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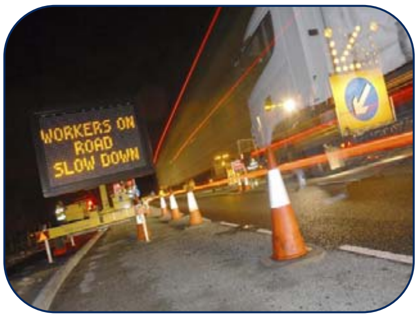

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Extreme Cold Solutions

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Contents

Executive Summary

Background

TRL has developed guidance for Transport Scotland and the NWSRG for the use of alternative treatment materials for spreading at extreme cold temperatures when the use of salt is unlikely to be practically effective. Development of the NWSRG guidance was informed by a literature study, a review of practices elsewhere and experience drawn from a working group comprising TRL and the NWSRG members and NWSRG's industry associates. This guidance formed a chapter, "Treatments for Extreme Cold", in the NWSRG "Practical Guide for Winter Service". For the purposes of winter service in the UK extreme cold is considered by the NWSRG as about -5°C to -7°C (the lower of air or road surface temperature at the time of spreading), depending on humidity.

The information contained in the final draft version of the NWSRG guidance was issued to the Highways Agency's Service Providers in early November 2011 in the form of draft Area Management Memo (AMM) 140/11. Issuing the draft AMM before the high risk period for such extreme cold conditions was important to give Service Providers opportunity to procure the alternative materials should they wish. However, early delivery of the AMM meant that a number of assumptions had to me made to determine appropriate spread rates.

It is expected that the alternative treatments will perform and provide for a more effective treatment in extreme cold conditions. However, the Highways Agency wishes to confirm that the assumptions underpinning the spread rate calculations were valid and the derived spread rates are appropriate and efficient.

Further testing was commissioned to test the validity of the assumptions underpinning the NWSRG guidance on the use of alternative materials in extreme cold and to monitor trials of the alternative materials, to confirm that the alternative treatments, when used in the ways recommended, will provide effective treatments.

The main objectives of the task were to:

- Validate (or otherwise) the assumptions made in the NWSRG guidance on the use of alternative materials in extreme cold
- Use the results of the testing, as required, to inform the development of revised treatment matrices within NWSRG's guidance
- Undertake research to show the extent to which skid resistance is affected by the alternative treatment materials when used, as recommended, in conjunction with rock salt
- Assist the Agency in monitoring the trial of alternative materials on the Agency's network

Validating assumptions underpinning NWSRG's extreme cold guidance

Tests were carried out on the alternative treatment materials included in the NWSRG extreme cold guidance, when used in conjunction with rock salt as part of a pre-wetted delivery method, for:

- Ice melting – to confirm that the alternative materials improve the ice melting ability of rock salt
- Rate of dissolution – to confirm that the alternative materials help the rock salt enter solution more quickly
- Freezing point suppression – to confirm that the alternative treatments suppress the freezing point of water to the degree required

Ice melting

The ice melting test method was based on the SHRP H-205.1 test method for ice melting of liquid de-icing chemicals. The results for salt pre-wetted with the alternative liquids showed an increase in ice melting in comparison to sodium chloride brine. Overall, the results from the ice melting tests show that, after 1 hour at -7°C, there was an increase of between 17% and 47% in the ice melting and, after 1 hour at -12°C, an increase between 13% and 41%. The results indicated that the ice melting is increased more by the use of calcium or magnesium chloride, where these chemicals comprise at least 5% by weight of the liquid de-icers.

In calculating the spread rates in the original guidance, it was assumed that all of the de-icer will dissolve over time in normal conditions and no allowance was made for any delays in the ice melting. Hence the increase in ice melting capacity of the salt pre-wetted with the alternative de-icers as compared to sodium chloride brine was taken as the ratios of the theoretical maximum ice melting calculated from the Eutectic curves. For practical purposes, there will not be unlimited time after spreading and the rate at which the ice can be melted is important. This rate of melting was assessed in the ice melting tests.

At -7°C, the salt pre-wetted with the alternative de-icers showed greater ice melting than assumed for both one and two hours after spreading, where up to 32% and 16% more ice melting than assumed was measured respectively. At -12°C, the result indicated the assumptions were correct.

While all the alternatives de-icers showed a benefit, there were differences measured between the different de-icers. The results indicate that the ice melting is increased more by the use of calcium or magnesium chloride, where these chemicals comprise at least 5% by weight of the liquid de-icers.

Rate of dissolution

A laboratory testing method was developed, to measure the rate of dissolution of salt pre-wetted with the alternative liquid de-icers. Samples of salt pre-wetted with liquid de-icers were spread evenly over metal trays and placed in an environmental chamber for set periods of time. The amount of salt dissolved was then measured, by vacuuming the salt from the tray through a 150 µm filter placed over the vacuum inlet to collect the undissolved salt. The collected salt was then dried, weighed and compared with the amount spread to calculate the dissolution.

The testing has shown that the salt pre-wetted with the alternative de-icers has greater dissolution relative to sodium chloride brine. On average, for all the alternative de-icers, the increase in dissolution at -7°C was 19% after 2 hours and 20% after 4 hours. At -12°C the increase was, on average, 18%.

There were also differences measured between the different de-icers. Greater increases in dissolution were measured for those alternative de-icers containing magnesium or calcium chloride, this may be as a result of the hygroscopic nature of these chemicals, however this was not tested. There was no significant increase measured for the sodium chloride brine with ABP, within the limits of precision in the testing.

In developing the original guidance, multiplying factors were applied to the spread rates to allow for the incomplete dissolution of the salt in the time required after spreading. Although the relative dissolution is greater than assumed for salt pre-wetted with the alternative de-icers compared to sodium chloride brine, the measurements of dissolution in the laboratory tests, with no additional water added or trafficking, are less than the total amount assumed for all de-icer types. In practice, on the road network, the action of traffic will crush and mix the salt and liquid de-icers which would be expected to increase the dissolution. It must also be considered that salt spreading is only required when roads are damp or wet, and this additional water on the road surface will also increase the dissolution. Further testing was carried out to demonstrate the effects of trafficking and additional water which resulted in significantly increased levels of dissolution, to greater than the amounts assumed in the guidance. There was also indication from testing that the use of calcium and magnesium chloride brine increased the dissolution relative to sodium chloride brine when tested under conditions more representative of those encountered on the network.

Overall, it is considered that the results have demonstrated that the assumptions are valid when there is sufficient traffic to aid dissolution of the salt. (Lack of traffic to aid dissolution is also recognised in guidance for salt spreading without alternative de-icers)

Freezing Point Suppression

Testing was carried out to determine the freezing point temperature of various de-icer solutions, by analysing the shape of the cooling curve using a method derived from that specified in ASTM D1177.

Solutions were made by diluting the liquid de-icers with deionised water. Further de-icer solutions were made up using dried rock salt and liquid de-icers mixed with de-ionised water. The de-icer consisted of dried rock salt and liquid de-icer in the ratio 70:30 by weight respectively. The concentrations were selected to produce solutions with freezing points covering the range of temperatures in the guidance i.e. -7°C to -12°C.

The measured freezing points of the de-icer solutions were in good agreement (less than 1°C difference) with the theoretical values used in developing the guidance spread rates.

The freezing points of the diluted liquids showed greater variation from the assumptions, however the effect of this variation is limited when used for pre-wetting salt, where the liquid makes up 30% of the de-icer, as demonstrated by the results of the de-icer solution freezing point tests. The greatest discrepancy was measured for the calcium and magnesium chloride brine, which showed lower freezing point than assumed, and the ABP liquid, which showed a higher freezing point.

Further tests were carried out using Differential Scanning Calorimetry (DSC), a thermal analytical technique used to study phase transitions, energy changes and kinetics. Evidence from the literature suggested that DSC can give a better indication of the effective temperature of a de-icer than using the eutectic temperature and provide a more reproducible value for ice melting capacity than the conventional SHRP methodology.

The Chemistry Department at the University of Sheffield was sub-contracted to carry out DSC analysis of the de-icers being studied. Initial experimentation was required to identify the most appropriate sample size, rate of heating and cooling and de-icer concentration for testing. All of these factors affect the reproducibility of the test and the accuracy with which the effective temperature and heat flows could be measured.

Overall, it was concluded that DSC can be used as an analytical tool for de-icers, but there are some difficulties surrounding the analysis. The scan rate and sample size used greatly affect the result and it can be difficult to identify and resolve the different peaks. The results obtained appear to support the freezing point depression results measured using the method based on ASTM D1177.

The use of DSC to measure ice melting capacity was less successful. The heat flow values for the brines with ABPs did not appear to correspond to the ice melting results obtained in the laboratory tests, as they showed larger heat flows than sodium chloride in the DSC analysis, but more volume of ice melted in the ice melting tests. The lack of correlation may be due to difficulties resolving the DSC peaks and warrants investigation beyond that which was possible during this project.

Effects of alternative treatment materials on skid resistance

Surfaces that have an applied de-icer solution have the potential to have less skid resistance than an untreated surface. Some alternative de-icers can be classified as hygroscopic so untreated surfaces may also dry more quickly than those surfaces that have been treated. Understanding and quantifying any effects on the skid resistance of typical road surfacings after application of certain de-icers is important in assessing the appropriateness of using these de-icers on the road network.

Tests were carried out in the laboratory using a portable Skid-Resistance tester to show the extent to which skid resistance is affected on typical road surfacings after spreading the alternative liquid de-icers. The Skid Resistance Values (SRVs) were measured for cores of 6mm and 14mm stone mastic asphalt (SMA) (i.e. a thin surface course system) taken from trafficked surfacings on the Agency's network after application of the different liquid de-icers.

If the alternative liquids have an adverse effect on the skid resistance of the test surfaces, the greatest effect will occur after application of the undiluted liquids (as supplied), when the concentration of the de-icers will be greatest. The results obtained for application of the undiluted liquids showed that all de-icer solutions tested have a SRV less than the wet skid resistance value with just water. Application of sodium chloride brine or brine with ABP did not show a significant reduction from the untreated wet skid resistance. Application of calcium chloride brine, magnesium chloride brine and ABP liquid resulted in greater reductions of up to 31% from the untreated wet skid resistance.

While there is clearly a significant reduction for the calcium chloride brine, magnesium chloride brine and ABP liquid, the concentrations of the liquids when tested undiluted are significantly higher than would be present on the road surface in practice. For precautionary treatments in conjunction with rock salt, and based on the expected amount of water present and typical losses after spreading, the concentration of the resulting solution of de-icer (salt and liquid de-icer) will be approximately 25%. Tests of 25% solutions resulted in skid resistance values for all the de-icers within 10% of the level measured with water.

If applying ABP liquid for treating ice and snow, the de-icer will be significantly diluted by the melt water. Test of 1:1 diluted liquids represented a concentration higher than can be expected under reasonable spreading scenarios and the skid resistance was again measured to be within 10% of the level measured with water.

When drawing conclusions form the laboratory tests, it must be noted that the Pendulum Tester results do not relate directly to the actual coefficient of friction experienced by a particular tyre in a particular situation, i.e. the actual coefficient of frictions at traffic speeds. It is also not possible to directly extrapolate the results to cover other types of surfacing than those tested, or the behaviour of the test surfaces on site. While the test results cannot be considered conclusive, they enable an initial check to be made of any significant differences in the skid resistance occurring from the use of the alternative de-icers compared with standard de-icing practices.

The alternative de-icers are only intended to be used when spreading is required and temperatures have already fallen below -7°C (or -5°C in low humidity conditions). If spreading is carried out above this temperature standard treatments should be used. The de-icers are therefore most likely to be used for isolated treatments rather than successive treatments over several days.

Overall, the results have given some indication that the amount of the alternative de-icers present on the road surface may not produce a significant drop (i.e. greater than 5 to 10%) in the skid resistance compared to a wet road. However, this could only be proven by appropriate tests at traffic speed.

In sustained Extreme Cold conditions, where successive treatments are made with the alternative de-icers over more than one day, there is the potential for residual levels of the de-icing chemicals to build up on the road surface and more concentrated solutions to be formed when small amounts of water are present. In these circumstances, it is recommended that Service Providers take appropriate action on routes where skid resistance is close to the minimum permitted level.

