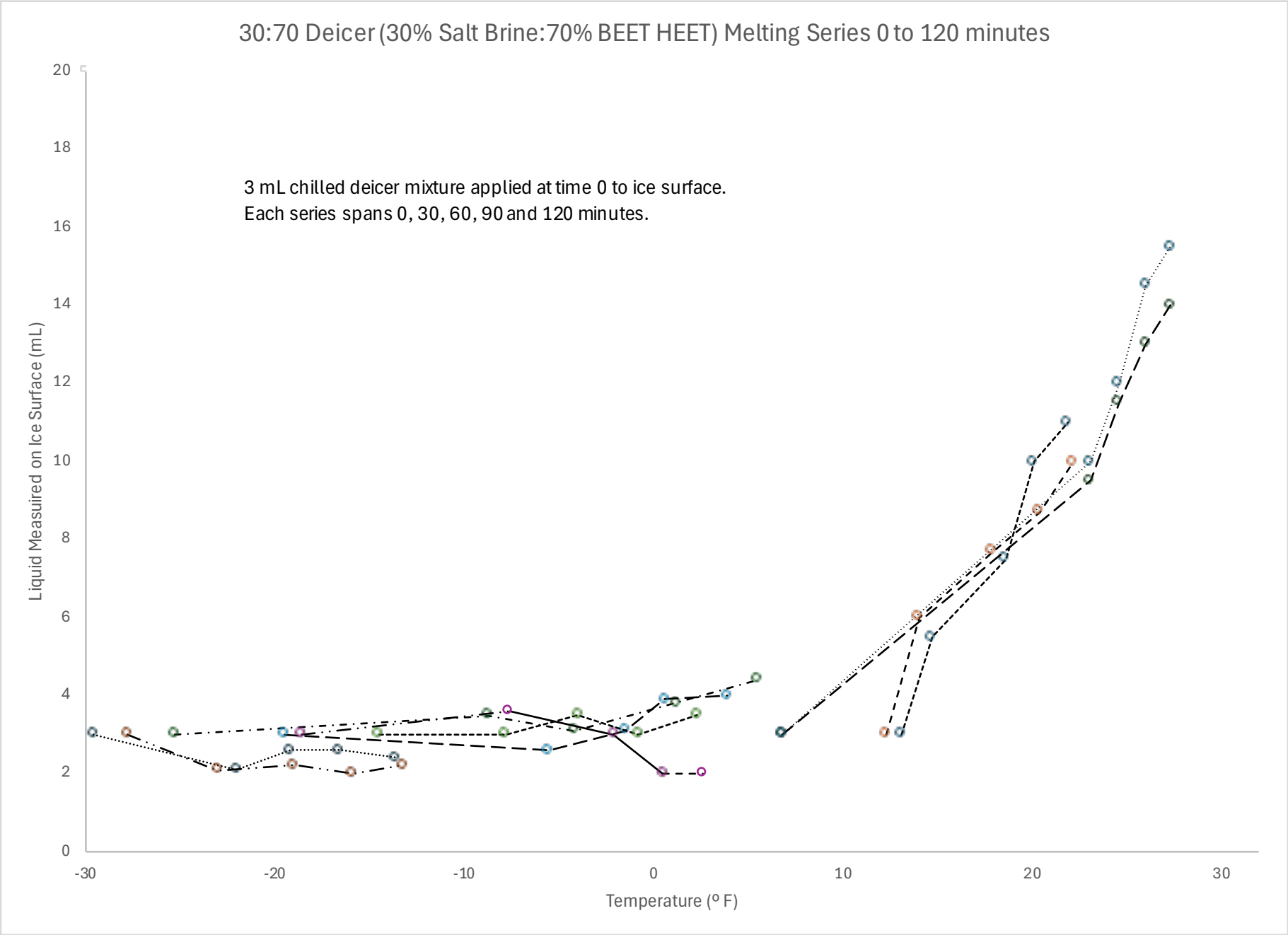

80:20 Deicer (80% Salt Brine:20% BEET HEET) Melting Series 0 to 120 minutes
3 mL chilled deicer mixture applied at time 0 to ice surface.
Each series spans 0, 30, 60, 90 and 120 minutes.
Liquid Measuired on Ice Surface (mL)
Temperature (º F)
20
18
16
14
12
10
8
6
4
2
0
-30
-20
-10
0
10
20
30

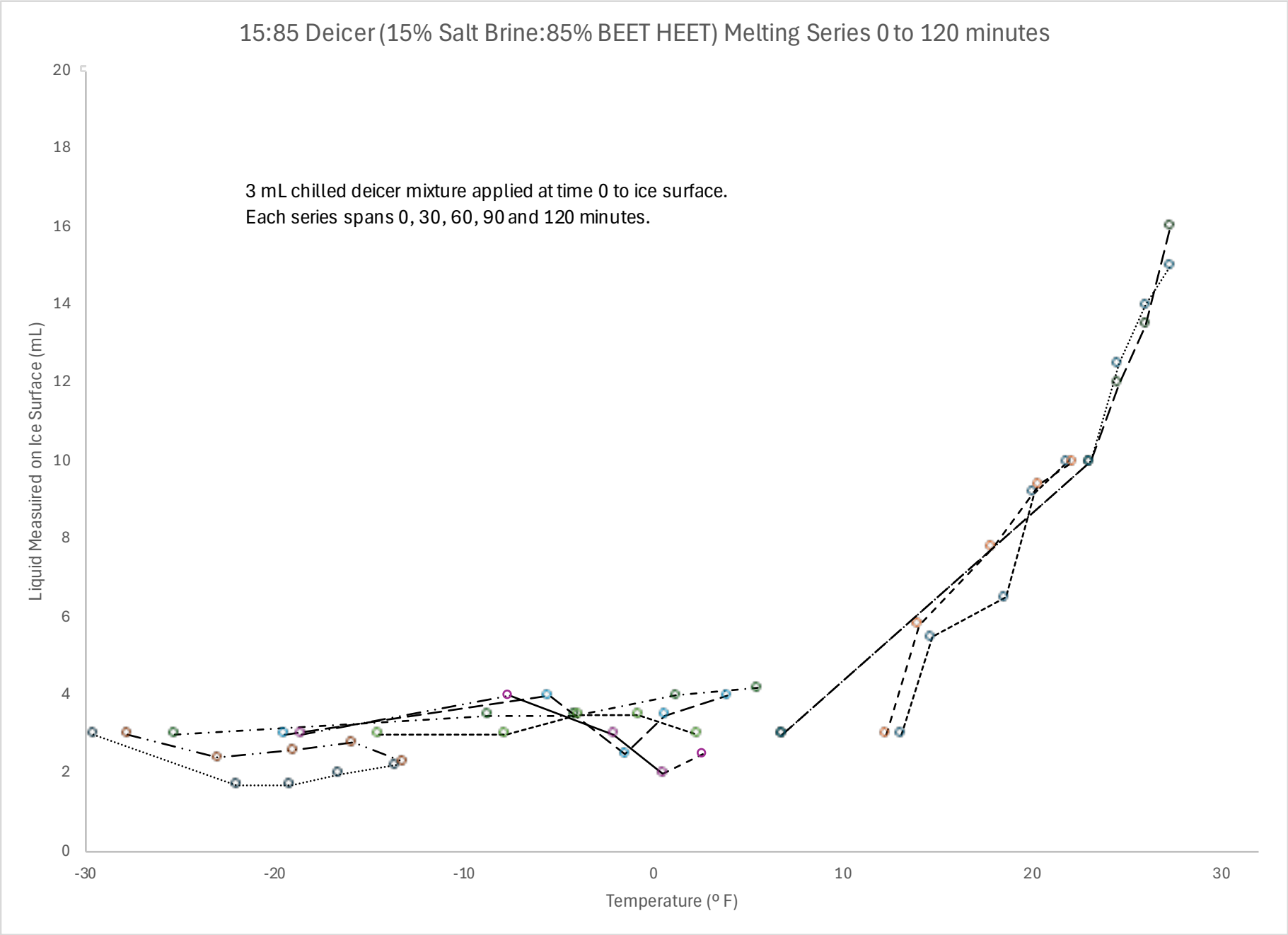

70:30 Deicer (70% Salt Brine:30% BEET HEET) Melting Series 0 to 120 minutes
3 mL chilled deicer mixture applied at time 0 to ice surface.
Each series spans 0, 30, 60, 90 and 120 minutes.
Liquid Measuired on Ice Surface (mL)
Temperature (º F)
20
18
16
14
12
10
8
6
4
2
0
-30
-20
-10
0
10
20
30

