





# Common Misconceptions about the Performance and Environmental Impact of Deicing

By Scott Koefod, PhD

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**C**hemical deicers are a standard tool in modern winter road maintenance, and standard rock salt remains the most commonly used deicing chemical. Salt has long been known to be a safe and cost-effective deicer, but, as is true with most things, it isn't perfect.

Salt melts ice poorly at temperatures below about 50F, its chloride content accelerates corrosion, and even though it's the least expensive of the common deicing chemicals, the high volumes in which salt is used make finding even cheaper alternatives desirable. Thus, the development of improved deicers continues to be an active area of research.

Patents on new deicers are published each year as formulators seek ways to make the products more effective while reducing their cost and environmental impact. The past 20

## Freezing Points and Ice Melting

Of course, the obvious way to melt ice is to raise its temperature, but heating thousands of miles of roadway isn't terribly practical. The use of chemical

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years, in particular, have seen a variety of new technologies move from the laboratory into common practice in actual winter road maintenance operations. In the early days of deicing, there were only two or three chemicals from which to choose; nowadays, the market enjoys a wide array of products and formulations.

With the increased variety of product offerings, it's often challenging to wade through all of the technical information to determine which deicing products are best for a given application. Several common misunderstandings have arisen regarding the meaning of the technical specifications as well. Fortunately, the basic chemistry behind chemical deicers is relatively simple, and these misunderstandings can be easily clarified with a little scientific explanation.

deicers is a rather clever way to accomplish the same thing.

Because it's impractical to heat the ice on a roadway above the freezing point of water, chemical deicers are used to lower the freezing point of water to below the ice's temperature. As long as its temperature is above the freezing point of water, the ice will melt. It doesn't matter how that is accomplished, whether by raising the temperature of the ice or lowering the freezing point of water. Chemical deicers take advantage of the fact that whenever any chemical is dissolved in water, the particles of that chemical interfere with the freezing process, causing the water to freeze at lower temperatures.

It is interesting to note that *any* chemical dissolved in water will have this same effect. Furthermore, not only will any chemical have the same effect, but all chemicals do it to the

same extent! This is an example of what chemists refer to as a “colligative property”—an effect that depends only on the quantity of chemical particles that are dissolved in water, not on their identity. This raises a good question: If any chemical will act to lower the freezing temperature of water, and if all chemicals do so to the same extent, what is so special about the deicing chemicals we use? The answer is that in order for deicing to work, the chemical must dissolve in the water. Not all chemicals do that equally well, and this is especially true at cold temperatures.

### Misunderstandings About Liquid Deicers

The use of deicers in a liquid form (that is, a solution of deicing chemicals in water) has increased dramatically over the past 15 years. Liquid deicers permit a much more efficient use of chemical in many applications than does the use of dry salt alone.

In addition to deicing, liquids are used in anti-icing, where a thin layer of chemical is applied before a storm to prevent the snow from bonding to the pavement. Liquids are also used to prewet salt, which increases the salt’s ability to adhere to the pavement, improves its storage characteristics (helping to prevent freezing and caking), and may improve its ice-melting performance at cold temperatures. Liquid formulations are

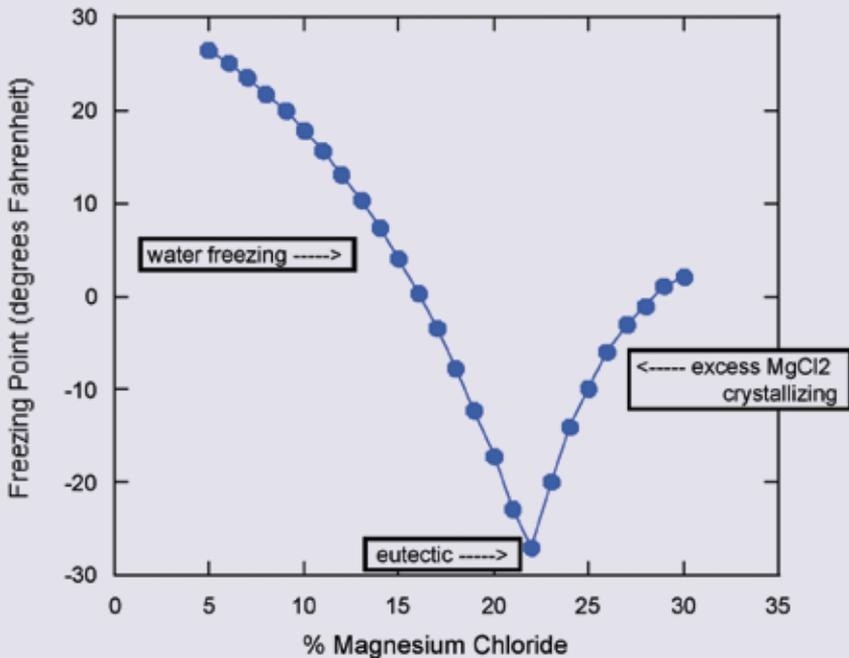
usually based on one of the common, basic deicing chemicals (sodium chloride, magnesium chloride, calcium chloride, potassium acetate, and calcium magnesium acetate) and often include other performance-enhancing additives designed to lower the freezing point, inhibit corrosion, and increase ice melting at lower temperatures.