In considering possible adverse effects from the alternative de-icers, it must be considered that ice formation on the road surface will result in a far more adverse effect on skid resistance than the effect of the alternative de-icers.

Monitoring of use of alternative de-icers

For the 2011/2012 winter period, Service Providers in Highways Agency Area 4 (South East and Kent) and 14 (North East and Northumberland) procured alternative liquid de-icers, for use in extreme cold conditions on selected routes of their network. Transport Scotland also procured a range of alternative materials during the previous winter for use on their network.

The materials procured for use on the Agency network were:

- Magnesium chloride brine (Area 14)
- Calcium chloride brine (Area 4)

There is limited operational experience of the use of the alternative de-icers in the UK and it was considered important that any use of the materials was carefully monitored, to assess the effectiveness of the treatments and to identify any practical issues related to storage and spreading of the materials.

The Service Provides in both Areas had selected a route prone to low temperatures for trialling the alternative de-icers. Weather station and road sensor information was available for these routes.

Evidence of the effectiveness of the treatments was sought. A reporting form was produced for Service providers, to specify the types of information to be recorded each time treatments were made. Wherever possible this included quantitative data together with qualitative data from observations of performance and sensor data.

Generally milder conditions prevailed during the 2011/12 winter period, resulting in limited opportunities to trial the use of the alternative de-icers in extreme cold conditions. Colder conditions occurred during early February 2012, and a small number of precautionary treatments were carried out using the alternative de-icers in both Areas.

All treatments carried out have been precautionary and the majority of treatments have also been carried out when spreading at temperatures greater than -5°C, with the minimum temperature after spreading around -7°C.

Overall, the service providers did not encounter any issues with the effectiveness of the treatments. Road sensor data and observations from cameras did not indicate any significant effect to the carriageway state when the alternative de-icers were spread on dry roads. i.e. salt going more quickly into solution

At present there is insufficient evidence from trials on the network to draw firm conclusions on any greater effectiveness from treatments with the alternative de-icers. There is some indication, at present anecdotal, that the alternative de-icers resulted in snow melting more quickly, when applied as a precautionary treatment before snowfall, and that the residual effects of the treatments are longer lasting after treatment.

There have been no issues reported with storage or spreading of the de-icers by either Area. The main practical issue reported related to the need to load and unload the spreader each time a treatment with the alternative de-icer is required. One Area noted that a spreader had been dedicated solely to the use of the alternative de-icers, such that it could remain filled with the de-icer and not require emptying after each treatment.

It is recommended that further monitoring of the use of the alternative de-icers is carried out in the next winter season, to provide more comprehensive data on the effectiveness of the treatments in a range of conditions.

Review of current guidance

Precautionary treatments

Overall, the laboratory testing has indicated that spread rates in the current guidance do not need to be revised to prevent ice forming in extreme cold temperatures. While the levels of dissolution measured in the laboratory testing were low without addition of water or simulating trafficking, it was considered that in practice the effects of traffic and additional moisture will increase the dissolution, if spreading at the correct rates, to provide an effective treatment.

The expected residual salt available in damp or wet conditions in extreme cold will provide further assurance that the current spread rates are adequate. There may be scope to reduce the rates, however it is considered that further site trials are needed before this could be implemented.

The use of the alternative de-icers may also offer advantages in terms of lower losses during and after spreading, and these have still been assumed when reviewing the rates. Some feedback from the site testing has indicated that the use of the alternative de-icers may increase the longevity of the treatments, however there has not been an opportunity to carry out significant monitoring of use on the network to confirm these assumptions due to the lack of extreme cold temperatures over the winter 2011/12.

Recommendations have been made for amendments to the current guidance, regarding situations where there are low traffic levels and for taking account of residual salt.

To be more cost effective, the priority should always be to treat before extreme cold conditions occur, using standard treatments. When necessary, the alternative de-icers should be used only when spreading is required in extreme cold temperatures.

The greatest benefit in using alternative de-icers for precautionary treatments would appear to be for spreading on drier road surfaces, conditions which are most similar to the laboratory tests carried out with no additional water or crushing of salt. An important consideration for further site testing could be the benefit from use of the alternative de-icers before heavy hoar frosts in the early morning, and not just for extreme cold temperatures, where it is necessary to spread salt on a dry surface with little traffic. This scenario has been highlighted by Service Providers as particularly problematic.

Treatments on snow and ice

The spread rates given in the current guidance have been calculated based on the assumption that $20g/m^2$ of dry salt is suitable for treating a thin layer of ice (not exceeding 1mm) when the lower of the air or road surface temperature is not less than -5°C. The spread rates were calculated by comparison of the theoretical ice melting at extreme cold temperatures with the theoretical ice melting with rock salt at -5°C. The measured increase in ice melting for alternative de-icers after both 1 and 2 hours is greater than assumed in calculating the spread rates in the guidance. This improved ice melting would allow de-icers to penetrate ice layers more quickly or allow slightly thicker layers of ice to be penetrated, per gram of de-icer.

Based on this increased ice melting, there is some scope to reduce the spread rates for the alternative de-icers relative to sodium chloride. However, it should be reiterated that the basis for the current spread rates for treating ice is that spreading $20g/m^2$ of dry salt is effective for treatments at -5°C. The absolute amount of de-icer needed is dependent on the thickness of the ice layer for undercutting, if thick ice, or melting of thin ice layers. The rates have been developed to provide the same relative performance in terms of time and number of treatments that may be required. It is therefore considered that monitoring of treatments in site trials is important to verify the effectiveness of the proposed spread rates.

Dependent on further site testing, the results indicate that for equivalent performance the spread rates for the alternative de-icers, and also rock salt pre-wetted with sodium chloride brine, could be reduced by at least 20% for treatments carried out between -5°C and -10°C. For treatments carried out between -10°C and -12°C, to provide an effective treatment in the same time scale, the results would indicate the spread rates for use of dry salt should be increased by about 20%, while the rates for use of alternative de-icers and sodium chloride brine remain unchanged.

The ice melting tests carried out with liquid only have demonstrated the risks of spreading liquids on sheet ice. The liquids were observed to spread out evenly over the surface, even when viscous liquids were applied in lines. This spreading out could result in a more slippery surface forming. The amount of ice melted per gram of de-icer was also measured to be significantly less than for dry or pre-wetted rock salt. The laboratory testing was on compacted sheet ice and therefore represents an extreme case compared to conditions on the network. If applying liquids on sheet ice consideration should be given to closing the roads to allow the de-icer to melt the ice sufficiently. The use of liquids in lines could offer benefits on less compacted surfaces e.g. snow layers where the liquid could penetrate more easily before spreading out. These could potentially be more effective than the use of pre-wetted rock salt, where the salt grains may be encapsulated within the snow rather than melting and penetrating the layer. Again, site trials in extreme cold conditions would be recommended to confirm the effectiveness of these treatments.

1 Introduction

TRL has developed guidance for Transport Scotland and the NWSRG (the NWSRG "Practical Guide for Winter Service") for the use of alternative treatment materials for spreading at extreme cold temperatures when the use of salt is unlikely to be practically effective. Development of the NWSRG guidance was informed by a literature study, a review of practices elsewhere and experience drawn from a working group comprising TRL and the NWSRG members, including the Highways Agency, and NWSRG's industry associates. The NWSRG process for formulating each individual section of the NWSRG Practical Guide for Winter Service is to set up a working group of experienced members, industry associates and the research contractor (TRL). For this chapter the working group was chaired by the Highways Agency representative. This guidance formed the chapter, "Treatments for Extreme Cold". For the purposes of winter service in the UK extreme cold is considered by the NWSRG as about -5°C to -7°C, (the lower of air or road surface temperature at the time of spreading), depending on humidity.

The information contained in the final draft version of the NWSRG guidance was issued to the Highways Agency's Service Providers in early November 2011 in the form of draft Area Management Memo (AMM) 140/11. Issuing the draft AMM before the high risk period for such extreme cold conditions was important to give Service Providers opportunity to procure the alternative materials should they wish. However, early delivery of the AMM meant that a number of assumptions had to me made to determine appropriate spread rates.

It is expected that the alternative treatments will perform and provide for a more effective treatment in extreme cold conditions. However, the Highways Agency wishes to confirm that the assumptions underpinning the spread rate calculations were valid and the derived spread rates are appropriate and efficient.

Further testing was commissioned to test the validity of the assumptions underpinning the NWSRG guidance on the use of alternative materials in extreme cold, to confirm that the alternative treatments, when used in the ways recommended, will provide effective treatments.

Surfaces that have an applied de-icer solution have the potential to have less skid resistance than an untreated surface. Laboratory testing was carried out on the skid resistance of road cores, taken from representative surfacing, after application of the alternative de-icers.

For the 2011/2012 winter period, Service Providers in Highways Agency Area 4 (South East and Kent) and 14 (North East and Northumberland) procured alternative liquid de-icers, for use in extreme cold conditions on selected routes of their network. Transport Scotland also procured a range of alternative materials during the previous winter for use on their network.

The materials procured for use on the Agency network were:

- Magnesium chloride brine (Area 14)
- Calcium chloride brine (Area 4)

There is limited operational experience of the use of the alternative de-icers in the UK and it was considered important that any use of the materials was carefully monitored, to assess the effectiveness of the treatments and to identify any practical issues related to storage and spreading of the materials.

In summary, the main objectives of the task were to:

- Validate (or otherwise) the assumptions made in the NWSRG guidance on the use of alternative materials in extreme cold
- Use the results of the testing, as required, to inform the development of revised treatment matrices within NWSRG's guidance.
- Undertake research to show the extent to which skid resistance is affected by the alternative treatment materials when used, as recommended, in conjunction with rock salt.
- Assist the Agency in monitoring the trial of alternative materials on the Agency's network

2 Validating assumptions underpinning extreme cold guidance

2.1 Assumptions made in deriving the spread rates

2.1.1 Precautionary treatments before frost

When deriving the precautionary spread rates in the guidance, a number of parameters were used as listed in Table 1.

In order to calculate spread rates for precautionary treatments, it was assumed that sufficient de-icer should be spread such that the freezing point temperature (from the phase diagram) of the solution formed with the water present on the road surface is lower than the forecast road surface temperature.

It was also assumed that not all the salt spread will enter solution in the time available after spreading in which the treatment must become effective, hence the spread rates were increased by a multiplying factor for each temperature band.

The benefits from pre-wetting the salt using the alternative de-icers to sodium chloride brine were assumed to be:

- Increased dissolution of the dry salt component of the pre-wetted salt i.e. a higher proportion of salt in solution due to the effect of the more hygroscopic de-icers (e.g. magnesium and calcium chloride) attracting moisture and facilitating the dissolution of salt.
- Less loss of salt due to trafficking than if sodium chloride brine is used, because the alternatives help the dry salt to enter solution more quickly and the rate of loss is lower for liquid than a solid de-icer.
- A small reduction in the freezing point of the solution formed on the road surface (As none of the pre-wetting solutions proposed contain much alternative de-icer their effect on the freezing point suppression is small compared to the dry salt component)

The parameters and the appropriate values which were assessed in this testing are shown in Table 2.