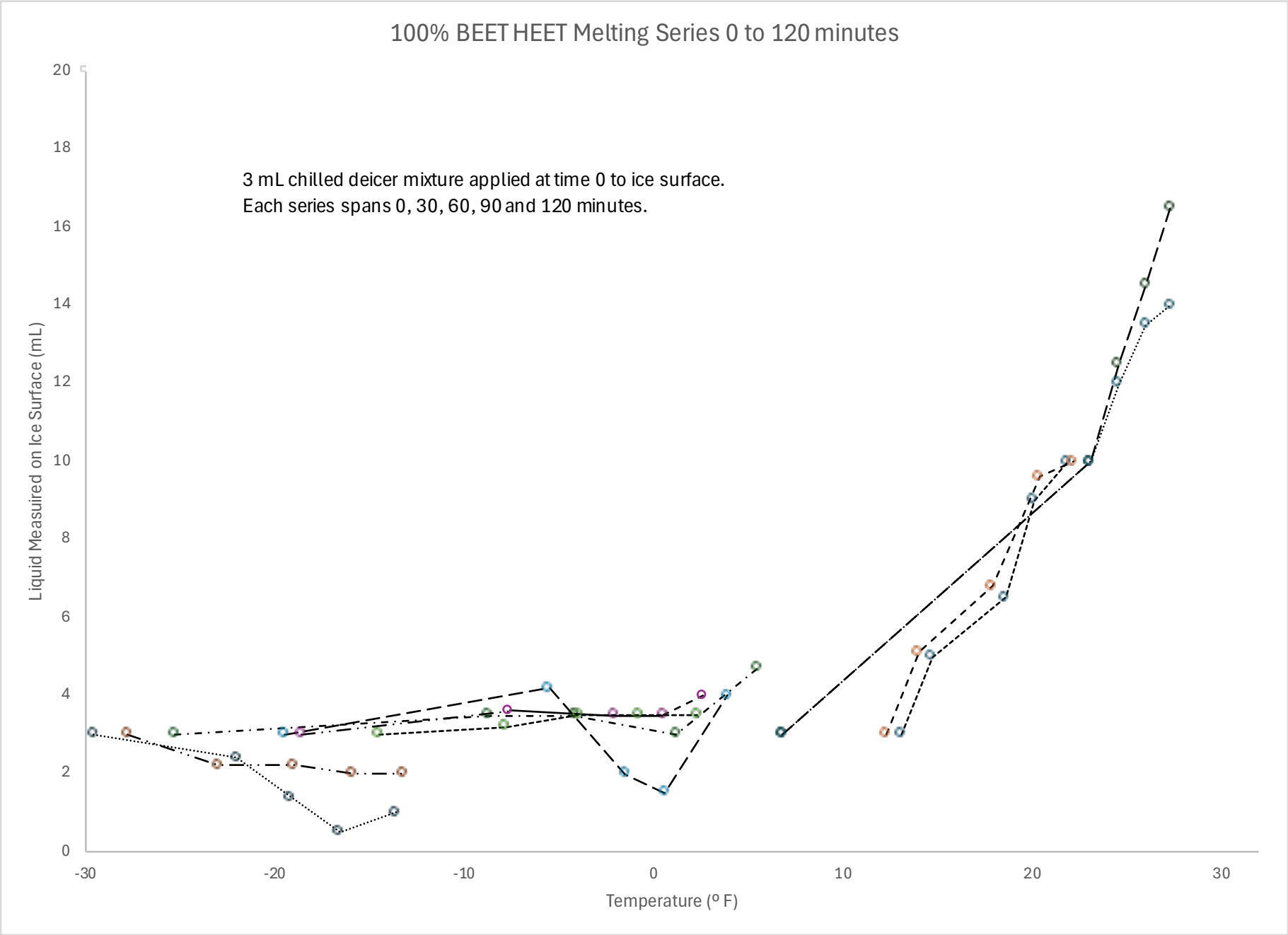

60:40 Deicer (60% Salt Brine:40% BEET HEET) Melting Series 0 to 120 minutes
3 mL chilled deicer mixture applied at time 0 to ice surface.
Each series spans 0, 30, 60, 90 and 120 minutes.
Liquid Measuired on Ice Surface (mL)
Temperature (º F)
20
18
16
14
12
10
8
6
4
2
0
-30
-20
-10
0
10
20
30

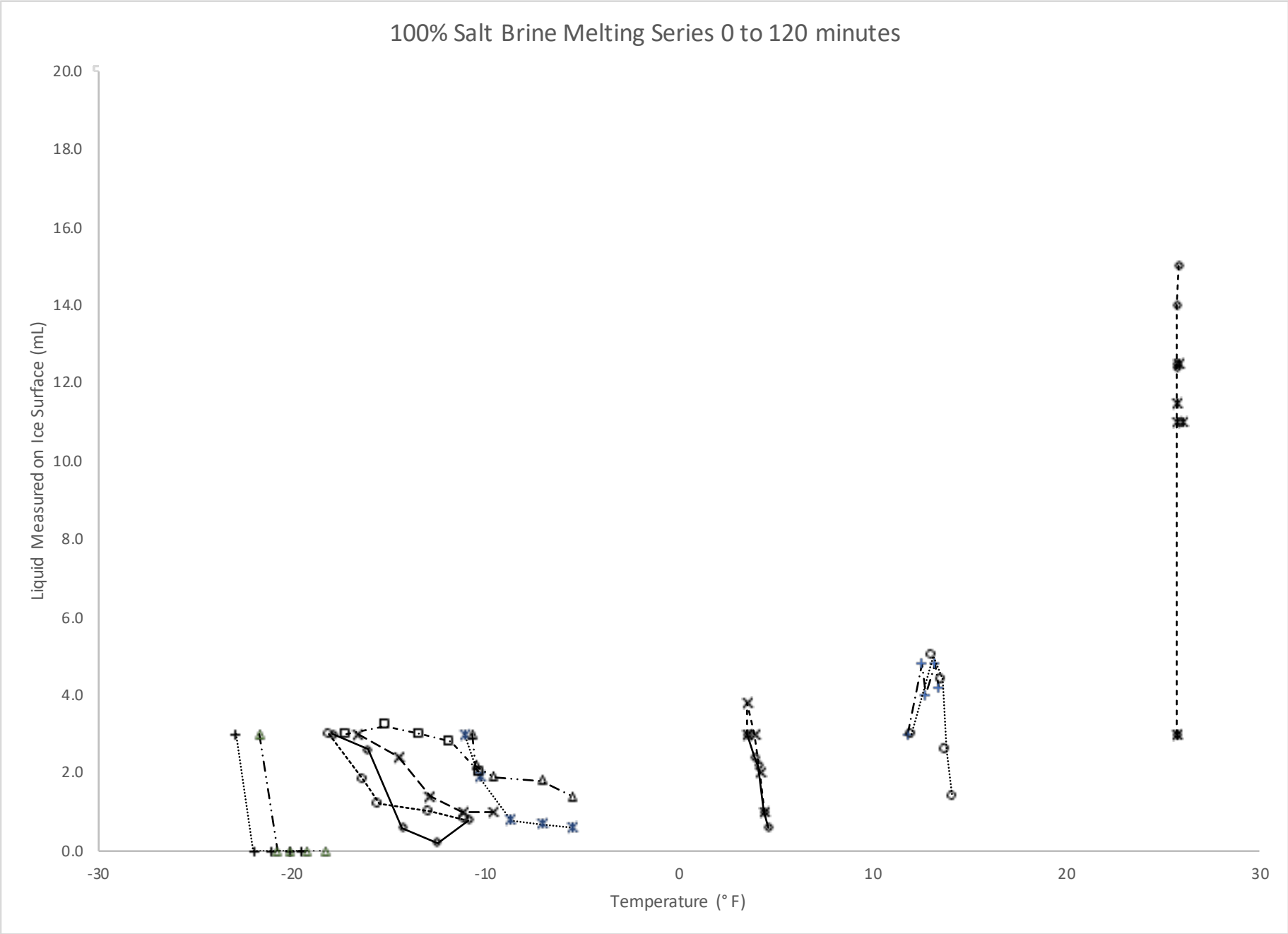

50:50 Deicer (50% Salt Brine:50% BEET HEET) Melting Series 0 to 120 minutes
3 mL chilled deicer mixture applied at time 0 to ice surface.
Each series spans 0, 30, 60, 90 and 120 minutes.
Liquid Measuired on Ice Surface (mL)
Temperature (º F)
20
18
16
14
12
10
8
6
4
2
0
-30
-20
-10
0
10
20
30

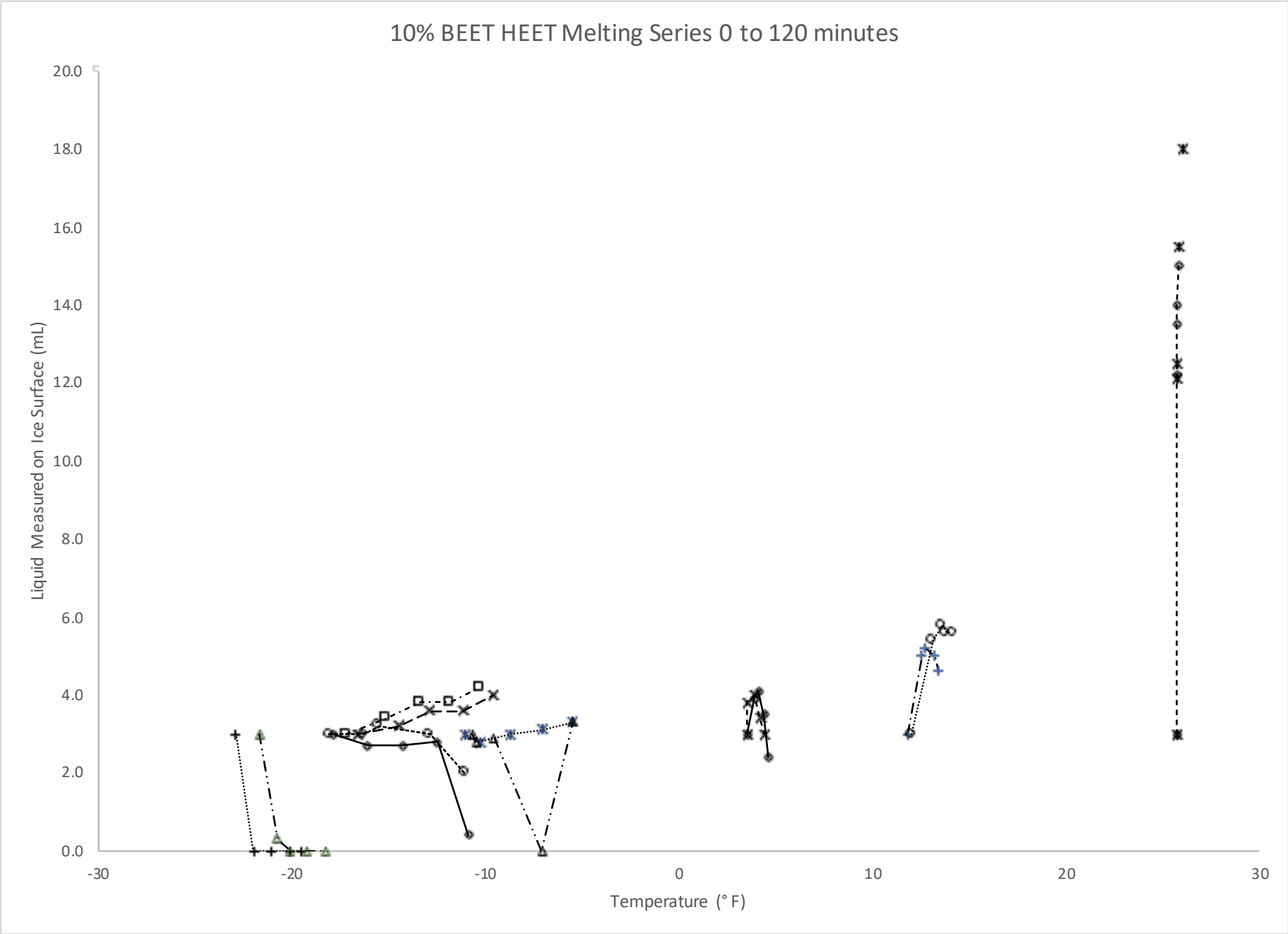

40:60 Deicer (40% Salt Brine:60% BEET HEET) Melting Series 0 to 120 minutes
3 mL chilled deicer mixture applied at time 0 to ice surface.
Each series spans 0, 30, 60, 90 and 120 minutes.
Liquid Measuired on Ice Surface (mL)
Temperature (º F)
20
18
16
14
12
10
8
6
4
2
0
-30
-20
-10
0
10
20
30

