Center for Environmentally Sustainable Transportation in Cold Climates

Estimating the Application Rate of Liquid Chloride Products based on Residual Salt Concentration on the

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This technical report summarizes the results of laboratory testing on asphalt and concrete pavement. A known quantity of salt brine was applied as an anti-icer, followed by snow application, traffic simulation, and mechanical snow removal via simulated plowing. Using a sample from this plowed snow, researchers measured the chloride concentration to determine the amount of salt brine (as chloride) that remained on the pavement surface. Under the investigated scenarios, the asphalt samples showed higher concentrations of chloride in the plowed-off snow, and therefore lower concentrations of chlorides remaining on the pavement surface. In comparison, the concrete samples had much lower chloride concentrations in the plowed-off snow, and much higher chloride concentrations remaining on the pavement surface. An interesting pattern revealed by the testing was the variation in the percentage of residual chloride on the pavement surface with changes in temperature. When pavement type was not considered, more residual chloride was present at warmer temperatures and less residual chloride was present at colder temperatures. This observation warrants additional testing to determine if the pattern is in fact a statistically valid trend. The findings from the study will help winter maintenance agencies reduce salt usage while meeting the defined Level of Service. In addition, findings will contribute to environmentally sustainable policies and reduce the level of salt usage (from snow- and ice-control products) introduced into the environment.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4		mm
ft	feet	0.3048		m
yd	yards	0.914		m
mi	Miles (statute)	1.61		km
		AREA		
in^2	square inches	645.2	millimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.4046	hectares	ha
		MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g
lb	Pounds (avdp)	0.454	kilograms	kg
T	Short tons (2000 lb)	0.907	megagrams	mg
		VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL
gal	Gallons (liq)	3.785	liters	liters
ft^3	cubic feet	0.0283	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

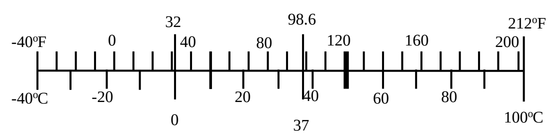
Note: Volumes greater than 1000 L shall be shown in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
ºF	Fahrenheit temperature	5/9 (ºF-32)	Celsius temperature	ºC
		ILLUMINATION		
fc	Foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

These factors conform to the requirement of FHWA Order 5190.1A *SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	Miles (statute)	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
km^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.471	acres	ac
		MASS (weight)		
g	grams	0.0353	Ounces (avdp)	oz
kg	kilograms	2.205	Pounds (avdp)	lb
mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	milliliters	0.034	fluid ounces (US)	fl oz
liters	liters	0.264	Gallons (liq)	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
ºC	Celsius temperature	9/5 ºC+32	Fahrenheit temperature	ºF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi



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EXECUTIVE SUMMARY

This technical report summarizes the results of laboratory testing on asphalt and concrete pavement. A known quantity of salt brine was applied as an anti-icer, followed by snow application, traffic simulation, and mechanical snow removal via simulated plowing. Using a sample from this plowed snow, researchers measured the chloride concentration to determine the amount of salt brine (as chloride) that remained on the pavement surface.

Under the investigated scenarios, the asphalt samples showed higher concentrations of chloride in the plowed-off snow, and therefore lower concentrations of chlorides remaining on the pavement surface. In comparison, the concrete samples had much lower chloride concentrations in the plowed-off snow, and much higher chloride concentrations remaining on the pavement surface.

An interesting pattern revealed by the testing was the variation in the percentage of chloride that remained on the pavement surface with changes in temperature. When pavement type was not considered, more residual chloride was present at warmer temperatures and less residual chloride was present at colder temperatures. This observation warrants additional testing to determine if the pattern is, in fact, a statistically valid trend.

The findings from the study will help winter maintenance agencies reduce salt usage while meeting the defined Level of Service (LOS). Moreover, findings will contribute to environmentally sustainable policies and reduce the level of salt (from snow- and ice-control products) introduced to the environment.

CHAPTER 1.0 INTRODUCTION

Winter maintenance operations include application of anti-icing and deicing products to keep roads clear of snow and ice and provide safe driving conditions for the public. Deicing products are used to remove the ice once it has formed; anti-icing products are used to prevent the snow and ice from bonding with the pavement. Most commonly, solid products are used as deicers and liquid products are used as anti-icers. Traditionally, chloride-based liquids (e.g., salt brine) and solid products (e.g., rock salt) have been used by transportation agencies for winter maintenance activities.

