THE EFFECTIVENESS OF DIFFERENT DE-ICING SALTS

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1. Abstract

A certain quantity of de-icing salt is required for clearing the roadway depending on the quantity of ice or snow. Due to lack of knowledge only very inaccurate recommendations regarding the quantity to be used are available for winter maintenance personnel. The application density depends on the following primary influences which, on the other hand, interact extensively with one another:

- Ice or snow present
- Location and structure of roadway
- Meteorological influences
- Traffic
- Spreading technique
- Quality of the de-icing salts

The Federal Highway Research Institute has determined the de-icing capacity of the following de-icing salts in laboratory tests using the Inzell ice slab procedure for evaluation of the effect of the de-icing salt quality:

- Sodium chloride in various grain sizes
- Calcium chloride
- Solutions of sodium, calcium and magnesium chloride.

In each case 4 g of solid de-icing salt or 4 g of dissolved de-icing salt as a 20 % solution were applied to an ice slab with dimensions of 24x18x3 cm. The melted quantity of ice and the de-icing salt were removed from the ice slab by means of centrifugal force following the specified effective periods at various temperatures and humidities. The de-icing capacity was defined as the difference in the ice slab weight previously and subsequently.

The results showed, among other things, the following properties of the various substances:

- For all substances, the de-icing capacity is reduced as the temperature decreases. In comparison to –2 °C, the de-icing capacity is reduced to approx. 20 to 25 % at –15 °C.
- Coarse sodium chloride (grain size >2.5-3.15 mm) reacts significantly slower than fine grain sodium chloride (grain size <2 mm).
- Fine sodium chloride (grain size 0.8-1.0 mm) is not less effective than standard commercial calcium chlorides for winter maintenance even at –15 °C.
- The atmospheric humidity affects the results only to a very limited extent.
- Although prewetted sodium chloride achieves lower de-icing capacities than dry sodium chloride in the laboratory, it is still more effective due to the significantly better distribution on the roadway and reduced losses resulting from drifting as well as being thrown to the side.

2. Introduction

Obstructions resulting from ice and snow on the roads lead to considerable economic losses at the high traffic volumes in the Federal Republic of Germany. For this reason, the highway administrations go to great efforts to avoid or quickly eliminate ice and snow. The use of de-icing salts in addition to mechanical clearing has proven to be considerably more effective in comparison to abrasive de-icing agents.

A certain quantity of de-icing salt is required depending on the quantity of ice or snow. Due to lack of knowledge only very inaccurate recommendations regarding the quantity to be used are available for winter maintenance personnel. Selection of the application density as well as the type of de-icing salt is accomplished very differently by the individual users.

High salt application quantities result in high costs and can also lead to environmental damage, which should be avoided particularly within cities.

The properties of various de-icing salts have been studied in detail in laboratory tests and the results evaluated to provide more exact recommendations for users for reduction of the de-icing substances.

3. Effects on the required application density

The application density depends on the following primary factors which, on the other hand, interact extensively with one another:

- Ice or snow present (quantity and type)
- Location and structure of roadway
- Meteorological influences (temperature, humidity, precipitation, wind)
- Traffic (number and speed of vehicles)
- Spreading technique (distribution of de-icing agents)
- Quality of de-icing salts (chemical composition, grain size and prewetting of solids)

4. De-icing agents used in Germany

In Germany, sodium, calcium and magnesium chloride are used almost exclusively as de-icing agents.

Here, sodium chloride (NaCl content > 96 %) is the de-icing salt used primarily due to its low cost. Calcium chloride ($CaCl_2$ content 79 %) is kept in stock at some points as a solid de-icing substance for clearing ice at extremely low temperatures. Magnesium chloride is not used as solid de-icing salt.

Sodium chloride is used basically in two different forms:

- Rock salt (percentage in Germany > 95 %, fine grain (grain size < 2mm) and coarse grain (grain size up to max. 5 mm)
- Vacuum salt (fine grain, grain size <1 mm)

The prewetted salt method is used primarily whereby the sodium chloride is moistened with a solution on the spreading plate of the spreading vehicle. As a rule, the ratio is 70 % of solid substance by weight: 30 % solution by weight. All three chlorides specified are used for producing the solutions.