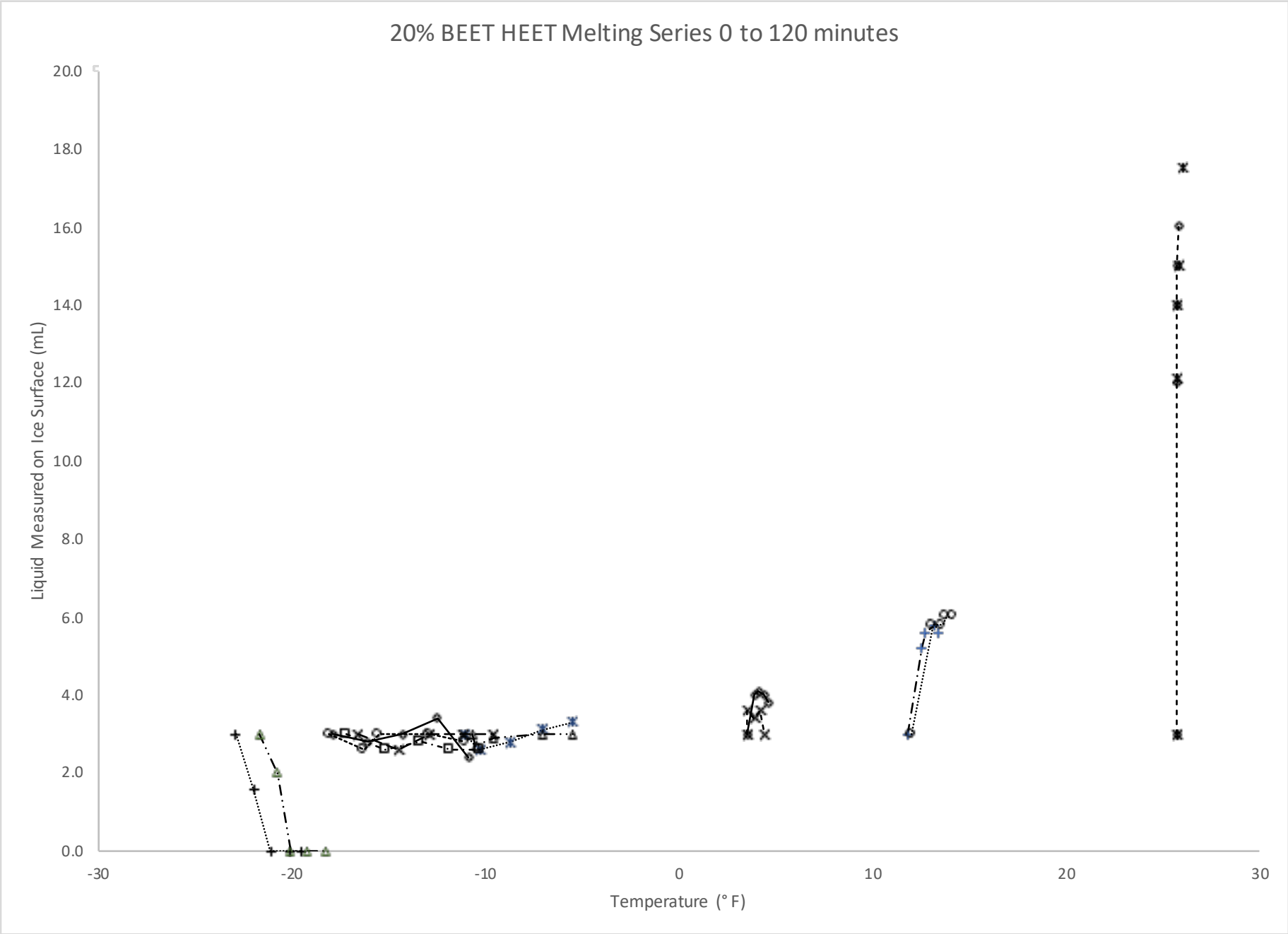

30:70 Deicer (30% Salt Brine:70% BEET HEET) Melting Series 0 to 120 minutes
3 mL chilled deicer mixture applied at time 0 to ice surface.
Each series spans 0, 30, 60, 90 and 120 minutes.
Liquid Measuired on Ice Surface (mL)
Temperature (º F)
20
18
16
14
12
10
8
6
4
2
0
-30
-20
-10
0
10
20
30

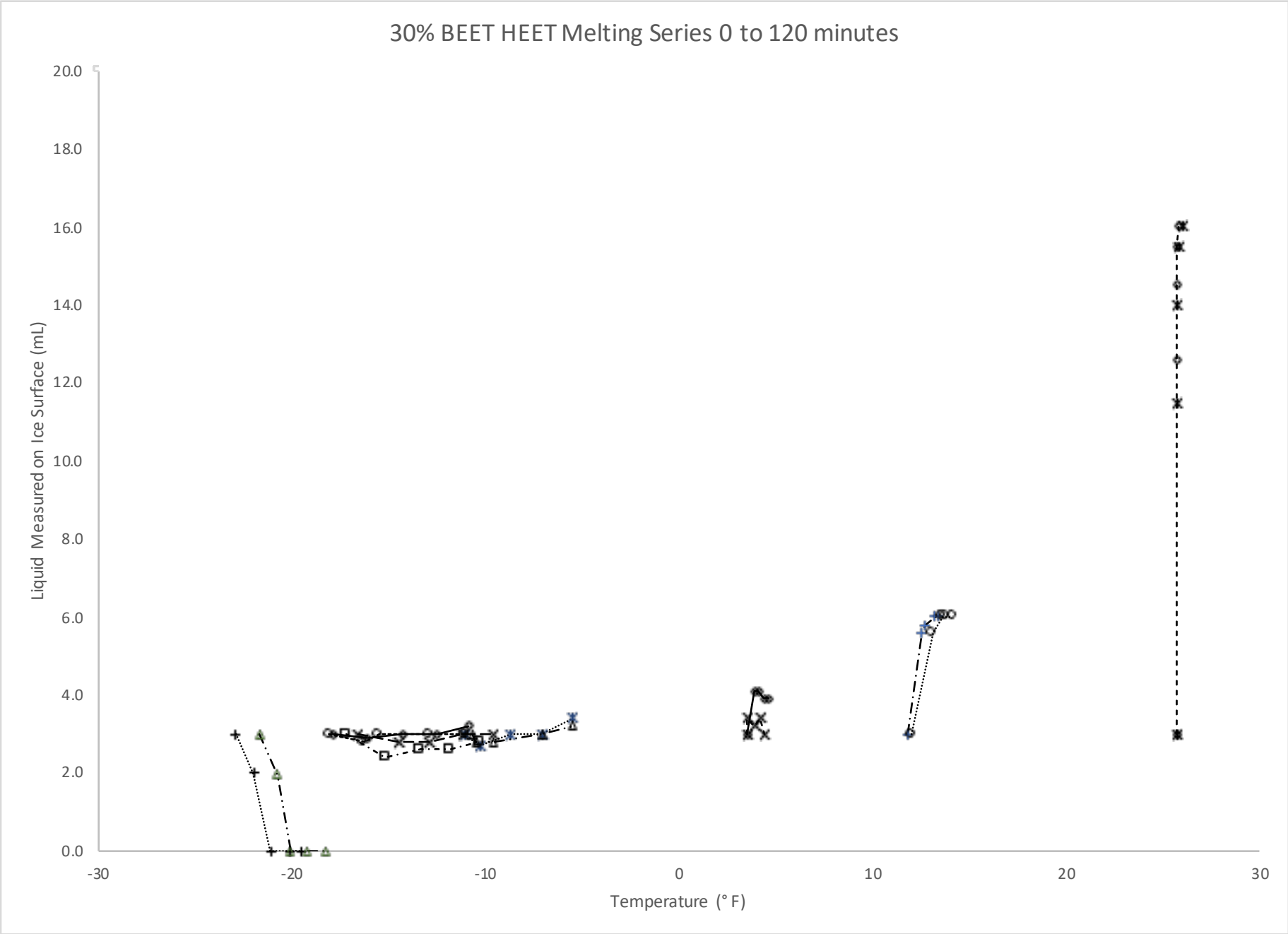

15:85 Deicer (15% Salt Brine:85% BEET HEET) Melting Series 0 to 120 minutes
3 mL chilled deicer mixture applied at time 0 to ice surface.
Each series spans 0, 30, 60, 90 and 120 minutes.
Liquid Measuired on Ice Surface (mL)
Temperature (º F)
0
2
4
6
8
10
12
14
16
18
20
-30
-20
-10
0
10
20
30

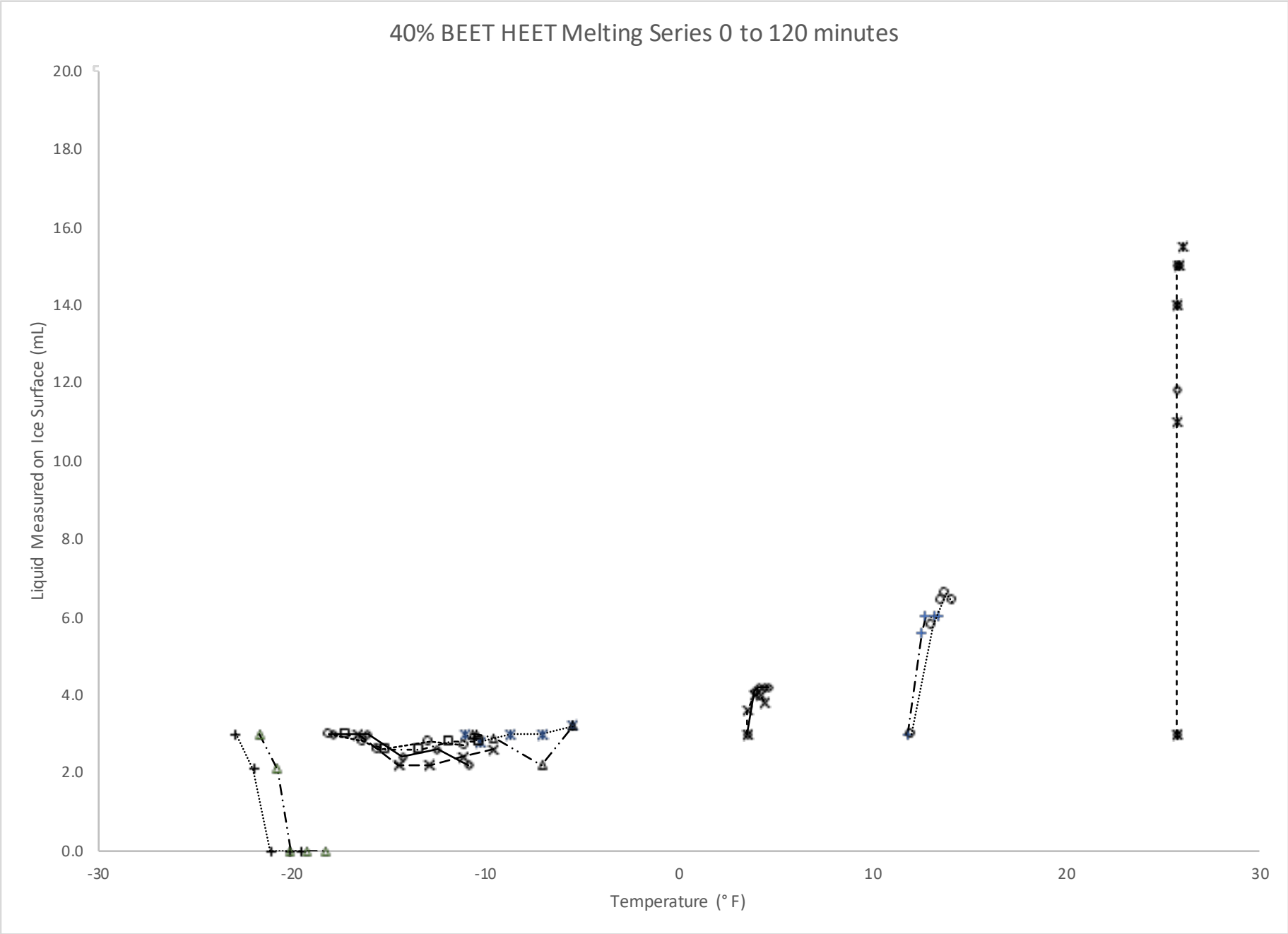

100% BEET HEET Melting Series 0 to 120 minutes
3 mL chilled deicer mixture applied at time 0 to ice surface.
Each series spans 0, 30, 60, 90 and 120 minutes.
Liquid Measuired on Ice Surface (mL)
Temperature (º F)
20
18
16
14
12
10
8
6
4
2
0
-30
-20
-10
0
10
20
30