Unfortunately, the growing popularity of deicing products has been accompanied by frequent confusion about their performance characteristics. In particular, there are several common misconceptions about the relationship between freezing point and the ice-melting ability of liquid deicers. For example:

1. The lower the freezing point of a liquid (the temperature at which the liquid first starts forming solids), the better a deicer it is.
2. Liquid deicers work best when formulated at their minimum freezing point (the “eutectic” point).
3. The lower the eutectic temperature of a chemical (the lowest freezing point that the chemical can cause when dissolved in water), the better a deicer it is.

These misunderstandings occur very easily and even reasonably. If deicers work by lowering the freezing point of water, it is easy to conclude that those liquids with the lowest freezing points must do this best and therefore must

**Figure 1. Magnesium Chloride Freezing Point Curve**



also melt ice at lower temperatures. Thus, product users commonly request freezing-point charts on liquid deicers and use the listed freezing points to gauge the different products' effective working temperatures. However, performance predictions based solely upon the freezing points of liquids are often inaccurate, because the relationship between the freezing point of a liquid and its ice-melting capacity isn't so simple.

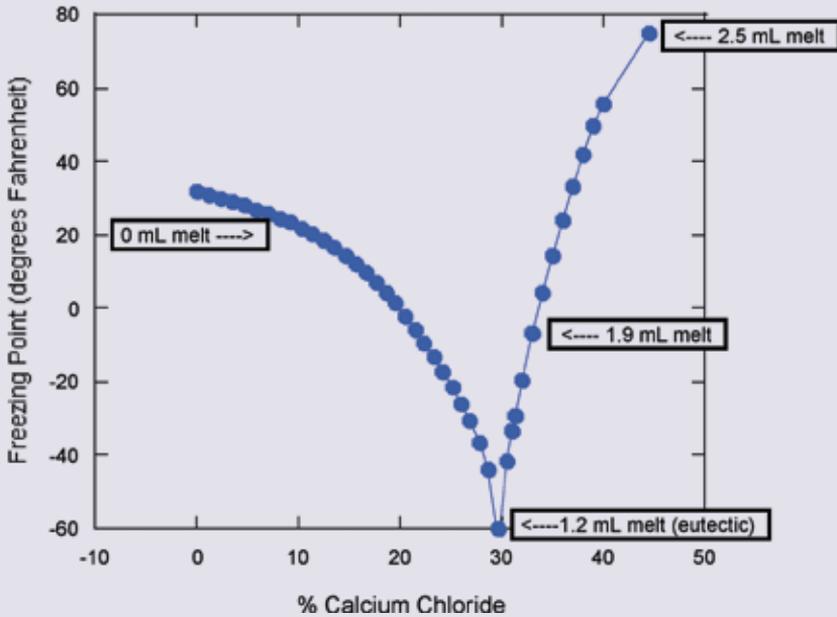
Figure 1 shows a typical freezing-point curve for a liquid deicer—in this case, a solution of magnesium chloride.

Freezing-point curves typically have this "V" shape. The curve shows how the

freezing point of the solution changes as the concentration of magnesium chloride increases. As the latter increases from zero, the freezing point of the solution steadily drops until it reaches a minimum at 22 percent magnesium chloride. This concentration of a chemical in water that yields the lowest possible freezing point is called the eutectic.