Different opinions exist regarding the effectivity and advantages and disadvantages of fine and coarse grain sodium chloride.

5. Determination of de-icing capacity

The de-icing capacity of de-icing agents has been evaluated in Germany for many years by the Federal Highway Research Institute using the Inzell ice slab method.

With this method, a 4-g sample of the salt to be tested, which is represented in terms of its grain size distribution, is applied in a refrigeration chamber (dimensions: 8 m x 6 m x 2.2 m) to an ice slab with dimensions of 24x18 cm and a thickness of approx. 3.5 cm. The de-icing agent is allowed to act on the ice slab for a specified period of time at a specified temperature. Then the de-icing agent and melted quantity of ice is removed from the ice slab by means of centrifugal force. The melted quantity of ice can be calculated from the difference in the weight of the ice slab before and after treatment. De-icing capacity results are given as the quantity of ice melted per gram of de-icing substance used.

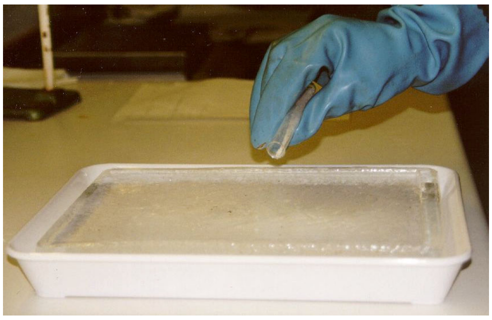

Figure 1: Application of dry salt to an ice slab

Application tests for de-icing salt suppliers and highway administrations are performed at –2 °C and –10 °C with an effective period of 10 and 60 min. each. The atmospheric humidity is specified to be 60%. Solid de-icing agents are always used in the dry state. The accuracy of this procedure is +/-5 % for solid de-icing agents.

In addition to the standard tests, basic studies were accomplished with various chlorides at different temperatures and humidities as well as different effective periods.

6. Results

6.1 Comparison of sodium chlorides in various grain sizes

4-g specimens, produced especially for these tests, were used with the following grain size distribution: 0.16 – 0.4 mm, 0.8 – 1.6 mm, 1.6 – 2.0 mm, 2.5 – 3.15 mm, 3.15 – 4.0 mm, 4.0 – 5.0 mm The tests were accomplished at 60 % relative humidity unless otherwise specified.

6.1.1 De-icing capacities depending on effective time

After an effective period of 10 min., the fine grain sodium chloride showed a significantly higher de-icing capacity on the ice slab in comparison to coarse grain sodium chloride. The differences decrease with increasing effective period (Figure 2). This process can be explained by the considerably larger contact areas of the finer salt grains.

During these tests, the coarse grains sink into the ice slab whereby the contact surface between the grains and the ice is increased significantly. Large grains melt all the way through the ice slab after a longer period of time. The solution formed can then also release the ice from the roadway from the bottom so that it can quickly be thrown to the side by vehicle tires. However, in Germany, the layers of ice are frequently only a few tenths of a millimeter thick. For this reason, the effect of larger salt grains would probably be poorer than with the ice slab procedure.