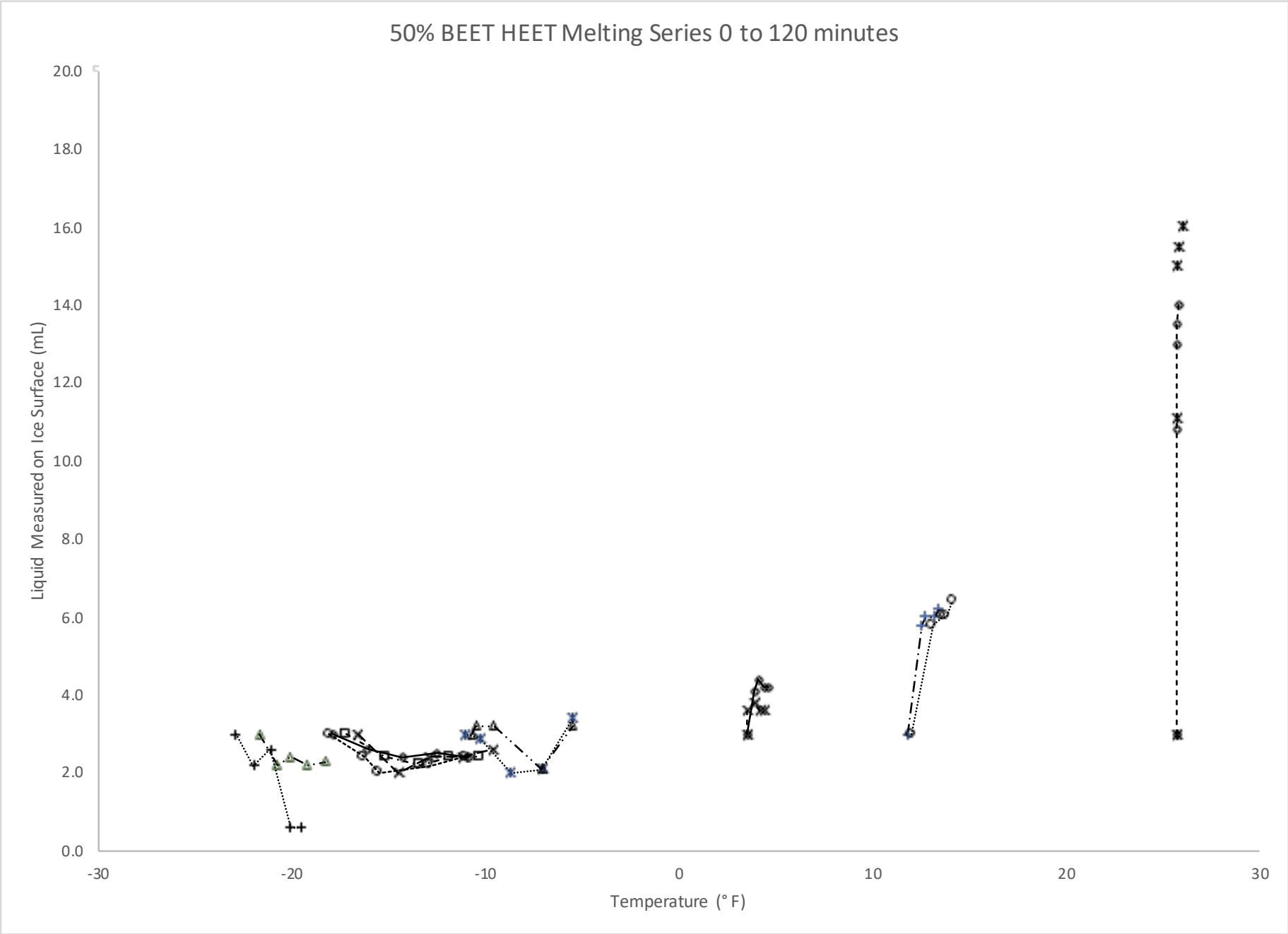

100% Salt Brine Melting Series 0 to 120 minutes
Liquid Measured on Ice Surface (mL)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-30
-20
-10
0
10
20
30
Temperature (° F)

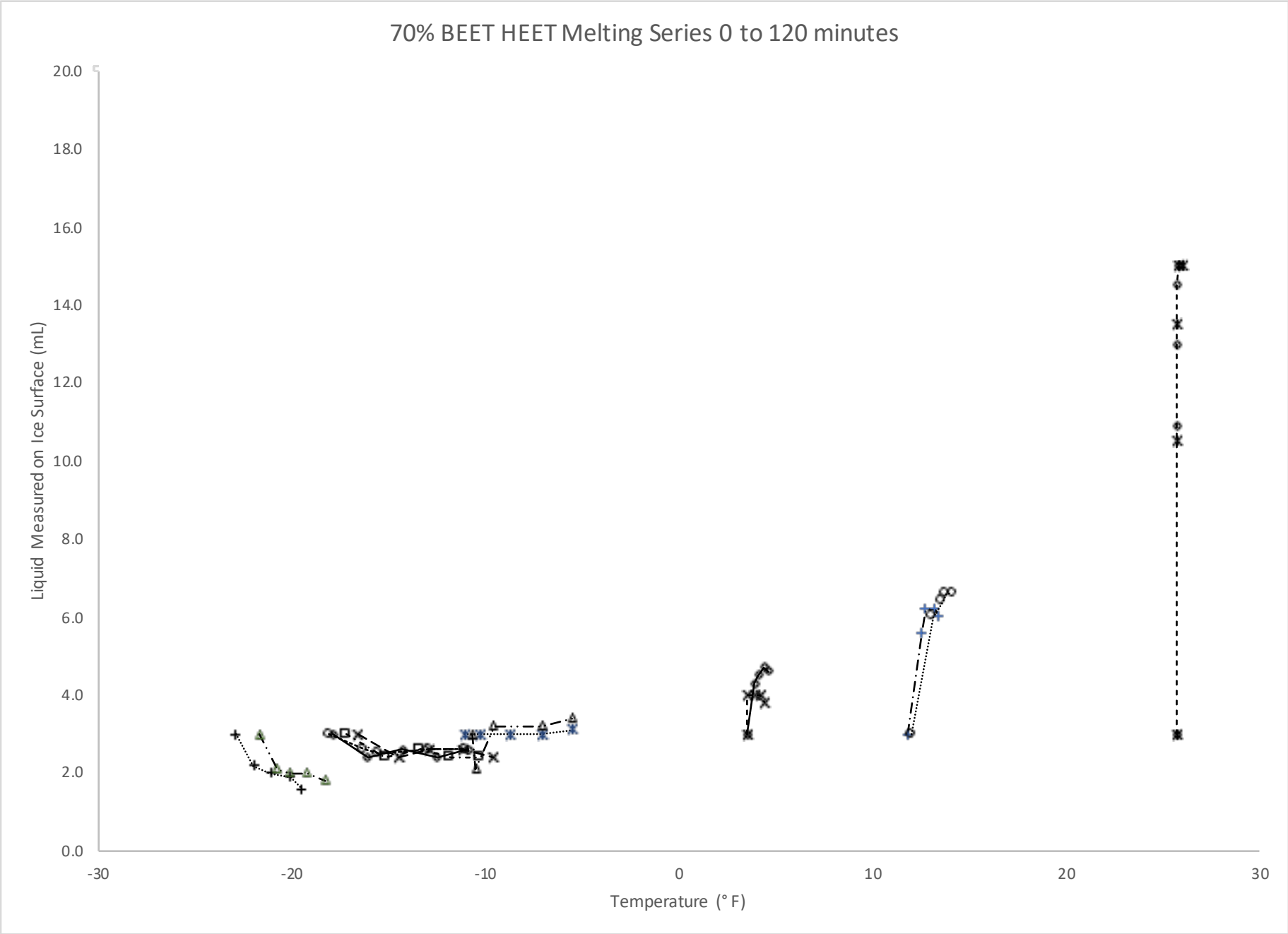

10% BEET HEET Melting Series 0 to 120 minutes
Liquid Measured on Ice Surface (mL)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-30
-20
-10
0
10
20
30
Temperature (° F)