Table 1. Parameters used to determine precautionary spread rates

Parameter
Sodium chloride concentration of dry salt component allowing for impurities and moisture content (%)
Minimum lane coverage as percentage of target spread rate (%)
Brine percentage loss after spreading due to heavy trafficking (%)
Dry salt percentage loss after spreading due to heavy trafficking (%)
Brine percentage loss after spreading due to light trafficking (%)
Dry salt percentage loss after spreading due to light trafficking (%)
Water film thickness for a dry or damp road that is well trafficked
Water film thickness for a damp road with little traffic or a well trafficked road at least one hour after rainfall
Water film thickness for a wet road with little traffic
Freezing point temperature (FPT) of liquid component (%)
Increase in spread rates for road surface temperatures at or below -5˚C and above -7˚C to allow for slow rate of dissolution of solid component (%)
Increase in spread rates for road surface temperatures at or below -7˚C and above -10˚C to allow for slow rate of dissolution of solid component (%)
Increase in spread rates for road surface temperatures at or below -10˚C and above -12˚C to allow for slow rate of dissolution of solid component (%)
Increase in spread rates for road surface temperatures at or from -12˚C (%)

Table 2. Parameter values assessed in the testing

Parameter	Liquid component					
	Sodium chloride brine	**Magnesium chloride brine**	**Calcium chloride brine**	**Brine with ABP – Sodium Chloride brine with ABP**	**Brine with ABP – Sodium Chloride and calcium chloride brine with ABP**	**Brine with ABP – Sodium Chloride brine with ABP liquid**
Freezing point temperature (FPT) of liquid component	According to sodium chloride phase diagram	According to magnesium chloride phase diagram	According to calcium chloride phase diagram	30% lower than FPT from sodium chloride phase diagram	30% lower than FPT from sodium chloride phase diagram for sodium chloride brine and ABP According to calcium chloride phase diagram	40% lower than FPT from sodium chloride phase diagram
Increase in spread rates for road surface temperatures at or below -5˚C and above -7˚C to allow for slow rate of dissolution of solid component (%)	10	10	10	10	10	10
Increase in spread rates for road surface temperatures at or below -7˚C and above -10˚C to allow for slow rate of dissolution of solid component (%)	30	20	20	20	20	20
Increase in spread rates for road surface temperatures at or below -10˚C and above -12˚C to allow for slow rate of dissolution of solid component (%)	50	30	30	30	30	30
Increase in spread rates for road surface temperatures below -12˚C (%)	70	40	40	40	40	40

2.1.2 Treatments before snow and freezing rain

While it is beneficial if solid de-icers enter solution before snow or freezing rain, this is less critical than for precautionary treatments before frost because solid de-icer will dissolve due to the presence of the snow or ice in much the same way as in an ice melting test. It is, however, important that the de-icer is spread before the snow or freezing rain starts to fall to avoid bonding to the road surface)

The spread rates given in the guidance have been calculated based on the principal that the alternative de-icers will help the sodium chloride to dissolve. They are based on the accepted condition that 20g/m^2 of dry salt or 20g/m^2 of 70:30 pre-wetted salt is suitable for treatments before snow and freezing rain when the road surface temperature is not less than -5˚C.

As the snow or freezing rain dissolves the solid particles, they will act to prevent bonding of ice to the carriageway. Therefore, it is inappropriate to increase pre-wetted salting spread rates to allow for undissolved de-icer as was the case for precautionary treatments before frost conditions. The loss of salt after spreading will be lessened if the alternative de-icers facilitate dissolution, and this has been allowed for in calculating spread rates which are based on the principles given above. However, spread rates are also given for dry salting and for these treatments a small allowance has been made for the slower rate of dissolution of dry salt. The spread rates assuming full dissolution have been increased by a factor of 1.1 for road surface temperatures from -5 to -7˚C and -7 to -12˚C and by a factor of 1.2 for road surface temperatures less than -12˚C, irrespective of humidity.

2.1.3 Treatments on snow and ice

The spread rates given in the guidance have been calculated based on the accepted condition that 20g/m^2 of dry salt is suitable for treating a thin layer of ice (not exceeding 1mm) when the lower of the air or road surface temperature is not less than -5˚C before the solid component has fully entered solution. This assumption was based on the current HA and NWSRG treatment matrix guide, which specifies the use of 20g/m^2 dry salt for treating ice at temperatures above -5°C.

It has further been assumed that all of the de-icer will dissolve over time in normal conditions and no allowance has been made for any delays in the ice melting.

In calculating the spread rates, the theoretical amount of solution formed from melted ice and de-icer, after applying the de-icers to ice and allowing an unlimited melting time, was calculated from the phase diagrams of the de-icers. At each temperature, based on the theoretical ice melting capacity, the spread rate required to produce the same ice melting as 20g/m^2 of dry salt at -5°C was calculated.

2.2 Types of de-icer tested

2.2.1 *Liquid de-icers*

Testing was carried out of all the alternative de-icer types included in the guidance:

- Magnesium chloride brine
- Calcium chloride brine
- Sodium chloride brine with ABP
- Sodium chloride and calcium chloride brine with ABP
- ABP Liquid
- Sodium chloride brine, for comparative purposes

Samples of the above de-icers and all relevant product data sheets were obtained from the Highways Agency Service Providers and Transport Scotland, where the various de-icers have already been supplied, in order to test the liquid de-icers in the condition "as delivered". Details of the de-icers tested are shown in Table 3.

Table 3 Liquid de-icers obtained from Service Providers and Transport Scotland

De-icer type	Where obtained	Composition (supplier)
Magnesium chloride brine	Area 14 (Balfour Beatty Mott MacDonald)	32% magnesium chloride solution (RS Minerals Ltd)
Calcium chloride brine	Area 4 (Balfour Beatty Mott MacDonald)	28% calcium chloride solution (OMEX Agriculture Ltd)
Brine with ABP – Sodium chloride with ABP	Transport Scotland (Bear Scotland)	A blend of sodium chloride brine (23% concentration) and ABP in the ratio 90:10 by weight respectively
Brine with ABP – Sodium chloride and calcium chloride with ABP	Transport Scotland (Bear Scotland)	A blend of sodium chloride brine (23% concentration), ABP and calcium chloride brine in the ratio 85:10:5 by weight respectively
ABP Liquid	Transport Scotland (Bear Scotland)	A blend of magnesium chloride brine and molasses
Sodium chloride brine	-	20% sodium chloride solution

Measurements were made of the density of the liquids as supplied and are shown in Table 4, compared with the density quoted on the datasheets (when given).

Table 4 Density of liquids

De-icer type	Density (kg/m^3) (measured)	Density (kg/m^3) (from data sheet)
Magnesium chloride brine	1.30	1.29-1.33
Calcium chloride brine	1.33	1.3
Sodium chloride brine with ABP	1.18	N/A
Sodium chloride and calcium chloride brine with ABP	1.17	N/A
ABP Liquid	1.26	N/A
Sodium chloride brine	1.08	N/A

Samples of the liquid de-icers were sent for chemical analysis and the results are summarised in Table 5, all measurements are in mg/l.

Table 5. Results of the chemical analysis

	Constituent(mg/l)			
	Magnesium	Calcium	Sodium	Chloride
Magnesium chloride brine	128,000	78	3,049	314,000
Calcium chloride brine	14	191,500	4960	298,000
Sodium chloride brine with ABP	203	756.5	95,650	151,500
Sodium chloride and calcium chloride brine with ABP	2077	5,141	87,600	157,000
ABP Liquid	14,030	398	20,692	53,700
Sodium chloride brine	96	445	83,450	113,500

2.2.2 Dry salt

There are a variety of salt types in use on the HA network. Samples of 6.3mm rock salt (Thawrox 6) and 8mm Egyptian marine salt were obtained from stockpiles at the Area 3 Hook depot in February 2012. The de-icers had been stored in a covered barn.

The moisture content and grading were measured for both salt types. The moisture content of the rock salt was measured to be 1.6% and the moisture content of the marine salt 3.1%. The particle size distributions of the salt types after drying, as determined in accordance with BS 1377 (BSI, 1990), are shown in Figure 1 and Figure 2 for rock salt and marine salt respectively. It can be seen that the grading curves were compliant with the specification for fine rock salt given in BS 3247 (BSI, 2011) and are similar to typical gradings measured during previous trials for the Agency on the same salt types.

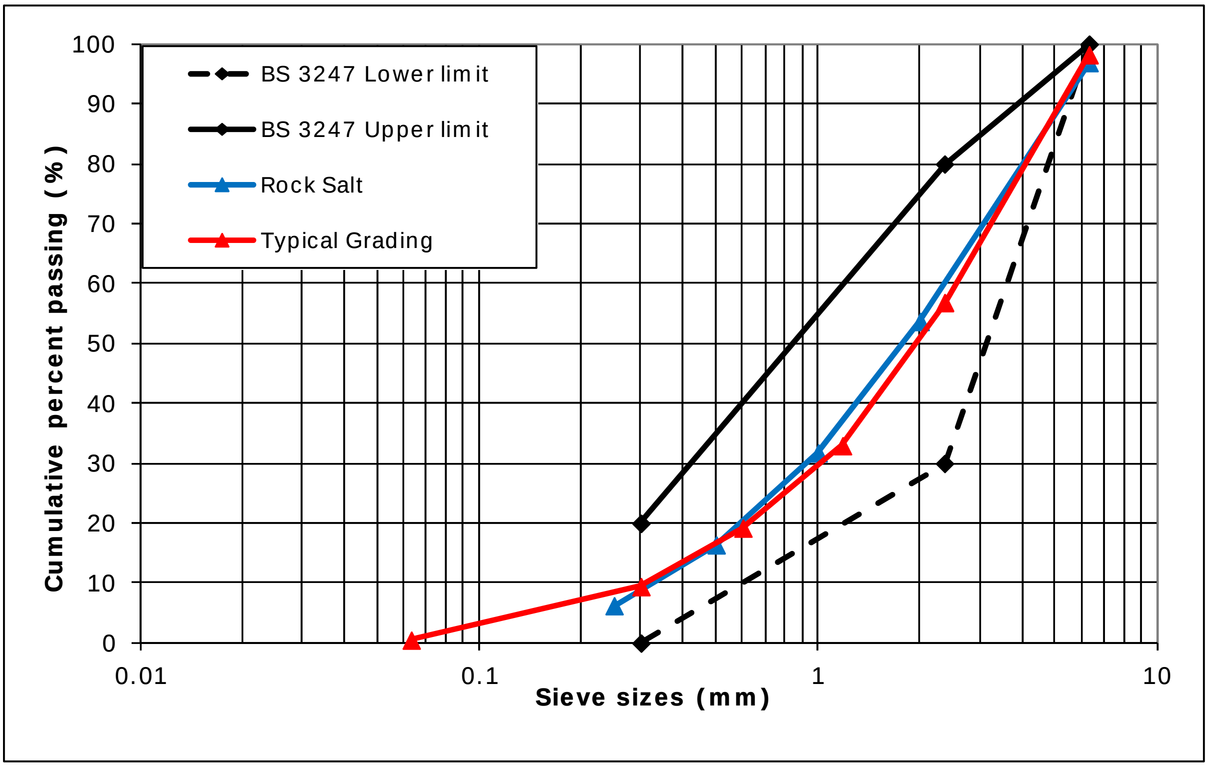

Figure 1. Grading of 6.3mm rock salt grading in accordance with BS 3247

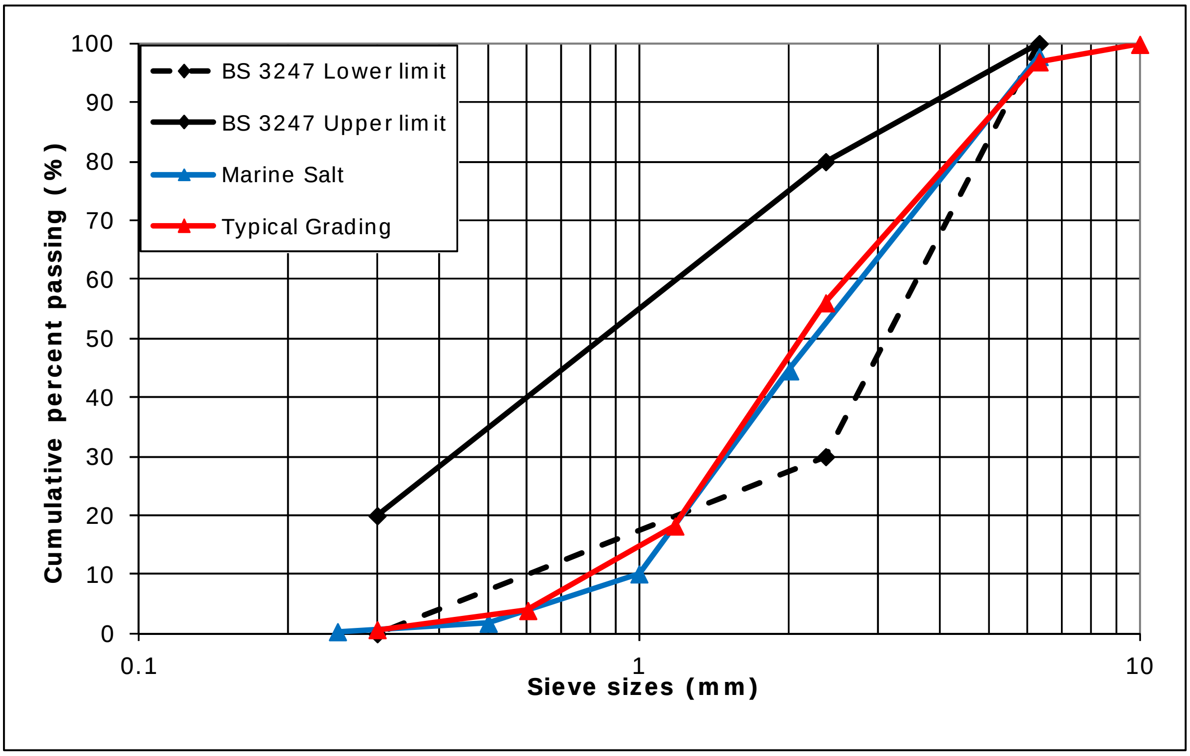

Figure 2. Grading of 8mm marine salt in accordance with BS 3247

2.3 Ice melting

2.3.1 Test methodology

Standard test methods for ice melting of solid and liquid de-icers can be found in the Strategic Highway Research Program (SHRP) publication 'Handbook of Test Methods for Evaluating Chemical De-icers'.