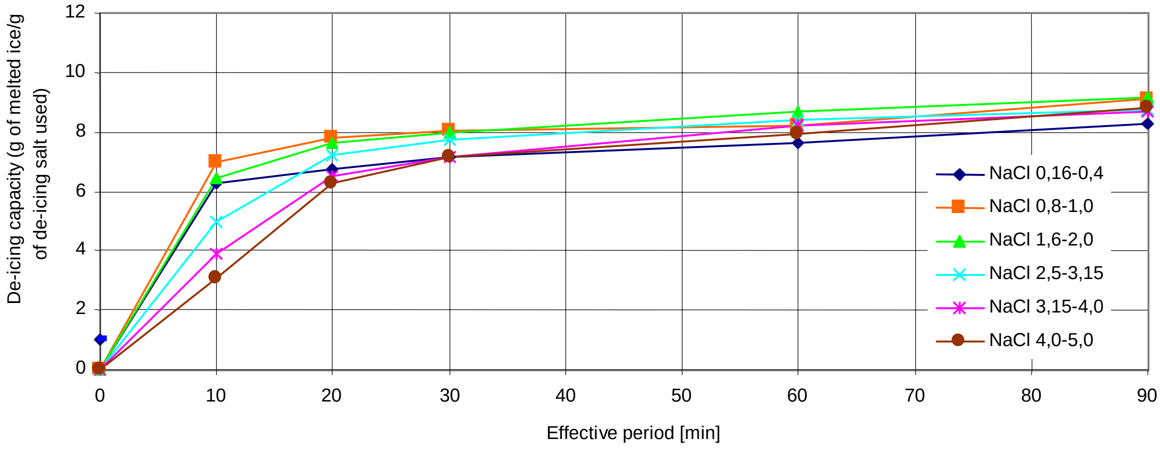

Figure 2: De-icing capacity of sodium chlorides with different grain size distributions at ice slab temperature of –5 °C depending on effective time

6.1.2 De-icing capacity in relation to ice temperature

The de-icing capacity depends significantly on the ice temperature. The lower the temperature, the lower the de-icing capacity (Figure 3), because the kinetic energy of the water and salt ions is reduced considerably and thereby reducing their capability of mixing with one another. In comparison to -2 °C, the de-icing capacity of fine grain sodium chlorides after an effective period of 10 min. is reduced to approximately one half at –10 °C and at –15 °C to approximately one third.

In comparison to the fine sodium chlorides (0.8-1.0 mm), the de-icing capacity of the coarse sodium chlorides (4.0-5.0 mm) after an effective period of 10 min. decreases to a greater extent at decreasing temperature. Although they still achieve approximately 50 % of the de-icing capacity of fine grain sodium chloride at –2 °C and an effective period of 10 min., this value is reduced to approximately 35 % at –10 °C and to less than 25 % at –15 °C. These results were caused by the various behavior of the different grain sizes on the ice slab.

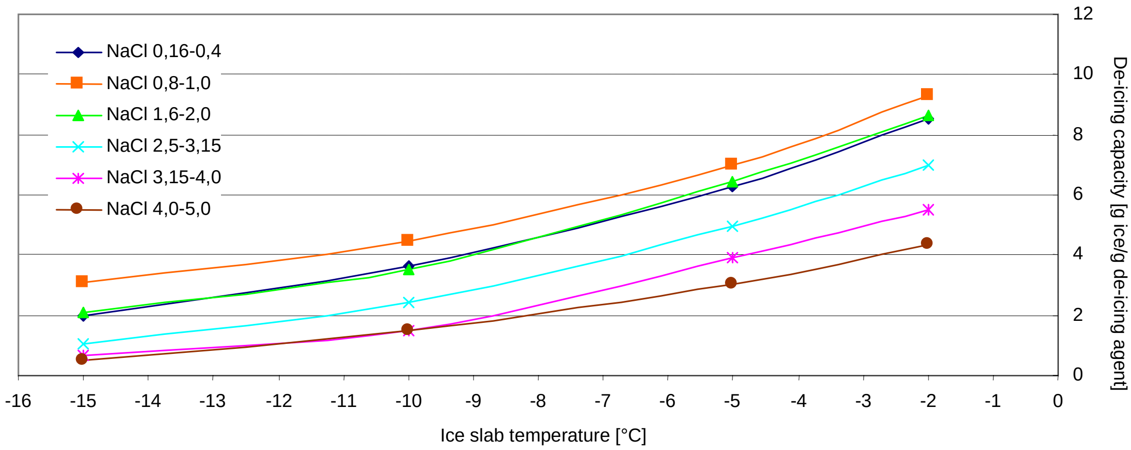

Figure 3: De-icing capacity of sodium chlorides with different grain size distributions after an effective period of 10 min. depending on the temperature of the ice slab

6.1.3 De-icing capacity depending on humidity

Frequently users are of the opinion that the initial de-icing effectivity increases significantly at increasing humidity.