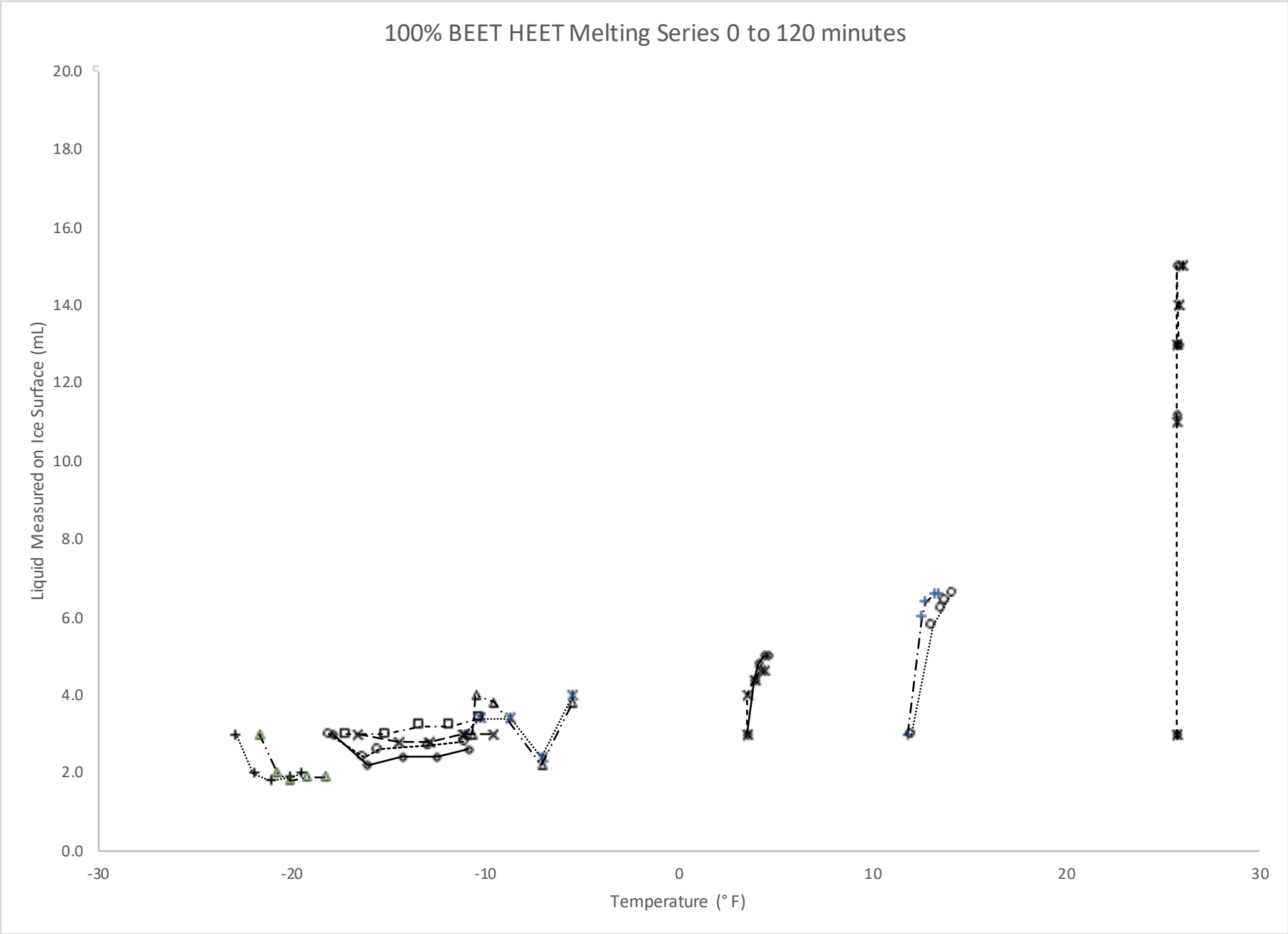

20% BEET HEET Melting Series 0 to 120 minutes
Liquid Measured on Ice Surface (mL)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-30
-20
-10
0
10
20
30
Temperature (° F)


30% BEET HEET Melting Series 0 to 120 minutes
Liquid Measured on Ice Surface (mL)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-30
-20
-10
0
10
20
30
Temperature (° F)


40% BEET HEET Melting Series 0 to 120 minutes
Liquid Measured on Ice Surface (mL)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-30
-20
-10
0
10
20
30
Temperature (° F)


50% BEET HEET Melting Series 0 to 120 minutes
Liquid Measured on Ice Surface (mL)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-30
-20
-10
0
10
20
30
Temperature (° F)


70% BEET HEET Melting Series 0 to 120 minutes
Liquid Measured on Ice Surface (mL)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-30
-20
-10
0
10
20
30
Temperature (° F)


100% BEET HEET Melting Series 0 to 120 minutes
Liquid Measured on Ice Surface (mL)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-30
-20
-10
0
10
20
30
Temperature (° F)

Appendix F
Experimental Plan

Camp Ripley BEET HEET Test Program
MSU Mankato
S. Druschel
January 10, 2025

REVISIONS PROPOSED/COMMENTS (Teams meeting of January 10th):

- Go/no go decision to be made on Friday of week before proposed field work. Will be based on temperatures and snow amount predicted.
- Center on rock salt application amount predicted from MDSS forecast, rather than 200 lb/LM everywhere…but aim low ("push the envelope") for cost efficiency consideration when results implemented.
- Wetting agent amount of 20 gal/LM good as standard; also good are factor evaluation from 25 – 20 – 15 – 10 gal/LM. District 1 reports that during dry snow conditions on long routes application will routinely be 10 – 12 gal/LM.
- To limit any incidental effect of tracking deicer from one test section to another:
    - When sequential, work from low – medium low – medium high – high application rate;
    - When in parallel, limit applied traffic to one dedicated vehicle.
- Temperature cutoff of 10 ºF maximum for MSU Mankato deployment – at least until February 10th upon which temperature restriction may change.
    - MnDOT may use reserved days for testing at warmer temperatures.
- District 3 will put "eyes on" track about 24 hours before testing to check snow situation/effect of wind blow.
- MnDOT will run truck outfitted with "Connor Sensor" for pavement images and friction measurement every 30 minutes after application.
- All trucks will be recording by AVL system to be certain of application rates and pavement temperatures.
- MSU Mankato to add lane demarcation flagging for skid pad parallel lanes.

Experimental Plan

Objectives:

1. Overall: Evaluate in full scale conditions the performance of BEET HEET deicer when used in combination with rock salt as an on-truck prepared "slurry" form.
    a. Performance defined as obtaining time to regain bare lane pavement.
    b. As base treatment to be compared against, use 200 lb/LM rock salt with 20 gal/LM wetting agent for treatment level.
    c. Incorporate 5 passes of truck traffic to simulate traffic effect of low volume roadway.
2. Evaluate effects of blending BEET HEET with salt brine as wetting agent with rock salt creating slurry deicer.

a. Use 5 different mixtures of salt brine:BEET HEET as wetting agent
    i. 100:0 (100% salt brine)
    ii. 90:10 (90% salt brine:10% BEET HEET)
    iii. 70:30 (70% salt brine:30% BEET HEET)
    iv. 50:50 (50% salt brine:50% BEET HEET)
    v. 0:100 (100% BEET HEET)
b. All applications at 200 lb/LM rock salt with 20 gal/LM wetting agents
c. All applications with 5 passes of truck traffic following
d. Use Skid Pad for application lanes: 5 lanes at 12 ft of treatment separated by 32 ft no-treatment zone; 300 ft application length.
e. Four time lapse cameras mounted at 5 ft height above pavement for each lane (two looking with traffic at start of lane, two looking at traffic from end of lane; organized with each pair straddling lane of treatment).
f. Additional photography:
    i. Ground-based Nikon digital SLR with telephoto lens
    ii. Truck based on-board camera;
    iii. Ground-based thermography to capture infrared imagery of melt out pattern and processes.
g. Instrumentation:
    i. Truck based pavement thermometer.
    ii. Ground-based area thermometer, sunlight meter, humidity meter.
h. Monitor for 4 hours after application

3. Evaluate effects of application rate of BEET HEET with salt brine as wetting agent with rock salt creating slurry deicer.
    a. Use 4 different levels of 70:30 (70% salt brine:30% BEET HEET) as wetting agent
        i. 25 gal/LM
        ii. 20 gal/LM
        iii. 15 gal/LM
        iv. 10 gal/LM
    b. All applications at 200 lb/LM rock salt
    c. All applications with 5 passes of truck traffic following
    d. Use <u>westbound</u> direction of four-lane highway (approximately 2000 ft long) for application lanes: <u>4 sections at 500 ft of treatment length</u>, (lane separation marked by location of median turn area)
        i. Centerline application.
    e. Four time lapse cameras mounted at 5 ft height above pavement for each section (two looking with traffic at start of lane, two looking at traffic from end of lane; organized with each pair straddling lane of treatment).
    f. Additional photography:
        i. Ground-based Nikon digital SLR with telephoto lens
        ii. Truck based on-board camera;

        iii. Ground-based thermography to capture infrared imagery of melt out pattern and processes.
    g. Instrumentation:
        i. Truck based pavement thermometer.
        ii. Ground-based area thermometer, sunlight meter, humidity meter.
        iii. Monitor for 4 hours after application
4. Evaluate effects of application rate of rock salt constant level of BEET HEET with salt brine as wetting agent creating slurry deicer.
    a. Use 4 different levels of rock salt
        i. 300 lb/LM
        ii. 250 lb/LM
        iii. 200 lb/LM
        iv. 150 lb/LM
    b. All applications with 70:30 (70% salt brine:30% BEET HEET) as wetting agent
    c. All applications with 5 passes of truck traffic following
    d. Use <u>eastbound</u> direction of four-lane highway (approximately 2000 ft long) for application lanes: <u>4 sections at 1000 ft of treatment length</u> (lane separation marked by location of median turn area)
        i. Centerline application.
    e. Four time lapse cameras mounted at 5 ft height above pavement for each section (two looking with traffic at start of lane, two looking at traffic from end of lane; organized with each pair straddling lane of treatment).
    f. Additional photography:
        i. Ground-based Nikon digital SLR with telephoto lens
        ii. Truck based on-board camera;
        iii. Ground-based thermography to capture infrared imagery of melt out pattern and processes.
    g. Instrumentation:
        i. Truck based pavement thermometer.
        ii. Ground-based area thermometer, sunlight meter, humidity meter.
        iii. Monitor for 4 hours after application

Effort total:
Five trucks and operators
52 time lapse cameras and stands
Pin flags and bases for lane demarcation
FLIR
Nikon
Kestral Drops
Hobo surface meters

Research student to ride with operators recording notes
Research student assisting with lane orientation