The ice melting test method used in this study was the SHRP H-205.1 test method for ice melting of liquid de-icing chemicals.

The SHRP methodology is to form a flat sheet of ice with a uniform 1/8 inch (3.175 mm) thickness on a circular Perspex dish of 9 inch (228.6 mm) diameter and conditioned to the test temperature. Initially, consideration was given in this testing to the use of larger area ice surfaces, to enable salt to be spread more thinly across the surface. This would allow the testing of spread rates that are more representative of those given in the extreme cold guidance. However, preliminary testing demonstrated that the rate of ice melting per gram of de-icer was not dependent on the amount and distribution of de-icer spread. Consequently it was decided to follow the SHRP methodology and use the 9 inch diameter Perspex dishes for producing the ice samples (see Figure 3).

Salt pre-wetted with liquid de-icers was spread as evenly as possible across the ice and left in the chamber for one or two hours depending on the type of test. The spread rate in the dish was $145 g/m^2$. The resulting brine was then drawn off by syringe and the volume was measured.

The test was repeated three times as recommended in the SHRP method, so that a single result consists of the average of three determinations. The result is given as the average volume of brine (after subtracting the volume of liquid de-icer initially spread) per mass of de-icer (ml/g) at each of the time intervals. The test temperatures were -7°C and -12°C.

The testing was carried out in an environmental chamber, which was modified to minimise temperature fluctuations during testing by addition of insulation behind the chamber door, with sections cut out to provide access for testing (see Figure 4 and Figure 5). The fluctuations in temperature during tests were recorded using a data logger. These were proven to be insignificant when opening and closing the chamber door (less than 1°C) at the start of the test and any fluctuation recovered quickly (less than 5 minutes) to the test temperature.

The pre-wetted salt was made up of 4.17g (± 0.005g) of dried salt as specified in the SHRP methodology. 1.787g (± 0.005g) of liquid de-icer was used to produce the correct 70:30 ratio of salt to liquid. Before the testing was carried out, the dried salt was graded. Representative test samples were then made up for each test by recombining the various size fractions in the correct weight proportions, i.e. the size ranges were recombined in the same proportion for each test sample as measured in the grading. The salt was then placed in a modified 20ml syringe. (The needle end of the syringe had been sawn off and a stopper placed in the opening to seal the syringe with the salt in it). The correct weight of liquid was drawn into a 10ml syringe. Both the salt and liquid samples were then conditioned to the test temperature for over an hour before carrying out the test within the chamber.

At the start of each test, the liquid de-icer was added to the dried salt in the 20ml syringe, then the mixture in the 20ml syringe spread evenly over the ice surface in the dish. By discharging using the syringe it was possible to discharge all salt and liquid onto the ice with no residue remaining on the syringe walls.

Air temperature and temperature of the dishes containing the ice were measured and recorded using thermistor probes and a Squirrel data logger, to ensure that any temperature variations were within tolerance.

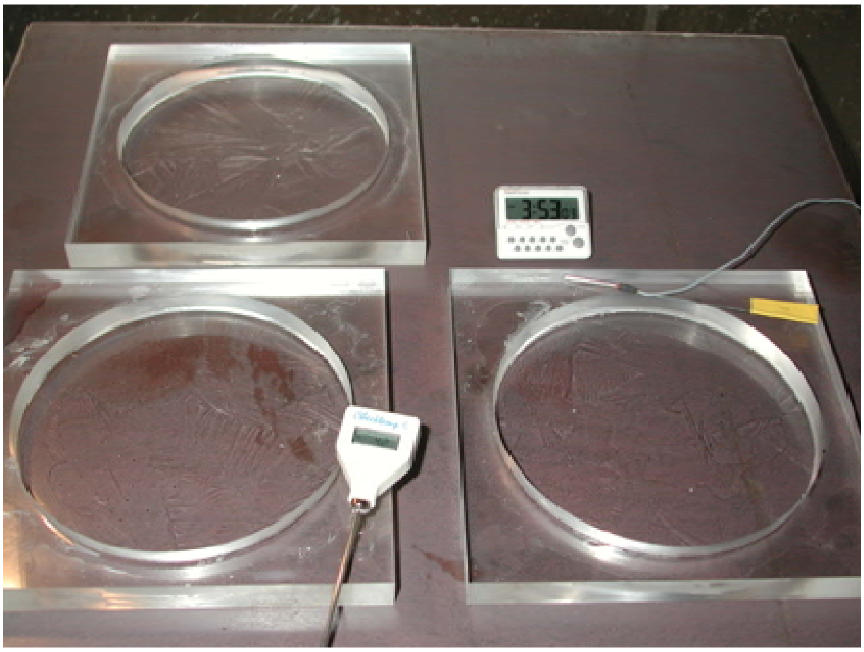

Figure 3. 9 inch diameter ice samples in Perspex dishes

Figure 4. Environmental test chamber

Figure 5. Insulated chamber door

2.3.2 Ice melting test results – Pre-wetted salt

The results obtained at -7°C are shown in Figure 6 and Figure 7 for testing over one and two hours respectively. The results at -12°C are shown in Figure 8 and Figure 9 for testing over one and two hours respectively.

The error bars shown in each figure are the standard errors, calculated based on at least 3 repeat measurements.

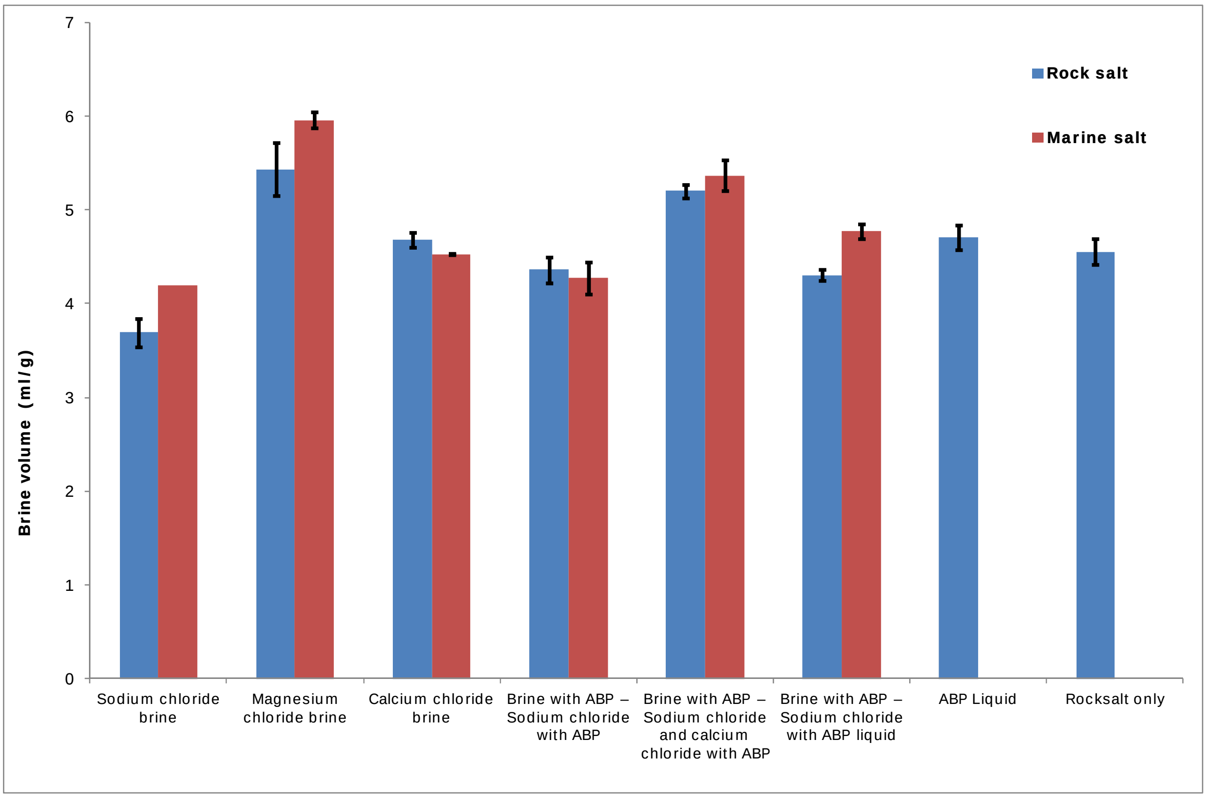

Figure 6. Comparison of the ice melting at -7°C for one hour

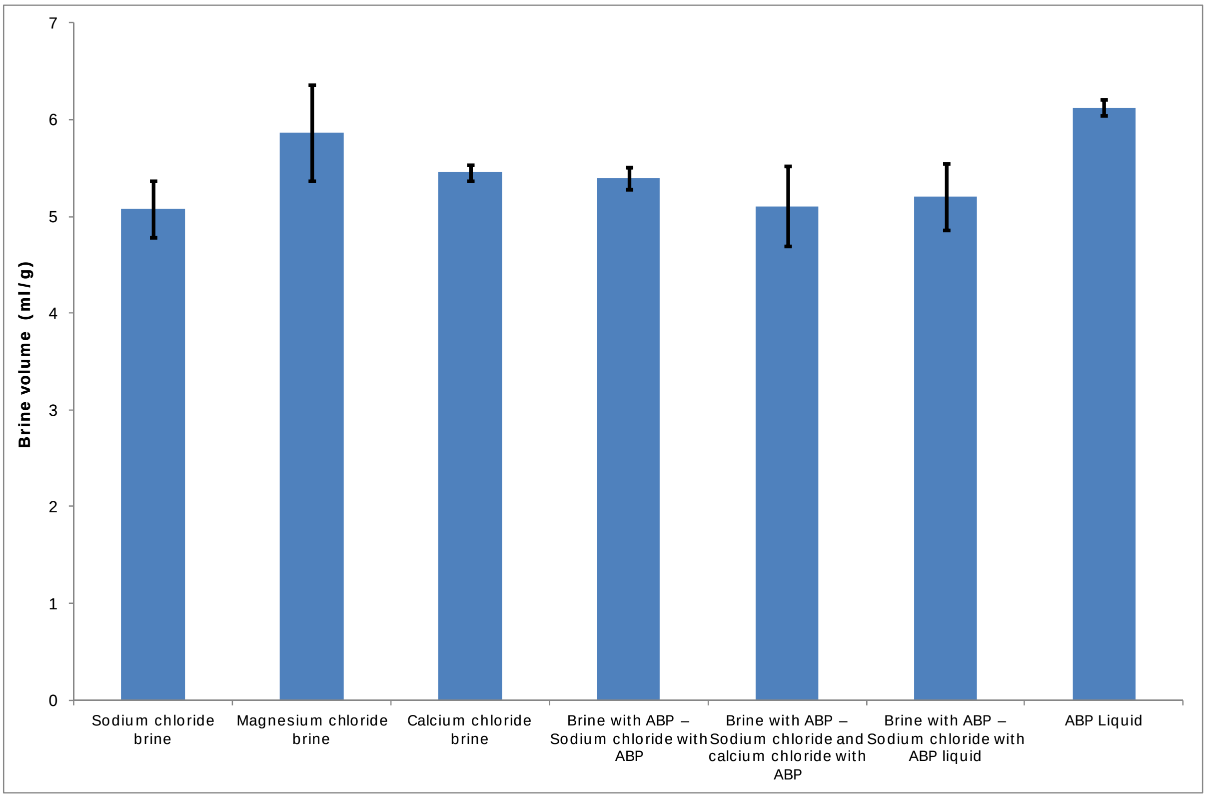

Figure 7. Comparison of the ice melting of pre-wetted rock salt at -7°C for two hours