In the past two decades, many studies have been conducted to determine the application rate of various products at different temperatures. Application rates play a vital role in efficiently melting snow and ice, preventing ice from bonding to the pavement surface, and achieving the defined Level of Service (LOS). Over-application of products can lead to inefficiency, wasted product, and damage to infrastructure and the environment. Conversely, insufficient application of product can lead to agencies not meeting the defined LOS, and reduced safety and mobility. The application rate is based on environmental conditions such as air and pavement temperature, temperature trends, humidity, pavement friction coefficient, precipitation type and amount, and field performance of the product. Laboratory data on ice-melting capacity, ice-penetration capacity, ice-undercutting capacity, and eutectic temperature can provide key information on the temperature range in which a product works, how much product is required to melt a specific amount of material, and how long the product will continue to melt snow and ice. However, very few studies have attempted to recommend application rates, considering residual salt concentration on the pavement.

CHAPTER 2.0 BACKGROUND

Measuring residual salt on pavement can greatly reduce the amount of salt applied during a storm event or even during each subsequent storm event. Liquid products have been shown to be effective longer on pavement surfaces than solid deicers, as traffic disperses dry materials (Kahl 2004, Muthumani et al. 2015). Following application, trafficking, and plowing, residual salt remains on the road surface and works during the next storm event. The residual effects of salt can help reduce labor and costs by allowing for less frequent application of snow- and ice-control material. Studying the longevity of snow- and ice-control products on pavement surfaces is important for optimizing material use, subsequent application rates, and timing. A series of studies have investigated the factors affecting deicer longevity, and equations to estimate the residual decay of deicers have been developed.

Factors determined to affect the longevity of deicers include traffic volumes, speed, vehicle types, length of time since application, dispensing rate, road conditions, and weather, as well as whether the salt has dried out and could have been trafficked or blown away (Ketcham et al. 1996, Kahl 2004). Recently, Muthumani et al. (2015) found that viscosity plays a role in determining the ability of the product to stay on the road surface. This finding is based on the fact that products with higher viscosity do not mix as well with snow and ice (Wahlin & Klein-Paste 2013), resulting in a slower speed of grain boundary penetration (German 2009). The more viscous products remain on the pavement surface instead of being wicked into the snowpack. Muthumani et al. (2015) found that agro-based products with higher viscosity remain on the pavement surface. However, data do not show a linear relationship between viscosity and reduction in bond strength; i.e., products with higher viscosity do not necessarily have the lowest bond strength between ice and the pavement surface.

Hunt et al. (2004) evaluated the persistence of anti-icing brine on various pavements in Ohio. A brine residual decay equation was provided as a function of time or traffic for three asphalt cement (AC) and two Portland cement concrete (PCC) pavements. *The factors affecting residual concentrations on the pavement were found to be application method, pavement porosity, and surface roughness*. The field studies yielded residual decay equations that provide an estimate of brine residual as a function of time or traffic for the various pavements investigated in the study.

The objective of the present project was to determine and document the residual salt concentration on pavement after initial application of salt brine during snow- and ice-control operations, and then recommend modified application rates for various temperatures based on the residual salt concentration on the pavement. To accomplish this, laboratory tests were run on asphalt and concrete pavement where a known quantity of salt brine was applied as an anti-icer. Snow and trafficking were simulated, and the remaining snow was plowed off. Using a sample from this plowed snow, researchers measured the chloride concentration to determine the amount of salt brine (as chloride) that remained on the pavement surface. Details of the methodology are presented in Chapter 3.0.

CHAPTER 3.0 METHODOLOGY

The overall approach to this research effort included using a set of laboratory experiments and sodium chloride-based deicing products to measure the residual salt concentration on pavement after compacting, trafficking, and plowing the snow. The following test methods were used to accomplish this.

To measure residual salt concentration, laboratory testing was conducted for liquid sodium chloride (NaCl, salt brine) at 28°F. The salt brine was made with deionized water and reagent-grade NaCl to create a 23.3% brine solution. The salt brine was applied to asphalt pavement (9 inch by 19 inch) using spray application methods to achieve application rates of 47.8 ± 11.7 gallons per lane mile (gal/l-m). Typical salt brine anti-icing application rates used by state departments of transportation (DOTs) range from 40–75 gal/l-m.