Results with the Inzell ice slab method at relative humidities of up to 70 % do not confirm this opinion (Figure 4). The de-icing capacities for the individual types of sodium chloride deviate approximately within the scope of the measuring accuracy. The de-icing capacity tends to increase slightly as the humidity increases. However, this increase is negligible for practical applications. No results are presently available regarding high humidities.

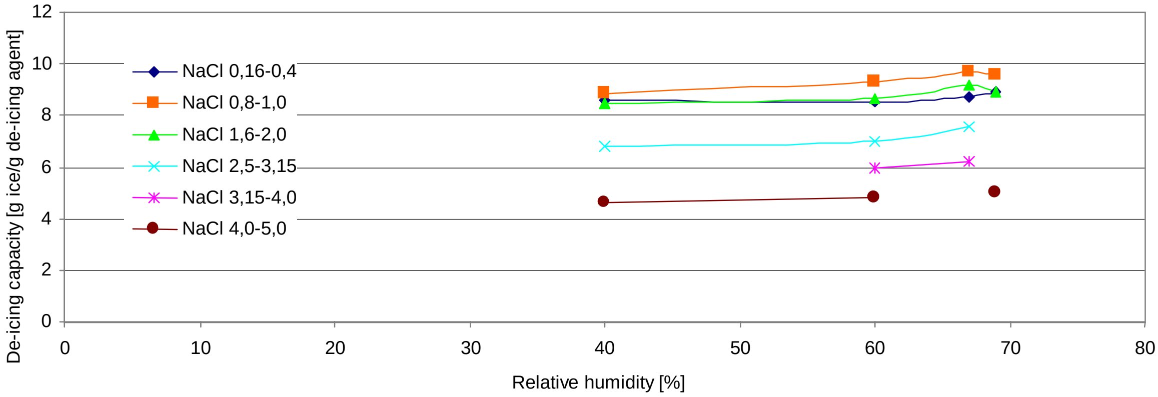

Figure 4: De-icing capacity of sodium chlorides in different grain size distributions at ice slab temperature of –2 °C and effective period of 10 min. depending on relative humidity

6.2 Comparison of de-icing salt solutions with solid sodium and calcium chloride

20 % solutions of sodium, calcium and magnesium chloride were used for these tests. 20 g of the solution was applied in each case to the ice slabs so that 4 g of the chlorides were effective in these cases. For comparison, 4-g samples of fine sodium chloride (0.8-1.0 mm) and coarse sodium chloride (3.15-4.0 mm) as well as a standard commercial 79 % calcium chloride were used.

The de-icing capacities of the solutions decrease significantly after an effective period of 10 min. at decreasing temperature (Figure 5) in comparison to the fine grain sodium chloride. At temperatures below –10 °C, the use of solutions as the sole de-icing agent is not practical. During an attempt to determine the de-icing capacity of a sodium chloride solution at –19 °C, the solution itself froze, increasing the mass of the slab.

The de-icing capacities of the solid forms are higher than that of the solutions because the water in the solution is included in addition to that of the melted ice in the intended balance between ice and solution.

At temperatures below –10 °C and effective periods of 10 min., the solutions already achieved their full de-icing capacity (compare Figures 5 and 6).

In comparison between fine grain sodium and calcium chloride, there are no great differences down to –15 °C. The solid calcium chloride melts significantly larger quantities of ice only at lower temperatures.