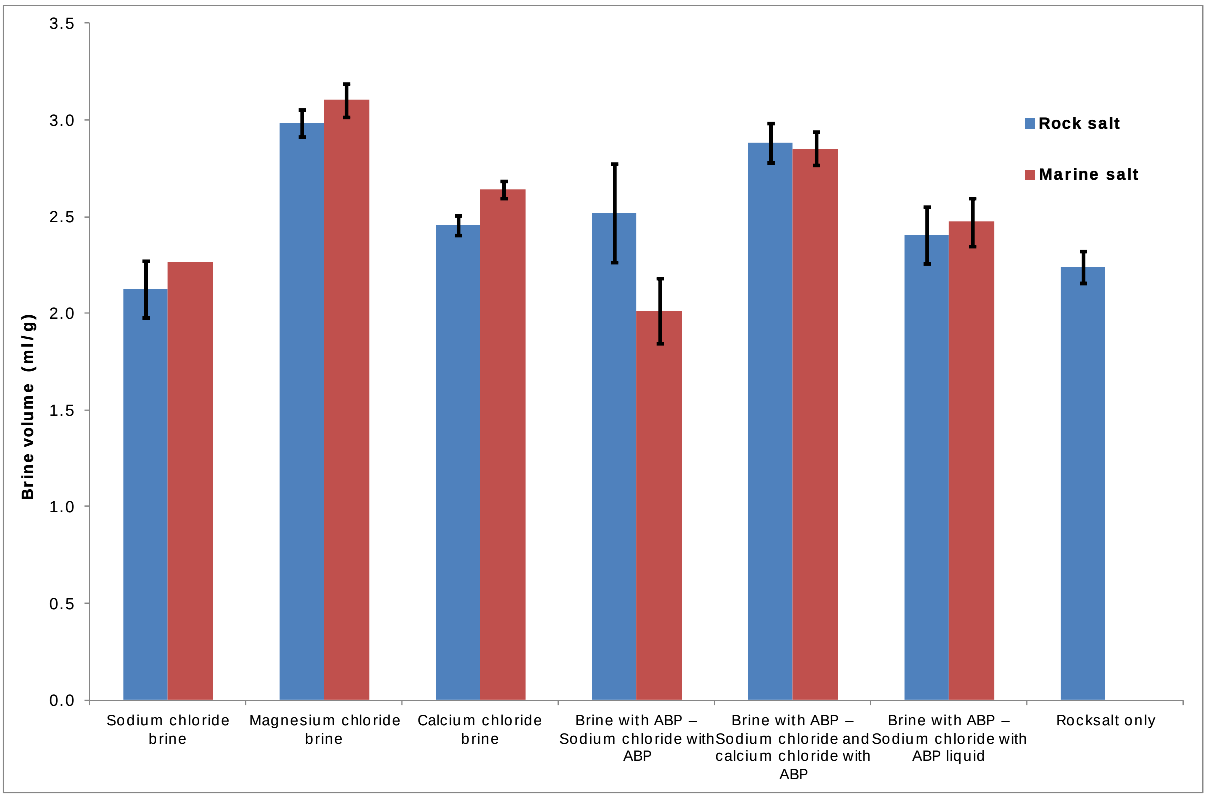

Figure 8. Comparison of the ice melting at -12°C for one hour

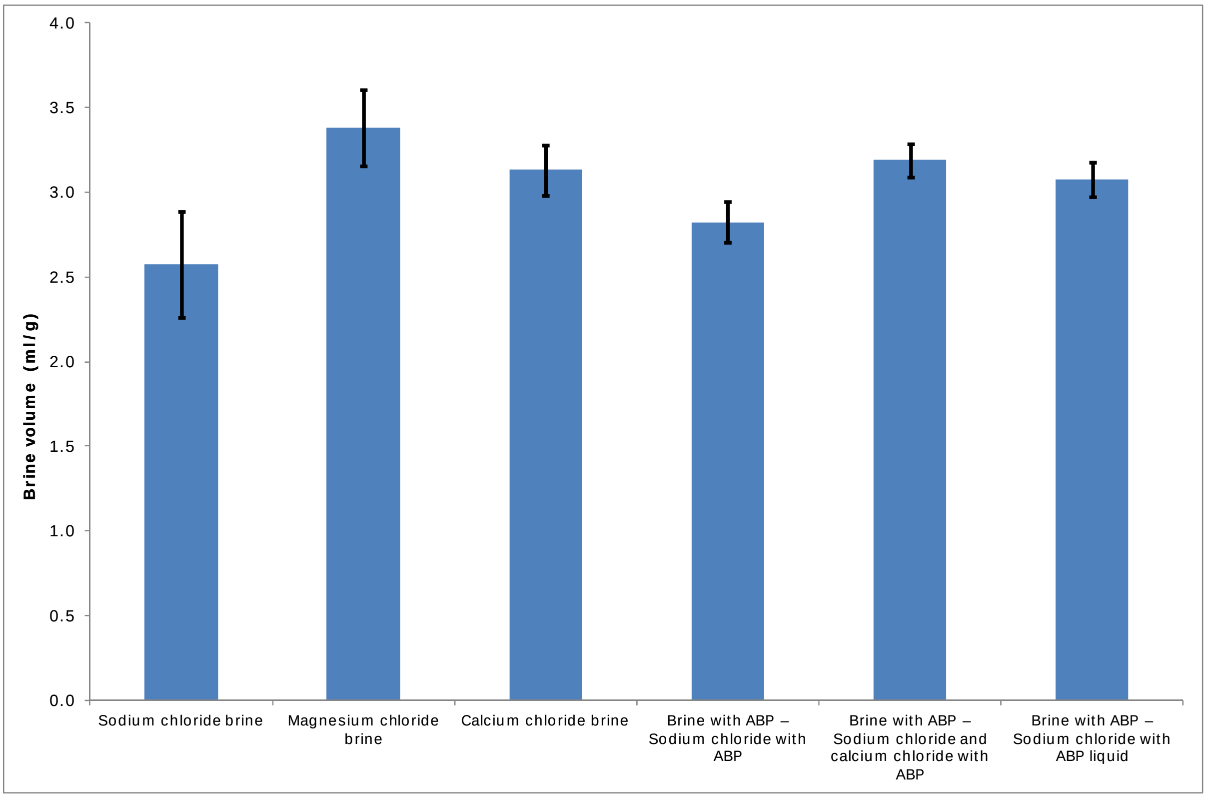

Figure 9. Comparison of the ice melting of pre-wetted rock salt at -12°C for two hours

Table 6. Comparison of the ice melting with pre-wetted rock salt

Liquid component of de-icer	-7°C		-12°C		Ice melted at -12°C as % of -7°C quantity	
	Volume of brine after 1 hour (ml/g)	Volume of brine after 2 hours (ml/g)	Volume of brine after 1 hour (ml/g)	Volume of brine after 2 hours (ml/g)	After 1 hour	After 2 hours
Sodium chloride brine	3.69	5.07	2.12	2.57	57	51
Magnesium chloride brine	5.43	5.86	2.98	3.38	55	58
Calcium chloride brine	4.68	5.45	2.46	3.13	53	57
Brine with ABP – Sodium chloride with ABP	4.36	5.40	2.52	2.82	58	52
Brine with ABP – Sodium chloride and calcium chloride with ABP	5.20	5.11	2.88	3.19	55	62
Brine with ABP – Sodium chloride with ABP liquid	4.30	5.20	2.40	3.08	56	59
ABP liquid	4.71	6.12	-	-	-	-
None (Rock salt only)	4.55	-	2.24	-	49	-

Table 7. Comparison of the ice melting with pre-wetted marine salt

Liquid component of de-icer	-7°C	-12°C	Ice melted by marine salt as % of rock salt quantity	
	Volume of brine after 1 hour (ml/g)	Volume of brine after 1 hour (ml/g)	-7°C	-12°C
Sodium chloride brine	4.19	2.26	114	107
Magnesium chloride brine	5.96	3.10	110	104
Calcium chloride brine	4.53	2.64	97	107
Brine with ABP – Sodium chloride with ABP	4.28	2.01	98	80
Brine with ABP – Sodium chloride and calcium chloride with ABP	5.37	2.85	103	99
Brine with ABP – Sodium chloride with ABP liquid	4.77	2.47	111	103

Table 8 Comparison of ice melting for rock salt pre-wetted with sodium chloride and the alternative liquids (marine salt in brackets)

Liquid component of de-icer	% more ice melted than NaCl wetted salt			
	-7°C at one hour	-7°C at two hours	-12°C at one hour	-12°C at two hours
Magnesium chloride brine	47 (42)	16	41 (37)	32
Calcium chloride brine	27 (8)	7	16 (17)	22
Brine with ABP – Sodium chloride with ABP	18 (2)	7	19 (-11)	10
Brine with ABP – Sodium chloride and calcium chloride with ABP	41 (28)	1	36 (26)	24
Brine with ABP – Sodium chloride with ABP liquid	17 (14)	3	13 (9)	20
ABP liquid	28	21	-	-
None (Rock salt only)	23	-	6	-

The results for all the alternative liquids show an increase in ice melting in comparison to sodium chloride brine. There is variation between the results obtained for the different de-icers. The results from the ice melting tests show that after an hour at -7°C there is an increase of between 17 and 47% in the ice melting and at -12°C an increase between 13 and 41%.

The standard error expected in this type of test was given in the SHRP test methodology as between 2% and 10%. The standard errors in these test results were predominantly less than 5%, within the range expected.

The quantity of ice melted after an hour at -12°C is approximately 50 to 60% of that melted at -7°C. The relative decrease in the amount of ice melted is similar for sodium chloride brine compared to the alternative de-icers.

The marine salt shows an approximately 5% higher melting rate compared to rock salt, which was attributed to the higher purity of the marine salt.

2.3.3 Ice melting results – liquid only application

The main focus of the testing was the ice melting of salt pre-wetted with the alternative de-icers. The NWSRG guidance also includes the use of ABP liquid for treating ice and snow and some further testing was carried out of the ice melting for liquid only application.

The same method was followed as for the pre-wetted salt testing. For each test, the liquid was applied from the syringe directly to the ice surface.

Two tests were carried out – in Test 1, 15g of liquid was applied evenly over the ice surface for each de-icer. In Test 2, 4.17g of each de-icer was spread in discrete lines across the ice surface.

The results obtained at -7°C are shown in Table 9 for testing over one hour.

Table 9. Comparison of the ice melting with liquid contained ABP

	-7°C	-7°C
	Test 1	Test 2
Liquid de-icer	Volume of brine after 1 hour (ml/g)	Volume of brine after 1 hour (ml/g)
Magnesium chloride brine	-	2.75
Brine with ABP – Sodium chloride with ABP	1.27	-
Brine with ABP – Sodium chloride and calcium chloride with ABP	1.37	2.39
ABP liquid	1.27	2.16

Following application of the liquids to the sheet ice, the liquids were observed to spread evenly over the surface, even after application in lines. The ice melting measured per unit weight of de-icer is clearly less than for salt pre-wetted with the liquids.