The lab testing was conducted at the Subzero Science and Engineering Research Facility (Subzero Lab) at Montana State University. The Western Transportation Institute (WTI) team has established operating procedures to grow and harvest snow particles, and to simulate the sequence of events consisting of periodic snow precipitation, trafficking, and plowing (Muthumani et al. 2015). To simulate driving on snow, a custom-operated trafficking machine designed and constructed at the WTI was used to simulate real-world conditions (Figure 1). The snow was sieved to 1 mm grain

Figure 1. Trafficking machine in action in the MSU Subzero Lab.

size, and 800 g of sieved snow was applied on the pavement sample. The applied snow was then compacted at 60 psi for 5 minutes using a custom-built compactor. After compaction, the snow on the pavement surface was approximately ½-inch thick. The speed of the trafficking device is about 1 ft/sec or 0.7 mph, and the trafficking device applies a total vertical load of 1130 lb. The sample was trafficked for 500 single tire passes, which took about 18 minutes.

After trafficking, snow was scraped from the pavement with a 4-inch stainless steel taping knife to simulate plowing. This snow was collected to quantify the amount of deicer that was removed with snow during plowing.

3.1 Chloride Concentration

To determine the amount of residual chloride on the pavement surface, the chloride concentration of the snow removed during plowing was measured using the following formula. The total chloride concentration applied ($[Cl]_T$) was the application rate minus the chloride concentration of plowed-off snow ($[Cl]_P$), which equals the residual chloride concentration on the pavement ($[Cl]_R$) (Equation 1). Muthumani et al. (2015) found that these methods accurately account for chloride application and loss.

$$[Cl]_T - [Cl]_P = [Cl]_R \qquad \text{Eq. 1}$$

Snow was collected after each plowing cycle and converted to liquid. The chloride concentration from the melted snow was then measured, and the residual amount of chloride on the pavement was calculated using Equation 1. Chloride analysis was completed by Bridger Analytical Lab, Inc., in Bozeman, Montana.

CHAPTER 4.0 RESULTS

During the snow and trafficking testing, the snow that was plowed/scraped off the pavement surface was collected, and the chloride concentration of the snow was measured to determine the amount of chloride removed from the pavement surface and the amount of chloride remaining on the pavement surface. **Table 1** provides a summary of the pavement sample type, the measured application rate of the salt brine, the measured chloride concentration of the snow that was plowed/scraped off the trafficked sample, and the calculated percentage of chloride removed from the pavement surface and remaining on the pavement surface.

Table 1. Summary table of chloride application rates, chloride concentration of the snow removed from the pavement, and the calculated percentage of chloride removed and remaining on the pavement surface by pavement type.

Pavement Type (C=concrete or A=asphalt)	Salt Brine app rate (gal/LM)	Measured Chloride Concentration (mg/L)	Percent of chloride in the plowed off snow (%)	Percent of chloride remaining on the pavement (%)
A	36.1	406	54.4	45.6
A	59.5	1110	87.9	12.1
A	47.8	865	85.2	14.8
C	55.7	141	11.6	88.4
C	27.9	14.3	2.4	97.6
C	39.3	187	21.9	78.1

The general trends that can be observed are the higher concentrations of chloride in the plowed-off snow from the asphalt samples (54%, 88%, and 85%), and therefore lower concentrations of chloride remaining on the asphalt pavement surface (46%, 12%, and 15%). By contrast, the concrete samples showed lower concentrations of chloride in the plowed-off snow (12%, 2%, and 22%), and therefore higher concentrations of chloride remaining on the pavement surface (88%, 98%, 78%) (**Table 1**). This trend has not been observed in previous testing, and additional work is recommended to confirm the trend. The percentages of chloride remaining on the pavement surfaces—Asphalt, 12–45% and Concrete, 78–98%—represent a wide range of residual chloride. For this reason, it is not yet feasible to make recommendations for changing subsequent deicer application rates based on pavement surface type (asphalt versus concrete).