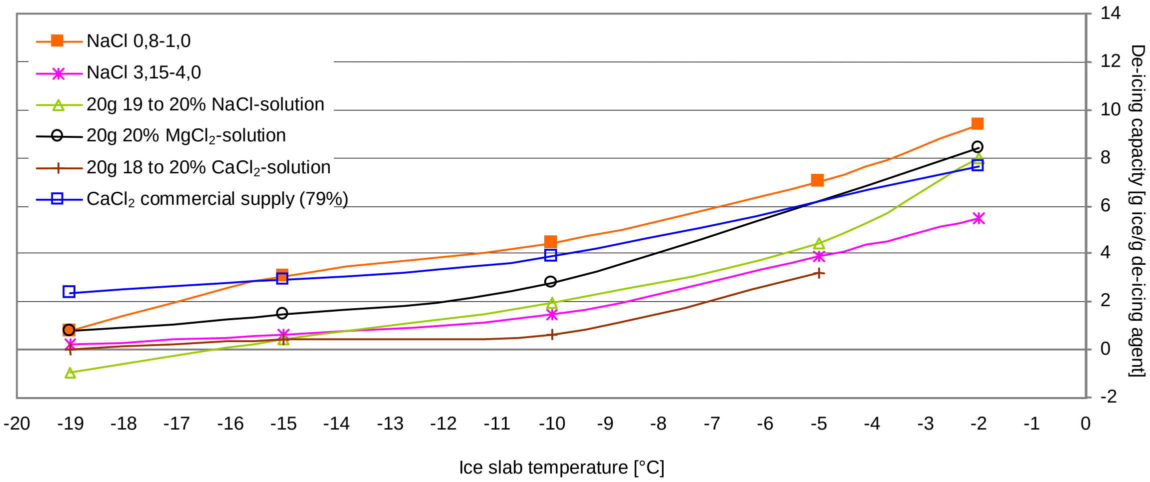

Figure 5: De-icing capacity of de-icing salt solutions in comparison to solid sodium and calcium chloride after an effective period of 10 min. depending on ice slab temperature

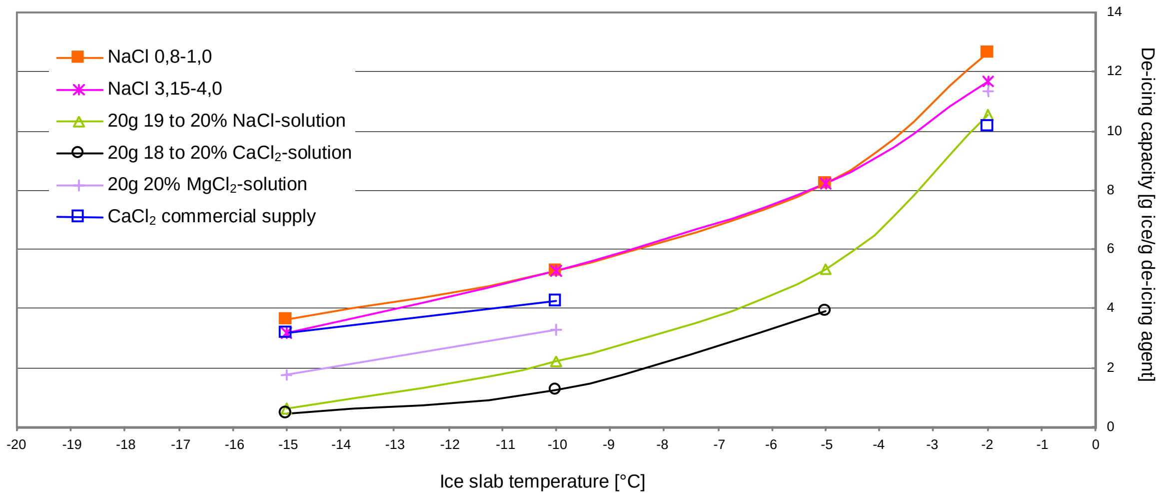

Figure 6: De-icing capacity of de-icing salt solutions in comparison to solid sodium and calcium chloride following an effective period of 60 min. depending on ice slab temperature

6.3 De-icing capacities of prewetted sodium chlorides

A widely held opinion is that sodium chlorides react significantly faster when prewetted than dry sodium chlorides. Tests using the ice slab method, however, indicate that the de-icing reaction with dry salt starts immediately after application. A small pile of salt on the ice slab cannot be distributed even after a few seconds. The salt remains moist and sticks to the object used for application.