2.3.4 Review of assumptions

The spread rates given in the current guidance have been calculated based on the assumption that $20g/m^2$ of dry salt is suitable for treating a thin layer of ice (not exceeding 1mm) when the lower of the air or road surface temperature is not less than -5°C. This assumption was based on the current HA treatment matrix guide, which specifies the use of $20g/m^2$ dry salt for treating ice at temperatures above -5°C. The intention is not to fully melt an ice layer (unless it is thin) but to penetrate and undercut.

In deriving the spread rates for treating ice for the extreme cold guidance, the increase in ice melting capacity of the salt pre-wetted with the alternative de-icers as compared to sodium chloride brine was taken as the ratios of the theoretical maximum ice melting. It was assumed that all of the de-icer will dissolve over time in normal conditions and no allowance was made for any delays in the ice melting. The theoretical amount of solution formed from melted ice and de-icer, after applying the de-icers to ice and allowing an unlimited melting time, can be calculated from the phase diagrams of the de-icers for comparison with the amount obtained in the ice melting tests.

The theoretical maximum amounts of solution formed in ice melting are shown in Table 10. The theoretical maxima expressed as a percentage of the theoretical maximum amount of solution formed by dry rock salt at -5°C are shown in Table 11.

Table 10. Theoretical maximum volume of melted ice and de-icer solution (ml/g)

Liquid component	Volume of melted ice and de-icer (ml/g)	
	-7°C	-12°C
Sodium chloride brine	6.52	4.06
Magnesium chloride brine	6.96	4.45
Calcium chloride brine	6.75	4.28
Brine with ABP – Sodium chloride with ABP	6.75	4.28
Brine with ABP – Sodium chloride and calcium chloride with ABP	6.75	4.28
Brine with ABP – Sodium chloride with ABP liquid	6.80	4.31
Rock salt only	8.53	5.41

Table 11. Theoretical maximum volume of melted ice and de-icer solution, as % of maximum at -5°C for dry rock salt

Liquid component	% of maximum at -5°C for dry rock salt	
	-7°C	-12°C
Sodium chloride brine	56	36
Magnesium chloride brine	60	38
Calcium chloride brine	58	37
Brine with ABP – Sodium chloride with ABP	58	37
Brine with ABP – Sodium chloride and calcium chloride with ABP	58	37
Brine with ABP – Sodium chloride with ABP liquid	59	37
Rock salt only	74	47

As shown in Table 11, the theoretical maximum amounts are similar for all the alternative de-icers and sodium chloride brine, as the dominant effect is the amount of salt dissolved. For practical purposes, there will not be unlimited time after spreading and the rate at which the ice can be melted is important. This rate of melting was assessed in the ice melting tests.

Table 12 shows the volume of melted ice and de-icer obtained in the ice melting tests as a percentage of the melted ice by dry rock salt at -5°C, after both 1 and 2 hours. It should be noted that the ice melting test results for 1 hour are compared to the ice melted at -5°C after 1 hour and the ice melting tests for 2 hours are compared to the ice melted at -5°C after 2 hours. Table 13 shows these measured values as a percentage of the theoretical values reported in Table 11.

Table 12. Measured volume of melted ice and de-icer solution, as % of -5°C for dry rock salt

Liquid component	% of maximum at -5°C for dry rock salt			
	-7°C		-12°C	
	1 hour	2 hours	1 hour	2 hours
Sodium chloride brine	54	60	31	31
Magnesium chloride brine	79	70	43	40
Calcium chloride brine	68	65	36	37
Brine with ABP – Sodium chloride with ABP	63	64	37	34
Brine with ABP – Sodium chloride and calcium chloride with ABP	76	61	42	38
Brine with ABP – Sodium chloride with ABP liquid	63	62	35	37
Rock salt only	66		33	

Table 13. Measured values (Table 12) as % of theoretical (Table 11)

Parameter	% of melted ice by dry rock salt at -5°C (%)			
	-7°C for 1 hours	-7°C for 2 hours	-12°C for 1 hour	-12°C for 2 hours
Sodium chloride brine	99	112	86	88
Magnesium chloride brine	132	116	114	106
Calcium chloride brine	117	112	97	101
Brine with ABP – Sodium chloride with ABP	109	111	99	91
Brine with ABP – Sodium chloride and calcium chloride with ABP	131	105	113	103
Brine with ABP – Sodium chloride with ABP liquid	106	105	94	99
Rock salt only	89	-	69	-

Where the values reported in Table 13 are greater than 100%, the amount of ice melted is greater than assumed and when less than 100% the amounts are less than assumed. It is clear that the alternative de-icers have increased the ice melting over 1 and 2 hours compared to the dry rock salt and rock salt pre-wetted with sodium chloride brine i.e. they are faster acting.

While all the alternatives de-icers showed a benefit, there were differences measured between the different de-icers. The results indicate that the ice melting is increased more by the use of calcium or magnesium chloride, where these chemicals comprise at least 5% by weight of the liquid de-icers.

2.4 Rate of dissolution

2.4.1 Test methodology

A laboratory testing method was developed, to measure the rate of dissolution of salt pre-wetted with the alternative de-icers.

Dissolution tests have previously been carried out by TRL on behalf of the NWSRG and the same general methodology was used for this testing.

Samples of salt pre-wetted with liquid de-icers were spread evenly over metal trays and placed in an environmental chamber for set periods of time. The amount of salt dissolved was then measured, by vacuuming the salt from the tray through a 150 µm filter placed over the vacuum inlet to collect the undissolved salt. The collected salt was then dried, weighed and compared with the amount spread to calculate the dissolution.

The method used for the NWSRG tests was further developed for this testing, with the flexible vacuum hose removed to minimise any errors resulting from salt adhering to the sides of the hose. The test apparatus is shown in Figure 10.

Figure 10. Modified vacuum equipment

Preliminary testing was carried out to confirm full salt recovery and to investigate the most appropriate grading of salt for testing. A salt particle size range of 0.5–1mm was selected, as this grading produced sufficient dissolution of the salt for an accurate measurement and was intended to replicate the crushing of larger salt grains due to the effect of trafficking. Pre-wetting a finer grade of the salt presented practical difficulties, as the salt particles adhered together and did not spread so evenly over the test surface.

The same method of preparing and spreading the pre-wetted salt was used as for the ice melting tests, with the dry salt and liquid placed in syringes and conditioned to the appropriate temperature before testing. The pre-wetted salt was made up of 7g (± 0.005g) of dried salt and 3g (± 0.005g) of liquid de-icer. The trays were also cooled to the test temperature before starting the test.

Testing was carried out at -7°C and -12°C at 85% relative humidity, over 2 and 4 hours. It was not considered necessary to test at temperatures above -7°C, where treatments are specified in the extreme cold guidance for humidity less than 80%, as these conditions are considered equivalent to the lower temperatures and higher humidity conditions included in the testing. All testing was carried out at 85% humidity, near to the low humidity boundary of 80%, to provide representative, non-extreme test conditions. Some testing was carried out at 0°C for comparison of the amount of dissolution at typical spreading temperatures, primarily to provide assurance that pre-wetted salt with sodium chloride brine will be fully dissolved at the typical spreading temperatures.

2.4.2 Dissolution test results

Figure 11 and Figure 12 show the percentage of salt dissolved at -7°C, after 2 and 4 hours respectively.

Figure 13 shows the percentage of salt dissolved after 2 hours at -12°C.

The error bars shown in each figure are the standard errors, calculated based on at least 3 repeat measurements.