Muthumani et al. (2015) found similar rates of chloride removal with trafficking and plowing/scraping of snow from asphalt pavement. At 5°F, the researchers observed 80–90% removal of chlorides from trafficking and plowing, and at 15°F, they observed 45–80% removal of chlorides from trafficking and plowing (**Figure 2**). The data from Muthumani et al. (2015) show a decrease in chloride removal with warmer temperatures, which could explain the lower chloride removal rates with plowing at 28°F testing; however, further testing is recommended to confirm this trend.

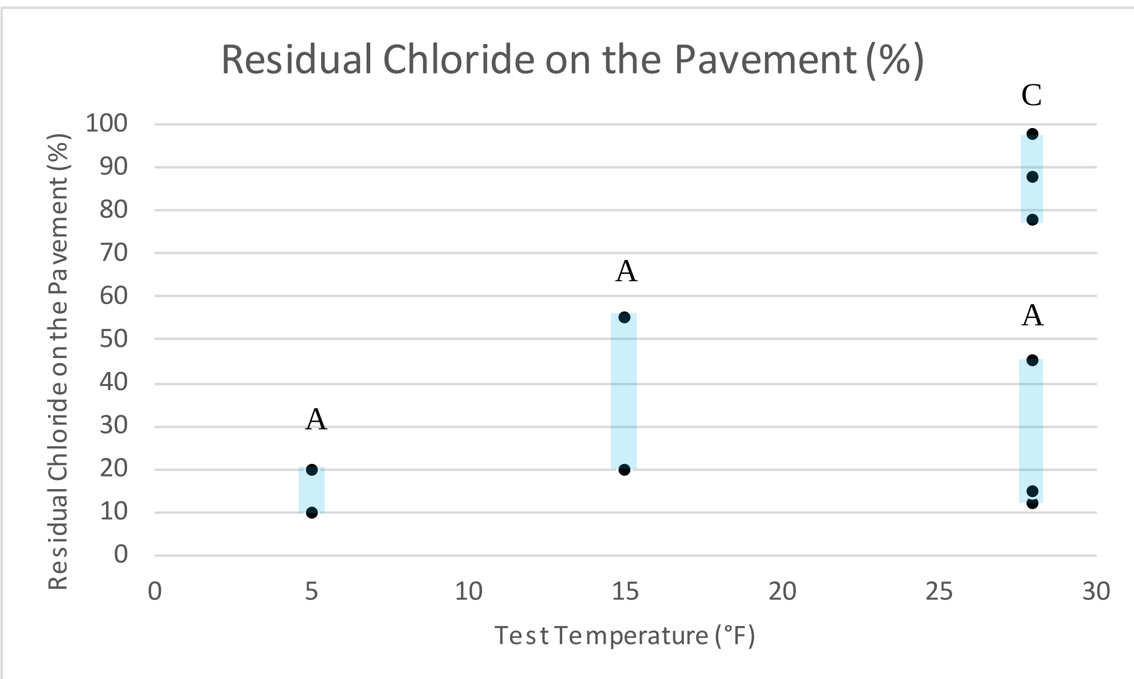

Figure 2. The range of residual chloride on the pavement surface (as %) after anti-icing, addition of snow and compaction, trafficking, and plowing, from this research effort (28°F on asphalt [A] and concrete [C] pavements) and from research by Muthumani et al. (2015) (5°F and 15°F) on asphalt (A) pavement.

The residual 12–97% of chloride on the pavement surface should facilitate anti-icing during a subsequent storm event, specifically on concrete pavement samples where the remaining percentages of chloride are higher. The remaining chloride on the pavement should be sufficient to allow for chemically wet readings measured by mobile non-invasive pavement surface sensors. Further testing is suggested to confirm this. With more testing it may also be feasible to determine a reduced subsequent deicer application rate with more consistent data and to collect a more robust data set on residual chloride on pavement surfaces. It is unknown how much chloride was lost in trafficking the sample, removing snow from the pavement surface, and processing samples. Additional testing that closely tracks chloride applied and chloride lost during testing will likely provide more accurate residual chloride data.

CHAPTER 5.0 CONCLUSIONS

This technical report summarizes the results of laboratory testing on asphalt and concrete pavement, where a known quantity of salt brine was applied as an anti-icer, followed by snow application, traffic simulation, and snow plowing. Using a sample from the plowed snow, researchers measured the chloride concentration to determine the amount of salt brine (as chloride) that remained on the pavement surface.

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