The specimens for these tests consisted of 2.8 g of sodium chloride in the form of vacuum salt, each of which was prewetted with 1.2 g of 20 % solution. The entire quantity of salt was approximately 3 g per specimen. (See Figure 7-9 for test)

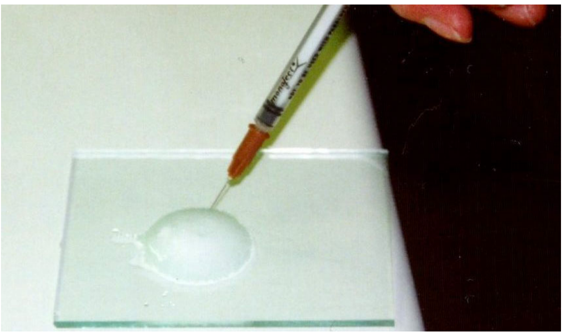

Figure 7: Prewetting dry sodium chloride with solution on a glass plate

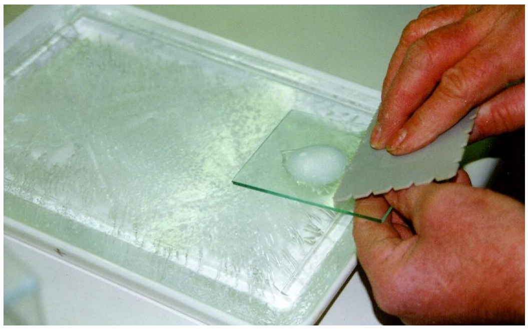

Figure 8: Application of prewetted salt to the ice slab

Figure 9: Distribution of prewetted salt on ice slab with toothed spatula

The dried sodium chloride does not show any lower de-icing capacity than sodium chloride in the delivery state with 1% adhering moisture considering the tolerances for the procedure. They are nearly the same. Both substances react immediately on the ice slab (Table 1).

De-icing agent	De-icing capacity [g of ice/g of de-icing agent]
Dried sodium chloride	5.23
Sodium chloride in delivery state (approx. 1 % moisture)	5.29
Dried sodium chloride with 30 % NaCl solution (FS30)	4.38

Table 1: De-icing capacity of vacuum salt with different degrees of prewetting (-6°C, 10 min.)

The specimens with the completed FS30 procedure achieved only approx. 83 % of the de-icing capacities in comparison to the two other forms of sodium chloride. In relation to the percentage of sodium chloride used (76 %), the de-icing capacity is slightly higher than with the other two forms. Figure 10 shows that the type of salt (NaCl, $CaCl_2$, $MgCl_2$) in the solution is insignificant.

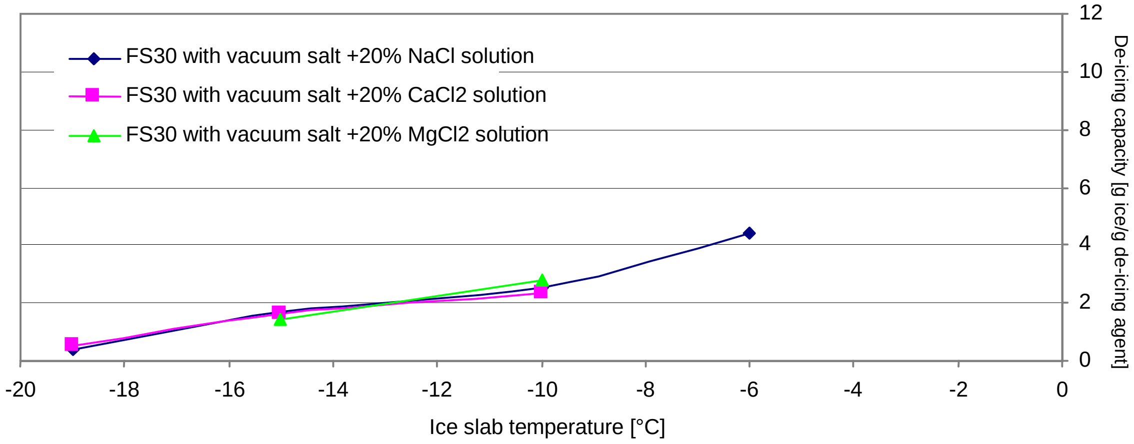

Figure 10: De-icing capacity of differently prewetted sodium chlorides after an effective period of 10 min. depending on ice slab temperature