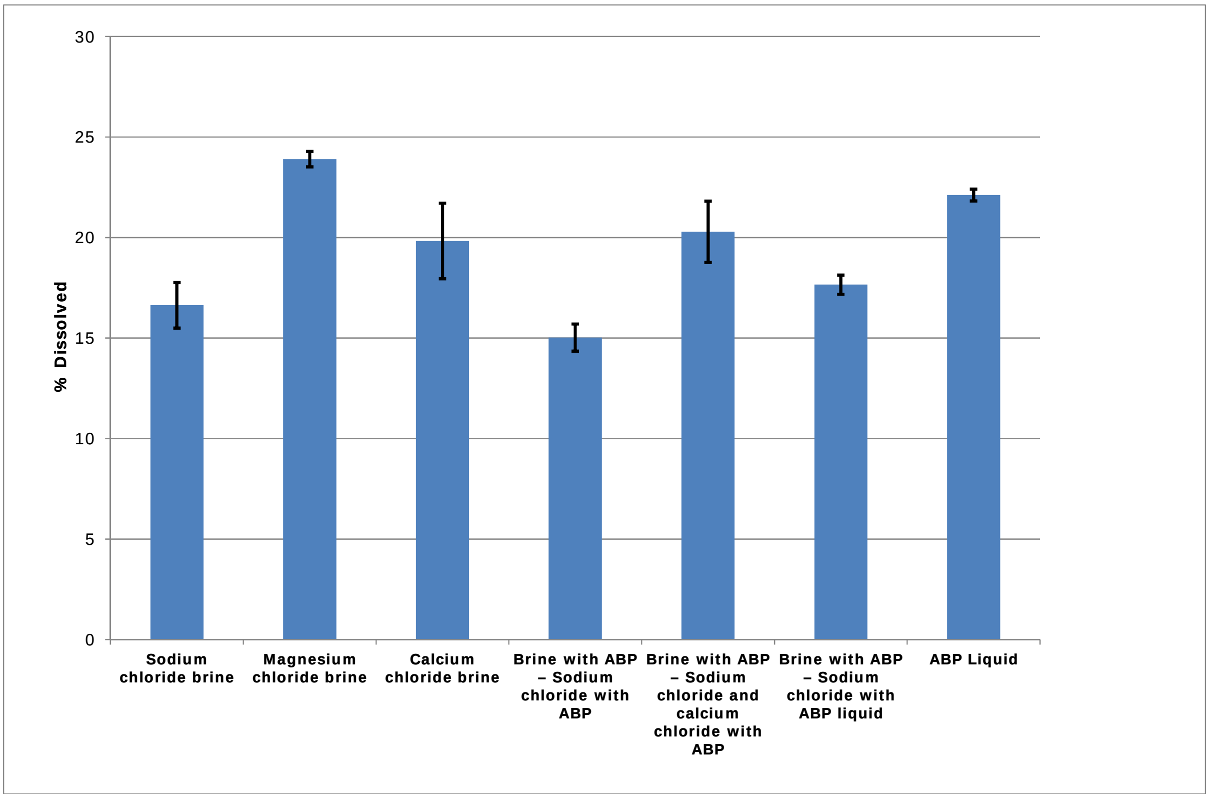

Figure 11. Comparison of salt dissolved at -7°C for 2 hours

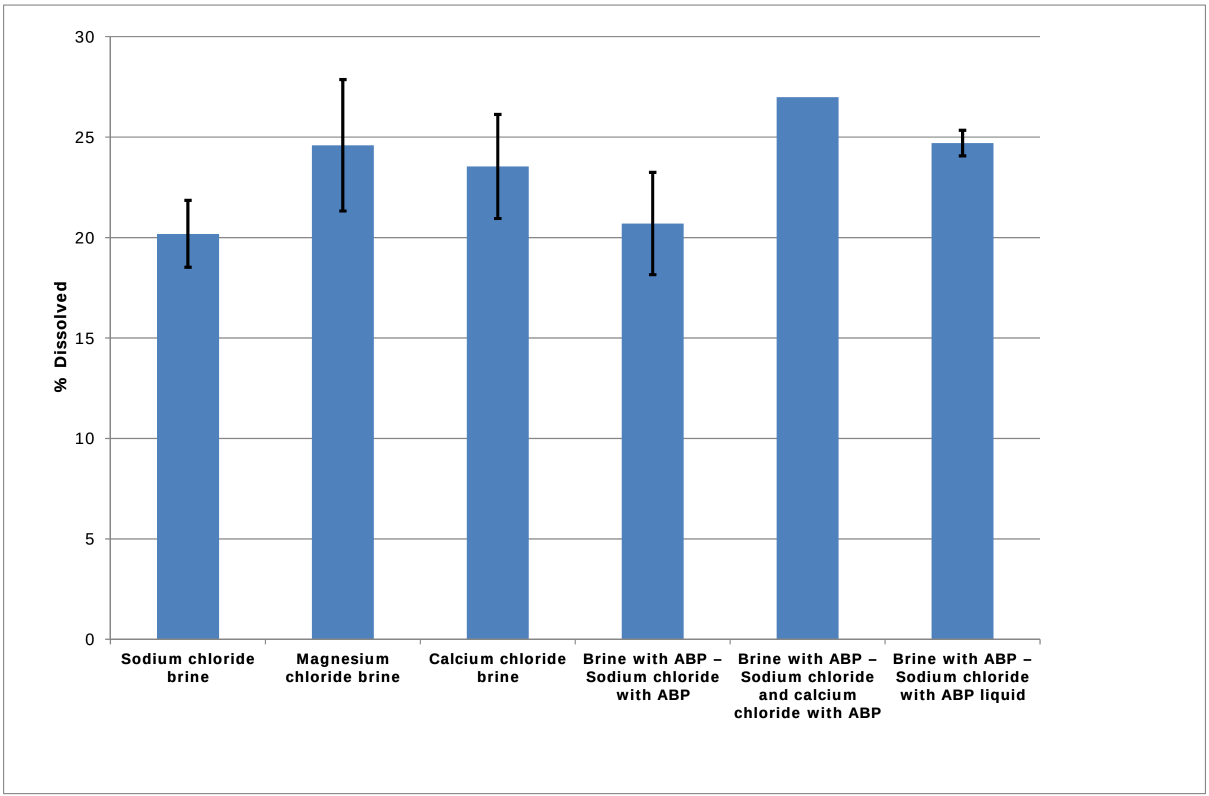

Figure 12. Comparison of salt dissolved at -7°C for 4 hours

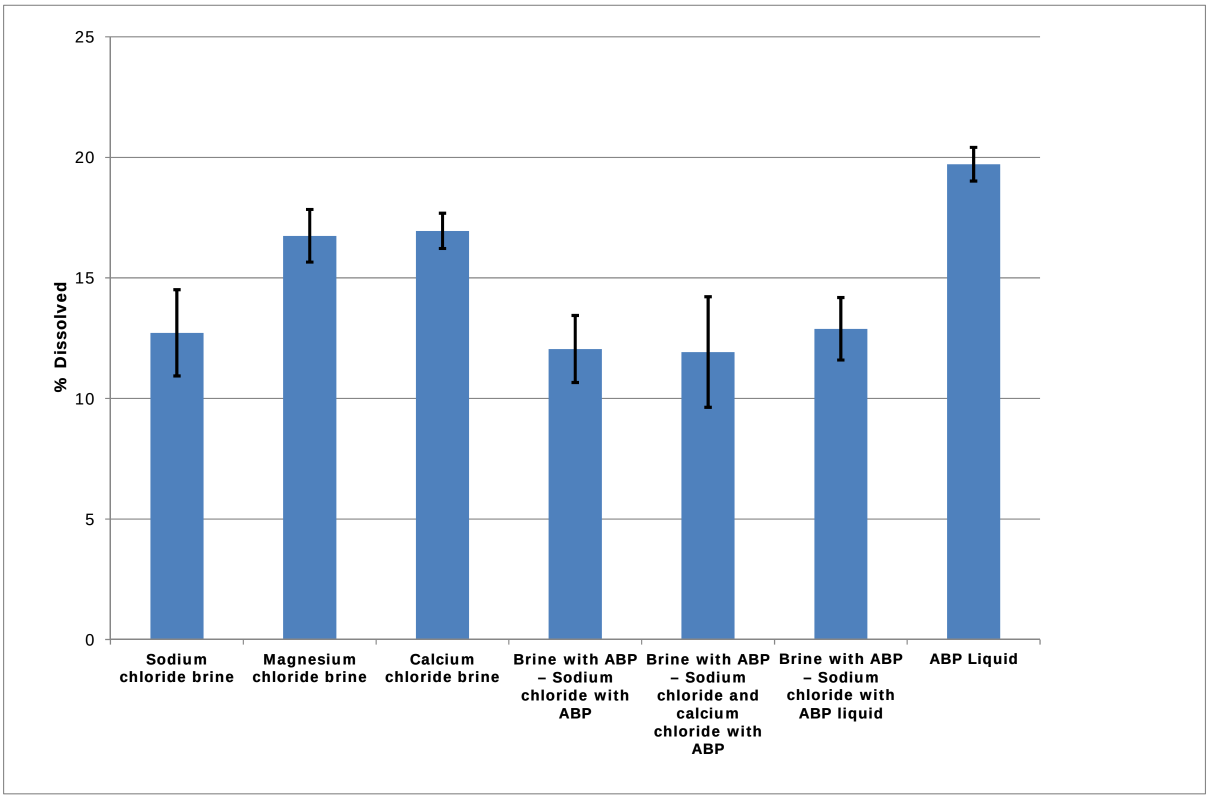

Figure 13. Comparison of salt dissolved at -12°C for two hours

Table 14. Comparison of salt dissolution

Liquid component of de-icer	0°C	-7°C	-7°C	-12°C	Dissolution at -12°C as % of -7°C
	% salt dissolved after 2 hours	% salt dissolved after 2 hours	% salt dissolved after 4 hours	% salt dissolved after 2 hours	After 2 hours
Sodium chloride brine	24	17	20	13	76
Calcium chloride brine	20	20	24	17	85
Brine with ABP – Sodium chloride and calcium chloride with ABP	31	20	27	12	60
Magnesium chloride brine	22	24	25	17	71
Brine with ABP – Sodium chloride with ABP	-	15	21	12	80
Brine with ABP – Sodium chloride with ABP liquid	-	18	25	13	72
ABP liquid	-	22	-	20	91

Table 15. Comparison of salt dissolution between alternative liquids and sodium chloride brine

Liquid component of de-icer	% more dissolution than NaCl wetted salt			
	0°C after 2 hours	-7°C after 2 hours	-7°C after 4 hours	-12°C after 2 hours
Calcium chloride brine	-18	19	17	33
Brine with ABP – Sodium chloride and calcium chloride with ABP	31	22	34	-6
Magnesium chloride brine	-9	44	22	32
Brine with ABP – Sodium chloride with ABP	-	-10	3	-5
Brine with ABP – Sodium chloride with ABP liquid	-	6	22	1
ABP liquid	-	33	-	54

The testing has shown that the salt pre-wetted with the alternative de-icers has greater dissolution relative to sodium chloride brine below -7°C. On average, for all the alternative de-icers, the increase in dissolution at -7°C was 19% and 20% after 2 hours and 4 hours respectively. At -12°C the increase was on average 18%.

There were also differences measured between the different de-icers. Greater increases in dissolution were measured for those alternative de-icers containing magnesium or calcium chloride, may be as a result of the hygroscopic nature of these chemicals. There was no significant increase measured for the sodium chloride brine with ABP, within the limits of precision in the testing.

A comparison can be made with previous dissolution tests which were carried out on behalf of the NWSRG (Evans, 2008). These tests were carried at higher temperatures, around 0°C, where various types of salt (of typical moisture content around 2%) were spread on a dry or damp surface and collected using the same basic method as used for these tests. The testing did not include trafficking, and most dissolution that occurred during the five-hour trials was within the first hour after spreading. The rate of dissolution from 1 to 5 hours was found to be higher on a damp than on a dry surface. On average, for all the de-icers tested in the NWSRG tests, 52% of the solid component was in solution after 5 hours on a damp surface and 37% on a dry surface. The samples in the NWSRG tests included the full range of particle sizes, and hence the finer particles (less than about 0.5mm) would have dissolved more quickly.

Further dissolution testing was carried out during roads trials carried out as part of the NWSRG research programme (Burtwell et al, 2004). These trials showed levels of dissolution of 24 to 27% for pre-wetted 6.3mm salt after one hour of trafficking.

The levels of dissolution measured in the NWSRG testing were higher than measured in the tests using the alternative de-icers, although not considered to be significantly higher taking into account the higher proportion of finer particles, higher temperature and humidity and greater salt moisture content of the NWSRG tests.

In practice, on the road network, the action of traffic will also crush and mix the salt and liquid de-icers which would be expected to increase the dissolution. It must also be considered that salt spreading is only required when roads are damp or wet, and this additional water on the road surface should also increase the dissolution.

2.4.3 Effect of road wetness

Testing was carried out with the addition of water to the liquid component of the de-icer, to attempt to replicate the effects of moisture on the road surface. The water was added to the syringe containing the liquid de-icer. After mixing the water and liquid de-icer the same method was then used as described in 2.4.1, with the dry salt and liquid mixed and spread together.

Figure 14 shows the percentage of salt dissolved at -7°C after 2 hours, with and without adding water to the liquid component of the de-icer. Water was added to the liquid component in a 1:1 ratio, i.e. 3g of water mixed with 3 g of liquid, before mixing with the salt and spreading in the usual manner.

Figure 15 shows the percentage of salt dissolved at 0°C for rock salt pre-wetted with sodium chloride and magnesium chloride brine and with increasing amounts of water added to the liquid component.

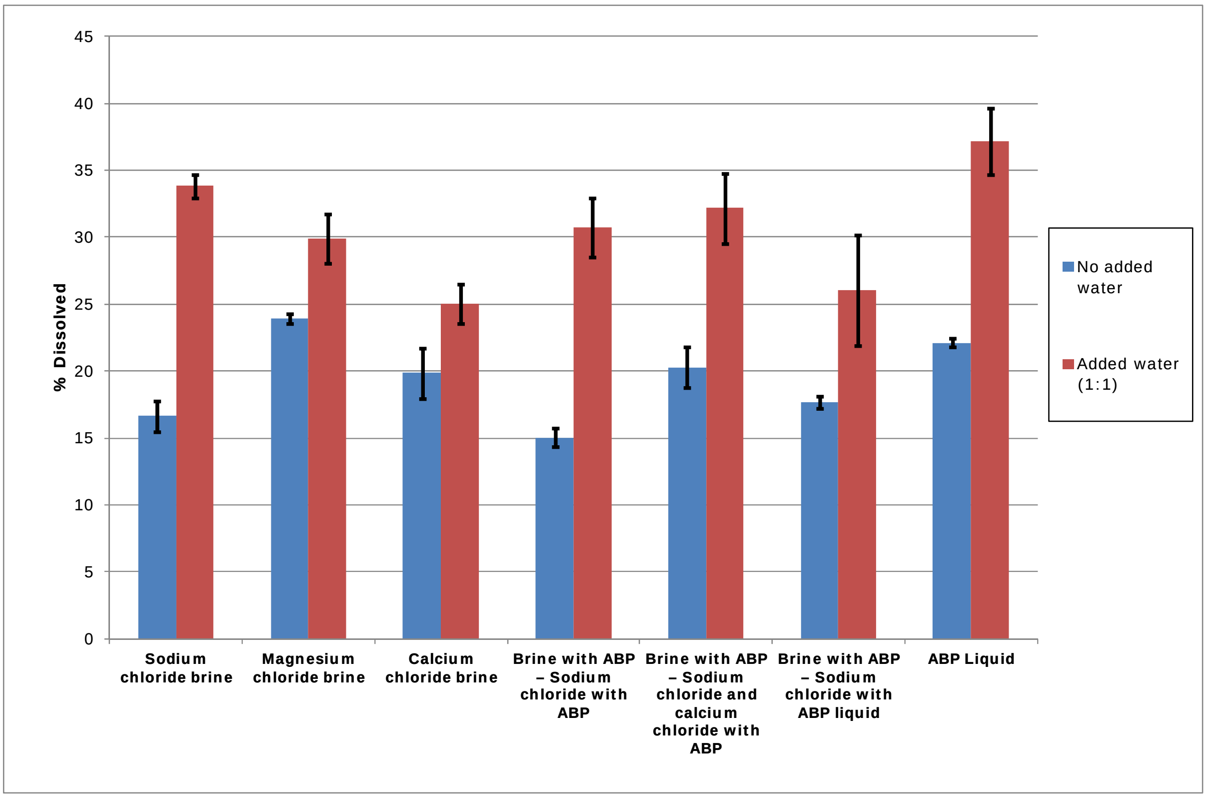

Figure 14. Comparison of salt dissolved with and without adding water, at -7°C for two hours