Appendix G
Weather Records of Field Set Up and Test Days

46.36 °N, **94.2** °W

Brainerd, MN Weather History ★ 🏠

86° BRAINERD

CM_VEN=LOCALWX_PWSDASH) | CHANGE

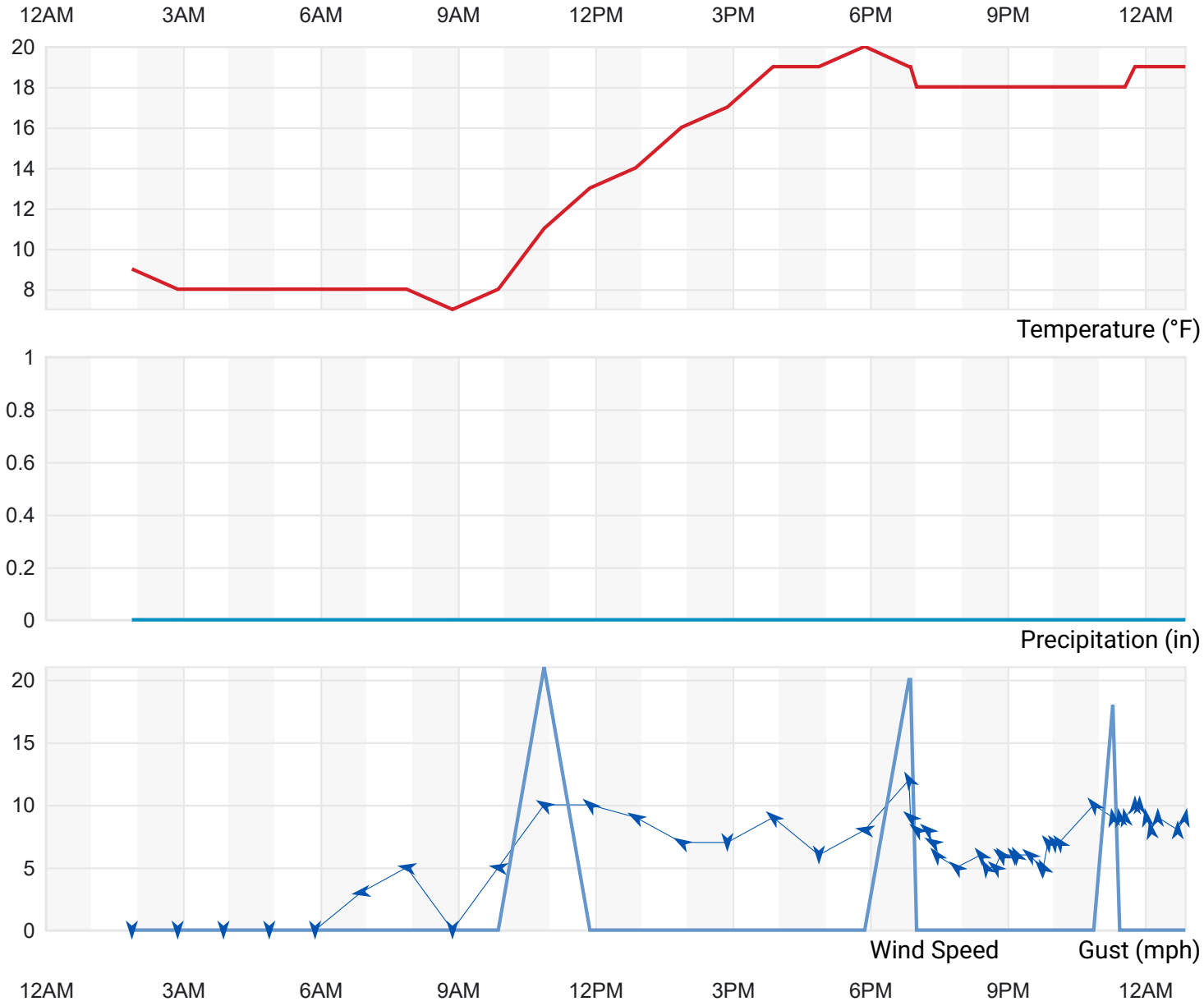
HISTORY (/HISTORY/DAILY/US/MN/BRAINERD/KBRD)

- TODAY (/WEATHER/US/MN/BRAINERD/KBRD)
- HOURLY (/HOURLY/US/MN/BRAINERD/KBRD)
- 10-DAY (/FORECAST/US/MN/BRAINERD/KBRD) CALENDAR (/
- CALENDAR/US/MN/BRAINERD/KBRD) HISTORY (/HISTORY/DAILY/
- US/MN/BRAINERD/KBRD) WUNDERMAP (/WUNDERMAP?
- LAT=46.356&LON=-94.201)

REGIONAL AIRPORT STATION (/DASHBOARD/PWS/KMKMNBRAIN1?

LAKES

February | 5 | 2025



Summary

Temperature (°F)	Actual	Historic Avg.	Record
High Temp	20	21.9	52
Low Temp	7	-2.5	-45
Day Average Temp	16	9.7	-

Precipitation (in)	Actual	Historic Avg.	Record
Precipitation (past 24 hours from 06:53:00)	0.00	5.50	-

Dew Point (°F)	Actual	Historic Avg.	Record

Dew Point	6.48	-	-
High	14	-	-
Low	-5	-	-
Average	6.48	-	-

Wind (mph)	Actual	Historic Avg.	Record
Max Wind Speed	12	-	-
Visibility	10	-	-

Sea Level Pressure (in)	Actual	Historic Avg.	Record
Sea Level Pressure	29.14	-	-

Astronomy	Day Length	Rise	Set
Actual Time	9h 52m	7:35 AM	5:28 PM
Civil Twilight		7:04 AM	6:00 PM
Nautical Twilight		6:28 AM	6:35 PM
Astronomical Twilight		5:53 AM	7:10 PM
Moon: waxing gibbous		10:45 AM	1:37 AM

Daily Observations

Time	Temperature	Dew Point	Humidity	Wind	Wind Speed	Wind Gust	Pressure	Precip.
1:53 AM	9 °F	-5 °F	53 %	CALM	0 mph	0 mph	29.14 in	0.0 in
2:53 AM	8 °F	-4 °F	58 %	CALM	0 mph	0 mph	29.12 in	0.0 in
3:53 AM	8 °F	-5 °F	55 %	CALM	0 mph	0 mph	29.10 in	0.0 in
4:53 AM	8 °F	-4 °F	58 %	CALM	0 mph	0 mph	29.08 in	0.0 in
5:53	8 °F	-5 °F	55 %	CALM	0 mph	0 mph	29.06 in	0.0 in

AM								
6:53 AM	8 °F	-5 °F	55 %	E	3 mph	0 mph	29.04 in	0.0 in
7:53 AM	8 °F	-5 °F	55 %	E	5 mph	0 mph	29.01 in	0.0 in
8:53 AM	7 °F	-5 °F	58 %	CALM	0 mph	0 mph	28.98 in	0.0 in
9:53 AM	8 °F	-5 °F	55 %	E	5 mph	0 mph	28.94 in	0.0 in
10:53 AM	11 °F	-5 °F	49 %	ESE	10 mph	21 mph	28.92 in	0.0 in
11:53 AM	13 °F	-3 °F	49 %	SE	10 mph	0 mph	28.88 in	0.0 in
12:53 PM	14 °F	-3 °F	47 %	ESE	9 mph	0 mph	28.84 in	0.0 in
1:53 PM	16 °F	-2 °F	45 %	ESE	7 mph	0 mph	28.79 in	0.0 in
2:53 PM	17 °F	-1 °F	45 %	VAR	7 mph	0 mph	28.74 in	0.0 in
3:53 PM	19 °F	1 °F	46 %	SE	9 mph	0 mph	28.68 in	0.0 in
4:53 PM	19 °F	1 °F	46 %	VAR	6 mph	0 mph	28.64 in	0.0 in
5:53 PM	20 °F	1 °F	44 %	E	8 mph	0 mph	28.59 in	0.0 in
6:51 PM	19 °F	5 °F	54 %	SSE	12 mph	20 mph	28.58 in	0.0 in
6:53 PM	19 °F	6 °F	57 %	SE	9 mph	20 mph	28.58 in	0.0 in
7:01 PM	18 °F	9 °F	68 %	SE	8 mph	0 mph	28.58 in	0.0 in
7:15 PM	18 °F	10 °F	71 %	SE	8 mph	0 mph	28.57 in	0.0 in
7:22 PM	18 °F	10 °F	71 %	ESE	7 mph	0 mph	28.56 in	0.0 in
7:27 PM	18 °F	10 °F	71 %	SE	6 mph	0 mph	28.56 in	0.0 in
7:53 PM	18 °F	10 °F	71 %	SE	5 mph	0 mph	28.55 in	0.0 in
8:25 PM	18 °F	11 °F	74 %	SE	6 mph	0 mph	28.56 in	0.0 in
8:32 PM	18 °F	12 °F	78 %	SSE	5 mph	0 mph	28.56 in	0.0 in
8:44 PM	18 °F	12 °F	78 %	SE	5 mph	0 mph	28.55 in	0.0 in
8:51 PM	18 °F	12 °F	79 %	SE	6 mph	0 mph	28.55 in	0.0 in

8:53 PM	18 °F	12 °F	78 %	SE	6 mph	0 mph	28.55 in	0.0 in
9:08 PM	18 °F	13 °F	81 %	SE	6 mph	0 mph	28.54 in	0.0 in
9:12 PM	18 °F	13 °F	81 %	SSE	6 mph	0 mph	28.54 in	0.0 in
9:29 PM	18 °F	13 °F	81 %	SE	6 mph	0 mph	28.53 in	0.0 in
9:44 PM	18 °F	13 °F	81 %	SE	5 mph	0 mph	28.53 in	0.0 in
9:47 PM	18 °F	12 °F	79 %	SSE	5 mph	0 mph	28.53 in	0.0 in
9:53 PM	18 °F	13 °F	81 %	SE	7 mph	0 mph	28.52 in	0.0 in
10:01 PM	18 °F	12 °F	78 %	SE	7 mph	0 mph	28.51 in	0.0 in
10:08 PM	18 °F	12 °F	78 %	SE	7 mph	0 mph	28.51 in	0.0 in
10:53 PM	18 °F	12 °F	78 %	SE	10 mph	0 mph	28.47 in	0.0 in
11:18 PM	18 °F	13 °F	81 %	S	9 mph	18 mph	28.47 in	0.0 in
11:27 PM	18 °F	13 °F	81 %	S	9 mph	0 mph	28.47 in	0.0 in
11:34 PM	18 °F	13 °F	81 %	S	9 mph	0 mph	28.47 in	0.0 in
11:47 PM	19 °F	12 °F	74 %	S	10 mph	0 mph	28.46 in	0.0 in
11:53 PM	19 °F	13 °F	77 %	S	10 mph	0 mph	28.46 in	0.0 in
12:02 AM	19 °F	13 °F	77 %	S	9 mph	0 mph	28.45 in	0.0 in
12:08 AM	19 °F	14 °F	81 %	S	8 mph	0 mph	28.45 in	0.0 in
12:17 AM	19 °F	14 °F	81 %	S	9 mph	0 mph	28.44 in	0.0 in
12:43 AM	19 °F	14 °F	81 %	S	8 mph	0 mph	28.44 in	0.0 in
12:53 AM	19 °F	14 °F	81 %	S	9 mph	0 mph	28.44 in	0.0 in