7. Calorimetric tests

The quick de-icing reaction of dry de-icing salts on ice can be proven quite well in a thermally sealed vessel (calorimeter). 200 g of ice grains with a diameter of < 2 mm are filled into a thermos vessel (volume approx. 2 l). After adjustment to a constant temperature in the calorimeter, 4-g specimens of various dry chlorides are stirred in. In this fully automatic process, the temperature of the ice is measured and recorded.

The temperature in the calorimeter drops due to the heat required for the melting process. Figure 10 shows that the reaction starts just a few seconds after addition and is completed after only a few minutes on the basis of the temperature curve. With fine grain sodium chlorides (grain sizes < 2 mm), the temperature initially drops more rapidly than with coarse grain sodium chloride (grain sizes up to 5 mm). Here again, this effect is the result of the larger reaction surfaces. After a temperature compensation time in the calorimeter, the final temperatures for sodium chlorides with different grain sizes are approximately equal.

Tests with prewetted sodium chlorides were not possible with the present calorimeter because the testing agent stuck to the application container.

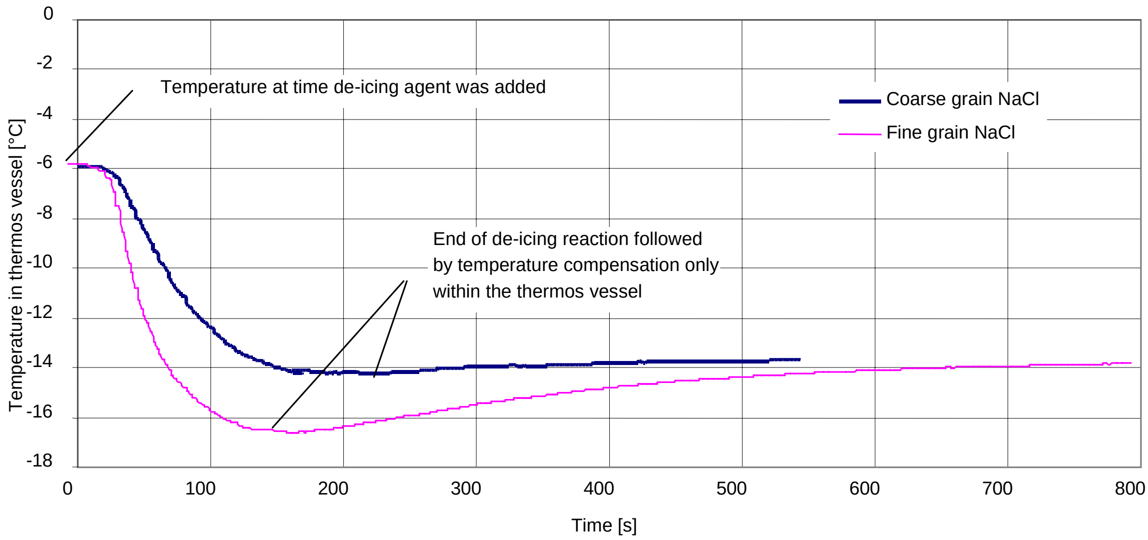

Figure 11: Temperature curve in a thermos vessel after adding 4 g of fine and coarse grain sodium chloride to 200 g of ice ground fine as snow

8. Advantages of applying prewetted salt

Why do prewetted de-icing agents still achieve a significantly higher effectivity in comparison to dry salt application?

Observations during the application procedure indicate clear drifting of the fine grain fractions (Figure 12). Even when the roadway is wet, these are not finely distributed on the roadway as desired. Before hitting the road, they drift to the edges or are not distributed equally. This effect increases with the speed of the application vehicle.