As the concentration of magnesium chloride rises above the eutectic, the freezing point of the solution begins to rise. This may lead one to assume that because the magnesium chloride's ability to lower the freezing point decreases at concentrations greater than 22 percent,

**Figure 2. Calcium Chloride Freezing Point Curve  
With Ice Melting Capacities**



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the liquid's ability to melt ice at low temperatures will also decrease.

This is an easy mistake to make, and it arises from misunderstanding what happens when a liquid deicer freezes. The freezing point of a solution is the temperature at which the liquid first starts turning solid. However, the freezing point measurement makes no distinction between what kind of solid is forming.

Over the first part of the curve, from 0 percent magnesium chloride to 22 percent, the solid that is forming is ice; that is, the curve is measuring the freezing of water. The trend in freezing point is exactly what we would expect—the freezing point of water drops proportionally as the concentration of chemical particles increases. On the right-hand side of the curve, however, at concentrations above the

eutectic, the solid that is forming is not ice, because what is taking place is no longer the freezing of water. Rather, the solution has reached a concentration that has exceeded the solubility of the chemical at low temperatures, causing excess solid chemical to crystallize out of the solution. The freezing-point measurement can't tell the difference between water freezing and solid excess chemical dropping out of the solution, resulting in an apparent increase in the freezing point of water.

If excess solid chemical “freezes” out of a solution at colder temperatures, this will have no impact on its ability to melt ice. This is illustrated in Figure 2, which shows the freezing-point

curve for another common deicing chemical, calcium chloride. Here, the ice-melting capacities of solutions of calcium chloride at different concentrations were measured by applying equal weights of liquid to ice in a controlled-temperature chamber at 150F and measuring the volume of ice melt after 60 minutes.

Looking at the amount of ice melt (measured in milliliters of melt per gram of deicer) at different concentrations, one can see that there is no relationship between the freezing point of the liquid and its ice-melting capacity. The ice-melting capacity is highest at the highest concentration of active chemical and drops steadily as



the chemical concentration decreases, regardless of the “freezing point” of the liquid deicer solution. Thus, the total ice-melting capacity of a deicer solution will always be at maximum at the highest concentration of chemical, regardless of the liquid’s freezing point.

### The Eutectic and Ice-Melting Capacity

The eutectic temperatures of chemical deicers are commonly used to rank their relative ice-melting effectiveness. However, the eutectic alone can be a misleading predictor of ice-melting ability. The eutectic temperature of a deicer is the lowest possible freezing point that it can produce in water. As illustrated above, the degree to which a chemical can lower the freezing point of water will be limited by its solubility.

The freezing point of water drops proportionally with the concentration of chemical particles, so once the water is saturated its freeze point can’t be lowered any further. Thus, the eutectic temperature may be interpreted as the theoretically lowest possible temperature at which a given chemical can melt ice. From this standpoint, it is tempting to use the eutectic temperature to compare the effectiveness of different chemicals. Unfortunately, the difference between the theoretical and *actual* lowest temperature at which a deicer will work is difficult to predict.

The eutectic is an example of

what chemists call a “thermodynamic property.” Thermodynamic properties have to do with whether a given process is even possible. Thus, if the temperature of the ice is colder than the eutectic temperature of a chemical, it

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is impossible for that chemical to melt any ice. The eutectic sets the minimum temperature at which the deicer could possibly work. But while a low eutectic temperature is necessary for deicing, it is not sufficient.

Two factors determine whether any chemical process, including chemical ice melting, will proceed. One is thermodynamics, which determines whether a process is even possible. The other is what chemists call “kinetics,” which has to do with the *speed* of a process. It turns out that the factors that determine the eutectic temperature of a chemical are unrelated to those that control how *quickly* a chemical can melt ice. Because the eutectic temperature doesn’t take kinetics into consideration, it can be a misleading predictor of practical ice-melting performance.

Comparing calcium magnesium acetate with sodium chloride illustrates this point. Calcium magnesium



acetate has a lower eutectic temperature (-180F) than sodium chloride (-60F). If we made a performance-related prediction based on eutectic temperature alone, we might assume that calcium magnesium acetate would melt more ice than sodium chloride at colder temperatures. But, in fact, the opposite is true. Sodium chloride has a significantly higher ice-melting capacity at cold temperatures than does calcium magnesium acetate. The former's eutectic temperature is misleading because it fails to account for kinetic factors that slow down calcium magnesium acetate's ability to melt ice.