46.36 °N, **94.2** °W

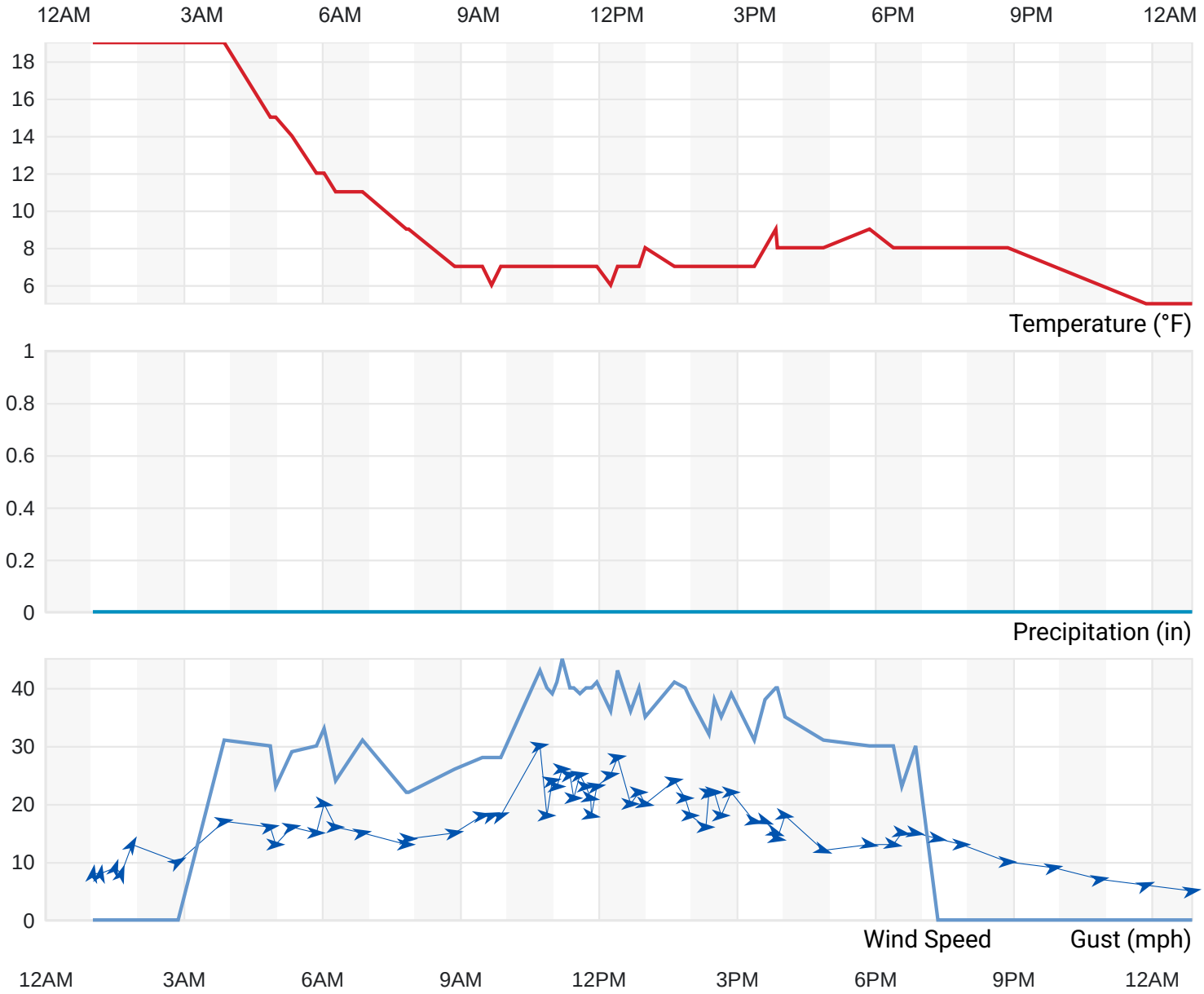
Brainerd, MN Weather History ★ 🏠

☀️ **53° BRAINERD LAKES REGIONAL AIRPORT STATION (/DASHBOARD/PWS/KMNBRAIN1?CM_VEN=LOCALWX_PWSDASH)** CHANGE

HISTORY (/HISTORY/DAILY/US/MN/BRAINERD/KBRD)

- TODAY (/WEATHER/US/MN/BRAINERD/KBRD)
- HOURLY (/HOURLY/US/MN/BRAINERD/KBRD)
- 10-DAY (/FORECAST/US/MN/BRAINERD/KBRD)
- CALENDAR (/CALENDAR/US/MN/BRAINERD/KBRD)
- HISTORY (/HISTORY/DAILY/US/MN/BRAINERD/KBRD)
- WUNDERMAP (/WUNDERMAP?LAT=46.356&LON=-94.201)

February | 6 | 2025



Summary

Temperature (°F)	Actual	Historic Avg.	Record
High Temp	19	22.2	48
Low Temp	5	-2.3	-45
Day Average Temp	9.21	9.9	-

Precipitation (in)	Actual	Historic Avg.	Record
Precipitation (past 24 hours from 06:02:00)	0.00	5.50	-

Dew Point (°F)	Actual	Historic Avg.	Record

Dew Point	-0.92	-	-
High	14	-	-
Low	-7	-	-
Average	-0.92	-	-

Wind (mph)	Actual	Historic Avg.	Record
Max Wind Speed	30	-	-
Visibility	10	-	-

Sea Level Pressure (in)	Actual	Historic Avg.	Record
Sea Level Pressure	28.78	-	-

Astronomy	Day Length	Rise	Set
Actual Time	9h 55m	7:34 AM	5:29 PM
Civil Twilight		7:02 AM	6:01 PM
Nautical Twilight		6:27 AM	6:37 PM
Astronomical Twilight		5:52 AM	7:12 PM
Moon: waxing gibbous		11:19 AM	2:58 AM

Daily Observations

Time	Temperature	Dew Point	Humidity	Wind	Wind Speed	Wind Gust	Pressure	Precip.
1:02 AM	19 °F	14 °F	81 %	S	8 mph	0 mph	28.43 in	0.0 in
1:12 AM	19 °F	14 °F	81 %	S	8 mph	0 mph	28.43 in	0.0 in
1:31 AM	19 °F	14 °F	81 %	SSW	9 mph	0 mph	28.43 in	0.0 in
1:39 AM	19 °F	14 °F	81 %	SSW	8 mph	0 mph	28.42 in	0.0 in
1:53 AM	19 °F	14 °F	81 %	SSW	13 mph	0 mph	28.42 in	0.0 in

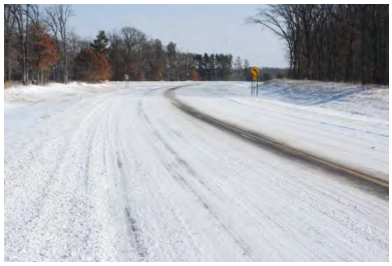
2:53 AM	19 °F	14 °F	81 %	WSW	10 mph	0 mph	28.41 in	0.0 in
3:53 AM	19 °F	10 °F	68 %	W	17 mph	31 mph	28.41 in	0.0 in
4:53 AM	15 °F	5 °F	64 %	W	16 mph	30 mph	28.41 in	0.0 in
5:00 AM	15 °F	5 °F	64 %	W	13 mph	23 mph	28.41 in	0.0 in
5:21 AM	14 °F	4 °F	64 %	W	16 mph	29 mph	28.42 in	0.0 in
5:53 AM	12 °F	2 °F	64 %	W	15 mph	30 mph	28.42 in	0.0 in
6:03 AM	12 °F	1 °F	61 %	W	20 mph	33 mph	28.42 in	0.0 in
6:18 AM	11 °F	2 °F	67 %	W	16 mph	24 mph	28.42 in	0.0 in
6:53 AM	11 °F	2 °F	67 %	W	15 mph	31 mph	28.44 in	0.0 in
7:50 AM	9 °F	0 °F	67 %	W	13 mph	22 mph	28.43 in	0.0 in
7:53 AM	9 °F	-1 °F	64 %	W	14 mph	22 mph	28.43 in	0.0 in
8:53 AM	7 °F	-3 °F	64 %	W	15 mph	26 mph	28.44 in	0.0 in
9:29 AM	7 °F	-4 °F	61 %	W	18 mph	28 mph	28.45 in	0.0 in
9:41 AM	6 °F	-4 °F	63 %	WSW	18 mph	28 mph	28.44 in	0.0 in
9:53 AM	7 °F	-4 °F	61 %	WSW	18 mph	28 mph	28.44 in	0.0 in
10:44 AM	7 °F	-5 °F	58 %	W	30 mph	43 mph	28.45 in	0.0 in
10:53 AM	7 °F	-4 °F	61 %	W	18 mph	40 mph	28.46 in	0.0 in
11:00 AM	7 °F	-5 °F	58 %	W	24 mph	39 mph	28.46 in	0.0 in
11:06 AM	7 °F	-5 °F	58 %	W	23 mph	41 mph	28.47 in	0.0 in
11:13 AM	7 °F	-5 °F	58 %	W	26 mph	45 mph	28.47 in	0.0 in
11:23 AM	7 °F	-4 °F	61 %	W	25 mph	40 mph	28.48 in	0.0 in
11:28 AM	7 °F	-4 °F	61 %	W	21 mph	40 mph	28.48 in	0.0 in
11:36	7 °F	-4 °F	61 %	W	25 mph	39 mph	28.48 in	0.0 in

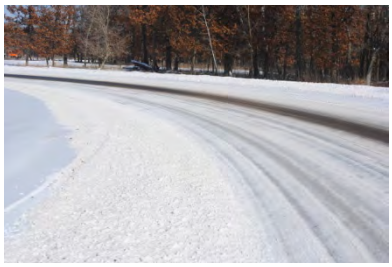
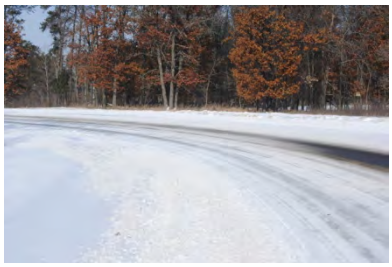
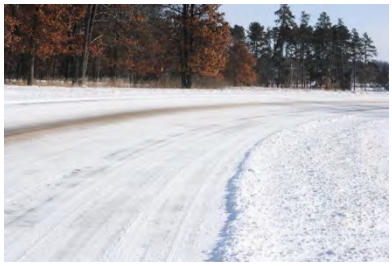
AM								
11:44 AM	7 °F	-3 °F	64 %	W	23 mph	40 mph	28.48 in	0.0 in
11:50 AM	7 °F	-6 °F	56 %	W	21 mph	40 mph	28.49 in	0.0 in
11:51 AM	7 °F	-5 °F	58 %	W	18 mph	40 mph	28.49 in	0.0 in
11:58 AM	7 °F	-5 °F	58 %	W	23 mph	41 mph	28.49 in	0.0 in
12:16 PM	6 °F	-6 °F	58 %	W	25 mph	36 mph	28.49 in	0.0 in
12:25 PM	7 °F	-6 °F	55 %	W	28 mph	43 mph	28.49 in	0.0 in
12:42 PM	7 °F	-6 °F	55 %	W	20 mph	36 mph	28.49 in	0.0 in
12:53 PM	7 °F	-5 °F	58 %	W	22 mph	40 mph	28.49 in	0.0 in
1:01 PM	8 °F	-6 °F	53 %	W	20 mph	35 mph	28.50 in	0.0 in
1:39 PM	7 °F	-6 °F	55 %	W	24 mph	41 mph	28.50 in	0.0 in
1:53 PM	7 °F	-7 °F	53 %	W	21 mph	40 mph	28.50 in	0.0 in
2:00 PM	7 °F	-5 °F	58 %	W	18 mph	38 mph	28.51 in	0.0 in
2:20 PM	7 °F	-5 °F	58 %	W	16 mph	33 mph	28.52 in	0.0 in
2:24 PM	7 °F	-5 °F	58 %	W	22 mph	32 mph	28.53 in	0.0 in
2:31 PM	7 °F	-4 °F	61 %	W	22 mph	38 mph	28.53 in	0.0 in
2:40 PM	7 °F	-3 °F	64 %	W	18 mph	35 mph	28.53 in	0.0 in
2:53 PM	7 °F	-5 °F	58 %	W	22 mph	39 mph	28.54 in	0.0 in
3:23 PM	7 °F	-5 °F	58 %	W	17 mph	31 mph	28.55 in	0.0 in
3:37 PM	8 °F	-4 °F	58 %	WNW	17 mph	38 mph	28.55 in	0.0 in
3:51 PM	9 °F	-4 °F	57 %	WNW	15 mph	40 mph	28.56 in	0.0 in
3:53 PM	8 °F	-4 °F	58 %	W	14 mph	40 mph	28.56 in	0.0 in
4:03 PM	8 °F	-4 °F	58 %	W	18 mph	35 mph	28.56 in	0.0 in