Figure 12: Application of dry salt (fine grain saline salt, approx. 30 g/m² at approx. 50 km/h)

The drifting effect does not occur to this extent with coarser grain sizes. Larger grains hit against the roadway and frequently jump or roll like a ball.

What happens with the prewetted fine grain fractions?

The fine grains are moistened on the distribution plate. This procedure causes a number of grains to stick together comparatively loosely. During the hurling phase, these conglomerated particles then have a higher weight which has less tendency to drift. When they hit against the roadway, they have less tendency to jump due to the flatter shape. The loose grains can then be distributed finely by traffic so that they can quickly become effective over the entire roadway.

In order to achieve effective prewetting, the salt must be free flowing. Solid lumps of sodium chloride can only be taken very unevenly from the salt container on the vehicle and distributed on the roadway. For this reason, the sodium chloride should only have small initial quantities of moisture. The smaller the grain size, the lower the percentage of moisture on the sodium chloride for it still to be free flowing.

Prewetted de-icing salt grains adhere better to the surface of the road after application and therefore have less tendency to be drifted by traffic.

The disadvantage of the lower de-icing capacity of prewetted salt is therefore compensated by lower drifting losses during application and less hurling away to the edge area due to the rolling traffic. At the same application density, 25 % less de-icing salt is required using the prewetted method making use of prewetted salt more ecological.

9. Conclusions for practical application

Based on the results, the following conclusions can be drawn for practical application:

- For thin layers of ice, fine grain types of sodium chloride with grain size up to 2 mm become effective considerably more quickly than coarse grain. Fine grain sodium chlorides are therefore recommended for preventative application as well.
- At low temperatures, it is necessary to apply significantly higher application densities than at temperatures just below freezing.
- Down to –15 °C, the use of calcium chloride has no advantages in comparison to fine grain sodium chloride. In many cases, it is not necessary to keep expensive calcium chloride in stock.
- The atmospheric humidity is negligible in calculating the application density.
- The type of solution (NaCl, $CaCl_2$ or $MgCl_2$) does not affect the de-icing capacity when applying prewetted salt.
- Although prewetted sodium chloride achieves lower de-icing capacities than dry sodium chloride in the laboratory, it is more effective due to its significantly better distribution on the roadway and lower losses from drifting and hurling to the side.
- Clearing ice with salt solutions requires higher application densities (g/m^2) and should be used only if necessary in the temperature range down to –10 °C (prevention, frost, thin ice). Due to the dilution of the salt solution, it should never be used prior to precipitation.

With this knowledge, it is possible to optimize the application density better than in the past, making winter maintenance more economical and ecological. Appropriate recommendations have been included in the standards for procurement of de-icing agents.

References

Badelt, H.; Moritz, K.; Herpertz, St.; Häusler, G. — Entwicklung eines vereinfachten Verfahrens zur Ermittlung der Wirksamkeit von Tausalzen, Abschlußbericht zum BASt-Projekt 87612, Bergisch Gladbach/Inzell 03/99.

Badelt, H.; Pohle, G.; Wendl, A.; Häusler, G. — Entwicklung einer relativen Beurteilungsgröße der Tauleistung und die Bestimmung der Wiederholbarkeit für Inzeller Tauleistungsmeßwerte, Abschlußbericht zum BASt-Projekt 94651, Inzell 02/98.

Chappelow, C.; et al. — Handbook of Test Methods for Evaluating Chemical Deicers. Strategic Highway Research Programm, Washington DC, 1992 (SHRP-H-332).

Öberg, G.; Gustafson, K.; Axelson, L. — More effective de-icing with less salt. Swedish Road and Traffic Research Institute, Linköping 1991 (VTI-Rapport 369 SA).

Pohle, G., Breitenstein, J. — Entwicklung eines Standardverfahrens zur Ermittlung der Wirksamkeit von Taustoffen, Abschlußbericht zum BASt-Projekt 87614, Inzell, 1/1993.