Some liquid formulations use additives to lower the apparent freezing point of the liquid. These are

sometimes also described as lowering the eutectic temperature of the formulation. Yet, although the freezing point of a liquid and its eutectic temperature are often confused with each other, they are not the same thing. A liquid's freezing point depends on the concentration of the chemical dissolved in the solution, whereas a chemical's eutectic temperature does not change with its concentration.

As discussed above, it is risky to make assumptions about ice-melting capacity based upon these thermodynamic measurements alone. The best way to determine relative ice-melting performance, rather, is to measure it directly by a method such as the Strategic Highway Research Program

(SHRP) Standard H205.2. (The SHRP produced a wide variety of research related to highway maintenance in the early 1990s.)

At Cargill, Inc., we've experimented with lowering the freezing points of liquids in our lab, and our results underscore the importance of measuring actual ice-melting capacities. For example, in one experiment, we found that a solution of 30 percent

of magnesium chloride and a higher freezing point.

### Corrosion Inhibitors

The common deicing chemicals may be roughly divided into three basic groups with respect to their corrosiveness: chloride deicers, nonchloride deicers, and corrosion-inhibited chloride deicers.

The chloride ion is the “bad

The chloride ion is the “bad actor” when it comes to corrosion. Chloride has a catalytic effect on the corrosion of ferrous metals and accelerates it.

magnesium chloride melted 0.94 pounds of ice per pound of deicer at 150F and 0.43 pounds of ice per pound of deicer at 50F. Blending this magnesium chloride solution in a 50/50 ratio with a particular agricultural additive lowered the apparent freezing point of the liquid from 20F to -50 0F. However, the effect on ice-melting capacity was disappointing. The solution's ice-melting capacity dropped from 0.94 pounds of melt to 0.52 pounds of melt at 150F and from 0.43 pounds of melt to no measurable melt at 50F. Thus, despite a dramatic decrease in its apparent freezing point, the formulation's ice-melting capacity was much less than it would be for a solution with a higher concentration

actor” when it comes to corrosion. Chloride has a catalytic effect on the corrosion of ferrous metals and accelerates it. One can measure differences between the relative corrosiveness of the three common chloride deicers (sodium chloride, magnesium chloride, and calcium chloride), but, roughly speaking, it probably makes sense to consider them as a single group, as they will all be relatively corrosive toward steel.

Nonchloride deicers, on the other hand, because they lack the aggressive chloride ion, are relatively benign. Chemicals such as potassium acetate and calcium magnesium acetate are far less corrosive to steel than any chloride-containing deicer. In areas where

minimizing steel corrosion is considered critical, using a nonchloride deicer will always be the best alternative. However, because the nonchloride deicers are cost-prohibitive for many applications, a third category of deicers has been developed: chloride deicers that contain corrosion inhibitors.

The idea behind corrosion-inhibited products is to provide a middle ground, a deicer that will be less corrosive than regular chloride

corrosion rate that encompasses all conditions in the field. Therefore, laboratory tests are typically used to provide a benchmark comparison of different chemicals under some set of “typical” exposure conditions.

Interpretation of laboratory corrosion tests should always be done with care, bearing in mind that their predictive value falls off the further the test conditions deviate from the specific field conditions. There are corrosion-

**There is no such thing as a single precise corrosion rate that encompasses all conditions in the field. Therefore, laboratory tests are typically used to provide a benchmark comparison of different chemicals under some set of “typical” exposure conditions.**

deicers but at a more affordable cost than nonchlorides. Quantifying the effectiveness of corrosion inhibitors is a significant challenge, however.

Corrosion is an extremely variable phenomenon. It will vary greatly depending upon specific exposure conditions, such as temperature, the particular metals involved, whether there are different metals in contact with each other, the concentration of chemical in the deicer runoff, the relative amounts of wetting and drying of the metal, the dirtiness of the metal, scoring on the metal, and so on. Thus, there is no such thing as a single precise

inhibited chloride deicers that will show corrosion rates as low as that of pure water in laboratory tests, but corrosion-inhibited chloride deicers will probably never be as low-corrosion as nonchloride deicers are across all field conditions.

In the late 1990s, the Pacific Northwest Snowfighters Association (PNS) developed its own deicer specifications. These may be the most detailed deicer specifications developed to date, and they include a corrosion test. The PNS requires that corrosion-inhibited deicers be at least 70 percent less corrosive than salt as measured by its test method.