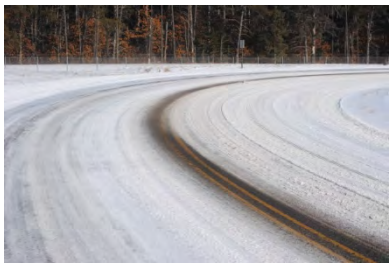
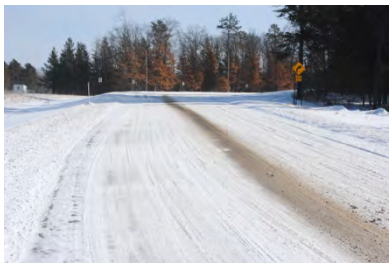
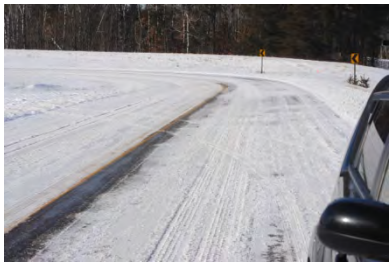
4:53 PM	8 °F	-3 °F	61 %	WNW	12 mph	31 mph	28.60 in	0.0 in
5:53 PM	9 °F	-2 °F	61 %	W	13 mph	30 mph	28.64 in	0.0 in
6:24 PM	8 °F	1 °F	73 %	W	13 mph	30 mph	28.65 in	0.0 in
6:35 PM	8 °F	0 °F	70 %	W	15 mph	23 mph	28.66 in	0.0 in
6:53 PM	8 °F	-1 °F	67 %	W	15 mph	30 mph	28.66 in	0.0 in
7:22 PM	8 °F	-1 °F	67 %	W	14 mph	0 mph	28.67 in	0.0 in
7:53 PM	8 °F	-1 °F	67 %	W	13 mph	0 mph	28.69 in	0.0 in
8:53 PM	8 °F	-1 °F	67 %	W	10 mph	0 mph	28.71 in	0.0 in
9:53 PM	7 °F	-1 °F	70 %	W	9 mph	0 mph	28.73 in	0.0 in
10:53 PM	6 °F	0 °F	76 %	W	7 mph	0 mph	28.76 in	0.0 in
11:53 PM	5 °F	-1 °F	76 %	WSW	6 mph	0 mph	28.78 in	0.0 in
12:53 AM	5 °F	-1 °F	76 %	W	5 mph	0 mph	28.78 in	0.0 in

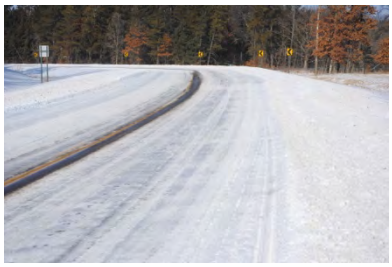
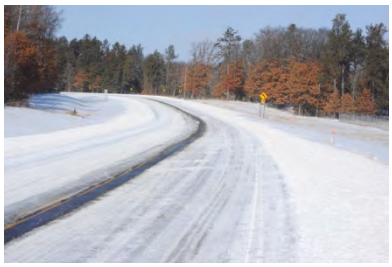
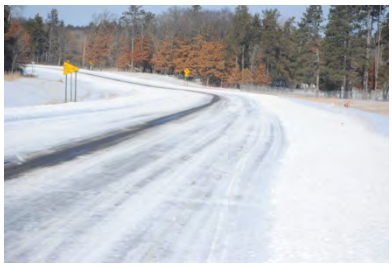
Appendix H
Directory of Testing Locations

Test Section	Treatment	Forward Photo of Location	Backward Photo of Location
WB 1A	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
WB 1B (selected for analysis)	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
WB 1C	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
WB 2A	25 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
WB 2B selected for analysis)	25 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		

WB 2C	25 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
WB 3A	30 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
WB 3B (selected for analysis)	30 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
WB 3C	30 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
WB 3D	30 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		

WB 4A	35 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
WB 4B (selected for analysis)	35 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
WB 4C	35 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
EB 1A	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 150 lb/LM rock salt		
EB 1B (selected for analysis)	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 150 lb/LM rock salt		

EB 1C	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 150 lb/LM rock salt		
EB 1D	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 150 lb/LM rock salt		
EB 1E	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 150 lb/LM rock salt		
EB 2A	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
EB 2B (selected for analysis)	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		

EB 3A	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 250 lb/LM rock salt		
EB 3B (selected for analysis)	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 250 lb/LM rock salt		
EB 3C	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 250 lb/LM rock salt		
EB 4A	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 300 lb/LM rock salt		
EB 4B (selected for analysis)	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 300 lb/LM rock salt		

SKID 1	20 gal/LM 100% Salt Brine and 200 lb/LM rock salt		
SKID 2	20 gal/LM 90% Salt Brine 10% BEET HEET (90:10) and 200 lb/LM rock salt		
	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		

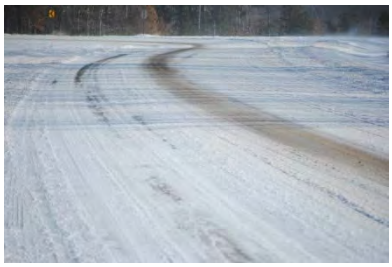
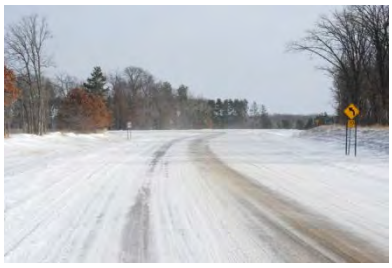
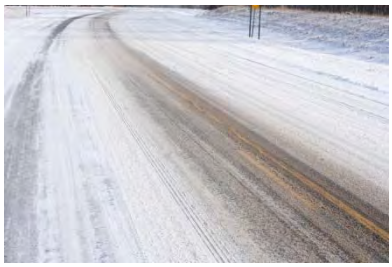
SKID 3	Note: delivery equipment frozen; treatment did not drop		
SKID 4	20 gal/LM 50% Salt Brine 50% BEET HEET (50:50) and 200 lb/LM rock salt		
	Note: delivery equipment frozen open; excessive amount appeared to drop		
SKID 5	20 gal/LM 100% BEET HEET and 200 lb/LM rock salt		

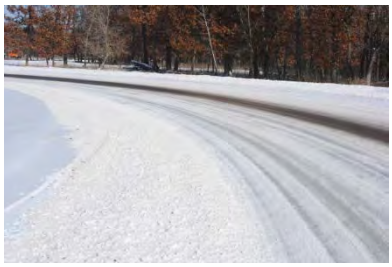
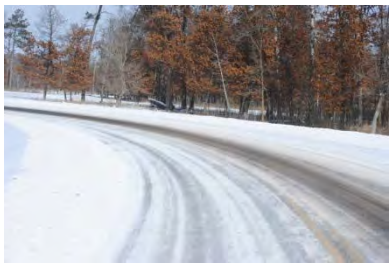
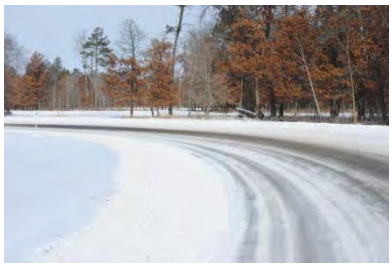
SKID 6	20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt		
SKID 7	20 gal/LM 50% Salt Brine 50% BEET HEET (50:50) and 200 lb/LM rock salt		

Appendix I
Treatment Effects by Time

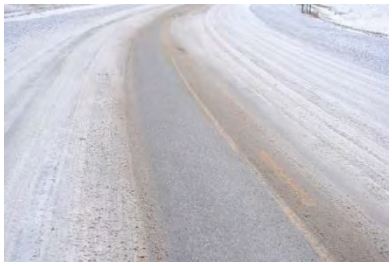
Test Section and Treatment	Time After Treatment	Forward Photo of Location	Pavement Forward Photo of Location
WB 1B 20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt	18 minutes		
	45 minutes		
	69 minutes		
	92 minutes		

WB 2B 25 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt	22 minutes		
	46 minutes		
	70 minutes		
	95 minutes		

WB3B 30 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt	24 minutes		
	50 minutes		
	74 minutes		
	96 minutes		

WB 4B 35 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt	27 minutes		
	52 minutes		
	76 minutes		
	97 minutes		

EB 1B 20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 150 lb/LM rock salt	33 minutes		
	54 minutes		
	78 minutes		
	98 minutes		

EB 2B 20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt	5 minutes		
	36 minutes		
	58 minutes		
	99 minutes		

EB 3B 20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 250 lb/LM rock salt	10 minutes		
	38 minutes		
	59 minutes		
	88 minutes		

EB 4B 20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 300 lb/LM rock salt	13 minutes		
	40 minutes		 (Pavement Backward Photo; Pavement Forward Photo Not Captured)
	67 minutes		
	90 minutes		

SKID 1 20 gal/LM 100% Salt Brine and 200 lb/LM rock salt	At Treatment		
	17 minutes		
	27 minutes		
	37 minutes		
	49 minutes		

	71 minutes		

SKID 2 20 gal/LM 90% Salt Brine 10% BEET HEET (90:10) and 200 lb/LM rock salt	At Treatment		
	17 minutes		
	27 minutes		
	37 minutes		
	49 minutes		

	71 minutes		

SKID 3 20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt Note: delivery equipment frozen; treatment did not drop	At Treatment		
	17 minutes		
	27 minutes		
	37 minutes		
	49 minutes		

	71 minutes		

SKID 4 20 gal/LM 50% Salt Brine 50% BEET HEET (50:50) and 200 lb/LM rock salt Note: delivery equipment frozen open; excessive amount appeared to drop	At Treatment		
	17 minutes		
	27 minutes		
	37 minutes		
	49 minutes		

	71 minutes		

SKID 5 20 gal/LM 100% BEET HEET and 200 lb/LM rock salt	At Treatment		
	17 minutes		
	27 minutes		
	37 minutes		
	49 minutes		

	71 minutes		

SKID 6 20 gal/LM 70% Salt Brine 30% BEET HEET (70:30) and 200 lb/LM rock salt	At Treatment		
	17 minutes		
	27 minutes		
	37 minutes		
	49 minutes		

	71 minutes		

SKID 7 20 gal/LM 50% Salt Brine 50% BEET HEET (50:50) and 200 lb/LM rock salt	At Treatment		
	17 minutes		
	27 minutes		
	37 minutes		
	49 minutes		

	71 minutes		