Perhaps because it was developed by state department of transportation customers themselves, the PNS specifications have become widely adopted outside the Pacific Northwest states, and their corrosion test is the closest thing to an industry standard. It is based upon a National Association of Corrosion Engineers Standard (NACE TM0169-95) and is likely a reasonable approximation of a common type of field exposure: the repeated wetting and drying of steel that is exposed to the splash and spray of diluted deicer solution in runoff ice melt. This test would not simulate well the corrosion of steel reinforced in concrete, which is a very different type of environment. Steel in concrete corrodes much more slowly than exposed steel. The corrosion of steel in concrete is most

efficiently measured by specialized electrochemical techniques such as polarization resistance and electrochemical impedance spectroscopy.

Users very commonly require that liquid deicers used for prewetting pass the PNS corrosion specifications. Typically, prewetted salt consists of about 8 gallons of liquid deicer per ton of dry salt (an addition rate of about 3.5 percent to 4.5 percent). It is important to bear in mind that even though the liquid additive may meet a low-corrosion specification, that doesn't necessarily mean that the final blended salt product will also pass those specifications. That is, if one wants to know the relative corrosion rate of the treated salt product once it gets into the ice melt, the whole product—including the salt—must be dissolved and tested, not just the liquid portion.

Most prewetting liquids probably don't contain enough corrosion inhibitor to control the corrosion of both their own chloride content as well as that of the large amount of additional salt with which they get blended. Thus,

and air quality, to name only some. Given such a broad range of criteria, there is no one deicing chemical that is clearly the most environmentally friendly in all respects.

Various environmental studies

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the value of a corrosion-inhibited liquid for prewetted salt is likely restricted to protecting the equipment that comes into direct contact with it, where it can act as a low-corrosion barrier between the steel and salt. In order to make the entire prewetted salt blend pass the PNS corrosion test, additional corrosion inhibitors are usually required. Such products are commercially available but are more expensive than standard prewetted salt.

### **Environmental Impact of Deicing**

The environmental impact of deicers is even more difficult to precisely quantify than corrosion because there are so many different factors that fall under the general heading of "environmental effects." Environmental impact includes effects on soil, groundwater, vegetation, aquatic life, animal life,

on deicing chemicals have been done over the years, and the relative ranking of their environmental impact differs depending on which specific type of effect is measured. For example, the relative toxicity of deicers to vegetation varies depending on the plant. A 2003 study of *Allium cepa* root elongation and duckweed *Lemna* growth inhibition ranked the acetate deicers as more harmful than salt, while a 2001 study on the germination and growth of cress and barley concluded that salt was more harmful than calcium magnesium acetate.

In instances where there is a very specifically defined environmental concern, it may be possible to identify chemicals with minimal impact. In general, however, there is no one chemical that is head and shoulders above the others. The

value that chemical deicers provide is high, and the key to their environmental management is using them with maximum efficiency. Liquid deicers are an important tool in that effort, and several technologies are readily available to enable users to take advantage of them, including the prewetting of salt, the direct application of liquid anti-icers, and the use of new porous bridge overlays that increase the residual effect of anti-icing liquids by absorbing them and slowly releasing them as needed.



### **Factors to Consider in Choosing a Deicer**

In choosing among the ever growing number of deicer formulations, it's important to understand their technical specifications—both what they reveal and what they don't reveal. Freezing points are useful for determining safe storage temperatures but are ambiguous predictors of ice-melting capacity, which is best measured directly by a standard test rather than predicted theoretically.

Laboratory tests can provide an approximate comparison of relative corrosiveness between products but can't precisely predict corrosion under all field conditions. Similarly, the relative environmental impact of deicers varies, and there is probably no one single deicer that is the most environmentally friendly. Technologies such as anti-icing and prewetting allow a more efficient use of chemicals and can help minimize environmental impact.

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Scott Koefod has a PhD in inorganic chemistry and is principal scientist at Cargill, Inc., an international provider of food, agricultural, and risk-management products and services based in Minneapolis. He has worked for the company for 15 years in the areas of deicer testing and development. Dr. Koefod also teaches chemistry at the University of Minnesota in Minneapolis. He may be reached at [Scott\\_Koefod@cargill.com](mailto:Scott_Koefod@cargill.com).