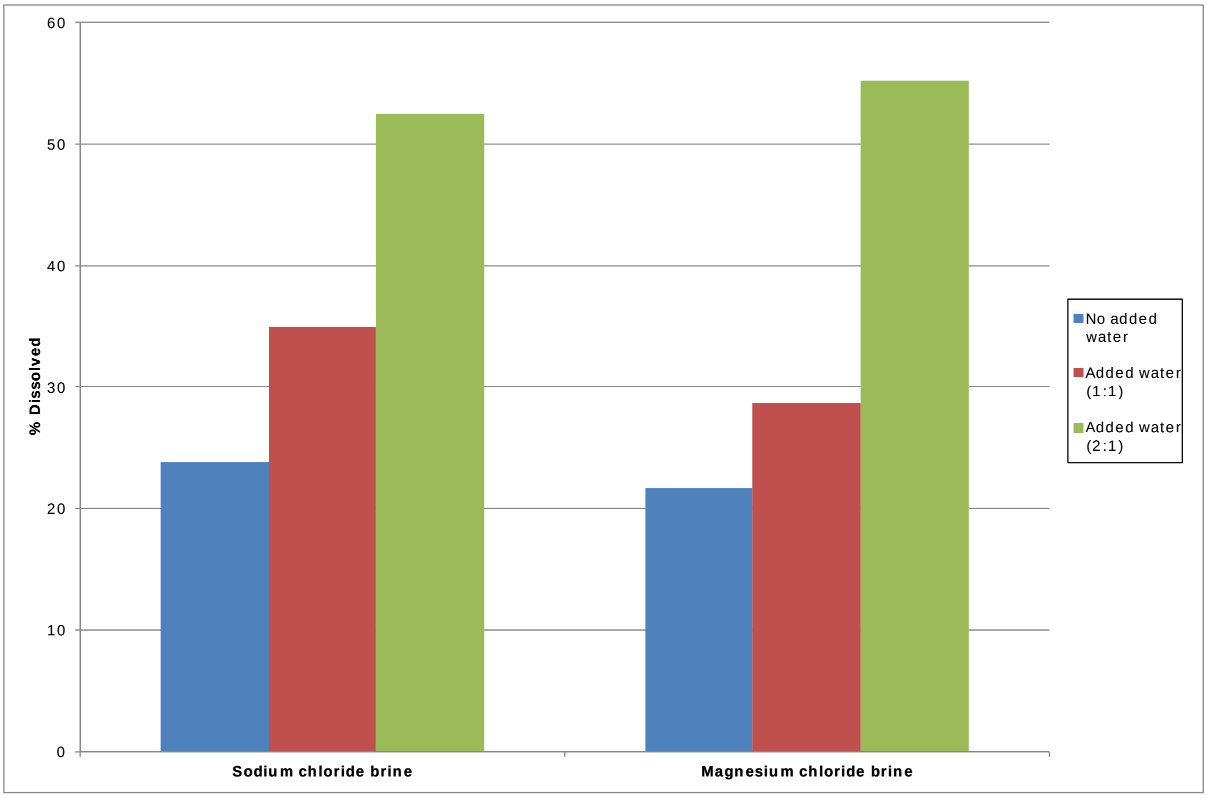

Figure 15. Comparison of salt dissolved at 0°C for 2 hours

When water was added to the liquid component, the dissolution increased for all the de-icers. When adding the equivalent amount of water to liquid de-icer (i.e. 1:1 ratio), there was on average a 62% increase in the proportion of salt dissolved. There was a greater measured increase in the dissolution at -7°C for salt pre-wetted with sodium chloride brine and sodium chloride brine with ABP, where there was an approximately 100% increase measured for both, compared to salt pre-wetted with magnesium and calcium chloride, where there was an approximately 25% increase measured for both. As a result, there was a similar dissolution measured for all the de-icers, after diluting the liquid component, within the limits of precision in the testing.

The results at 0°C are only based on 1 measurement for each de-icer for each condition and consequently will be subject to variability in the results. However the results clearly show the trend of increasing dissolution resulting from increasing amounts of water.

While the addition of the water indicated that increased dissolution can be expected in practice, it was not considered that the addition of the water to the syringe resulted in salt being spread in a manner fully representative of real life conditions. In practice, the salt particles will be coated in a liquid film and spread out separately on the road surface. In the laboratory testing, due to the increased ratio of liquid to solid resulting from the addition of the water, the liquid and solid particles were spread together almost as a slurry, and it was considered this may lessen the benefit of the alternative de-icers. It was also not possible to compare the performance of the alternative liquids with sodium chloride brine below -7°C as the diluted sodium chloride solution froze below this temperature.

2.4.4 Effect of trafficking

To investigate the effect of trafficking, tests were carried out where the salt was rolled and crushed after spreading. It was also considered that this would help to spread out the salt particles and liquid on the surface and provide a more representative test of real life conditions.

The same methodology was used for spreading the salt as described in 2.4.1. Every 20 minutes after spreading, the salt in the tray was then rolled using a rubber roller to mix the salt and liquid and crush the salt grains.

The testing introduced a number of variables that were hard to control, such as the relative degree of crushing between tests. Sources of error also included the pick-up of salt and liquid on the roller surface. Table 16 shows the dissolution measured for a test period of 2 hours.

Table 16. Effects of trafficking

Liquid component of de-icer	Temperature (°C)	% Dissolution	% increase from un-trafficked result
Sodium chloride brine	-7	39	234
Magnesium chloride brine	-7	37	157
Sodium chloride brine	-12	24	185
Magnesium chloride brine	-12	34	203
Calcium chloride brine	-12	35	205

The trafficking of the salt clearly resulted in increased dissolution, with approximately twice the amount of salt being dissolved than for the un-trafficked tests. The results were based on limited numbers of tests and are subject to other sources of variability as previously discussed; hence it was difficult to draw firm conclusion on the relative effects of the alternative de-icers compared to sodium chloride brine. However, during the testing it was observed that the alternative liquids resulted in a significantly wetter appearance to the salt after spreading, compared to the use of sodium chloride wetted salt, which would indicate that more moisture was being absorbed from the surroundings. At -7°C, similar percentage dissolution was measured for sodium chloride and magnesium chloride brine. At -12°C there was an increased dissolution when using the calcium and magnesium chloride brine, with approximately 45% more dissolution for both de-icers.

It was further noted during the tests that there was limited crushing of the salt grains, with the predominant effect that of more evenly spreading out the salt grains and liquid across the test surface. Further tests were subsequently carried out using a harder rubber material for the roller. This harder surface allowed the salt grains to be more effectively crushed, and was considers to more accurately replicate the crushing of salt grains by vehicle tyres. Some tests were also carried out where additional water was added, in the same manner as described in Section 2.4.3.

Table 17 shows the dissolution measured in the testing with the harder material roller and additional water.

Table 17. Effects of trafficking with harder material roller

Liquid component of de-icer	Temperature (°C)	Water added	% Dissolution
Calcium chloride brine	-12	None	75
Magnesium chloride brine	-12	None	91
Sodium chloride brine	-7	1:1	81
Magnesium chloride brine	-7	1:1	91
Magnesium chloride brine	-12	1:1	89
Calcium chloride brine	-12	1:1	86

The use of the harder material significantly increased the amount of salt that was either dissolved or crushed to a size less than 150 µm, the filter size used in this testing. Particles of this small size are considered to be effectively dissolved as they will very quickly dissolve in any moisture available.

2.4.5 Review of assumptions

In developing the original guidance, multiplying factors were applied to the spread rates to allow for the incomplete dissolution of the salt in the time required after spreading. Table 18 shows the assumed percentage of salt in solution based on these multiplying factors.

Table 18. Assumed % of salt in solution for each temperature band

Parameter	Liquid component					
	Sodium chloride brine	Magnesium chloride brine	Calcium chloride brine	Brine with ABP – Sodium chloride with ABP	Brine with ABP – Sodium chloride and calcium chloride with ABP	Brine with ABP – Sodium chloride with ABP liquid
% salt in solution at or below -5˚C and above -7˚C	90	89	90	90	90	90
% salt in solution at or below -7˚C and above -10˚C	76	81	82	82	82	82
% salt in solution at or below -10˚C and above -12˚C	65	73	75	75	75	75
% salt in solution at or from -12˚C (%)	58	67	69	69	70	70

As shown in Table 18 the assumption was that, below -7°C, the alternative de-icers increased the dissolution relative to salt pre-wetted with sodium chloride brine and that the amount of dissolution was approximately the same for all the alternative de-icer types. The assumed percentage increase in dissolution relative to rock salt pre-wetted with sodium chloride brine is shown for each temperature band in Table 19.

Table 19. Increase in dissolution for salt pre-wetted with alternative de-icers compared to sodium chloride brine (from assumptions)

Temperature band	% increase in dissolution
At or below -5˚C and above -7˚C	0
At or below -7˚C and above -10˚C	8
At or below -10˚C and above -12˚C	15
At or from -12˚C	19

The testing has shown that the salt pre-wetted with the alternative de-icers has greater dissolution relative to sodium chloride brine than was assumed in developing the NWSRG guidance. On average, for all the alternative de-icers, the increase in dissolution at -7°C was 19 and 20% after both 2 hours and 4 hours respectively. This was in comparison to 8% in the assumptions for the temperature band at or below -7˚C and above -10˚C. At -12°C the increase was on average 18% compared to 15% in the assumptions for the temperature band at or below -10˚C and above -12˚C.

There were also differences measured between the different de-icers. Greater amounts of dissolution were measured for those alternative de-icers containing magnesium or calcium chloride, may be as a result of the hygroscopic nature of these chemicals.

Although the relative amounts of dissolution are greater than assumed, the measurements of dissolution in the laboratory tests, with no additional water added or simulated trafficking, for all de-icer types are clearly less than the assumed amounts shown in Table 18. In practice, on the road network, the action of traffic will crush and mix the salt and liquid de-icers which would be expected to increase the dissolution. It must also be considered that salt spreading is only required when roads are damp or wet, and this additional water on the road surface will also increase the dissolution.

The testing with additional water and crushing of the salt resulted in significantly increased levels of dissolution, to the levels assumed in the guidance in some cases. These tests could not be carried out in such a controlled manner, however there was indication that the use of calcium and magnesium chloride brine increased the dissolution relative to sodium chloride brine when tested under conditions more representative of those encountered on the network.

The spread rates in the guidance were calculated based on the amount of water expected to be present on the road surface. The ratio of water to de-icer will typically be greater in practice than tested in the laboratory. For example, for the temperature band below -7°C and above -10°C, the ratio will be approximately 6:1. This increased amount of water in practice provides further assurance that the required levels of dissolution will be achieved.

Overall, it is considered that the results have demonstrated that the assumptions are valid when there is sufficient traffic and water to help dissolve the salt. (Lack of traffic to aid dissolution is also recognised in guidance for salt spreading without alternative de-icers)

2.5 Freezing point suppression

2.5.1 Freezing point test methodology

Testing was carried out to determine the freezing point temperature of various de-icer solutions, by analysing the shape of the cooling curve using a method derived from ASTM D1177- Standard Test Method for Freezing Point of Aqueous Engine Coolants. This method is specified as an appropriate test method in the SHRP Handbook of Test Methods for Evaluating Chemical De-icers.

De-icer solutions were made up using dried rock salt and liquid de-icers mixed with de-ionised water. The concentrations were selected to produce solutions with freezing points covering the range of temperatures in the guidance i.e. -7°C to -12°C.

Solutions for each de-icer were formed with the following concentrations:

- 15% de-icer to 85% deionised water
- 20% de-icer to 80% deionised water
- 25% de-icer to 75% deionised water

The de-icer consisted of dried rock salt and liquid de-icer in the ratio 70:30 by weight respectively.

Further solutions were made, by diluting the liquid de-icers with deionised water in the ratio 1:1.5 by weight i.e. 40% liquid de-icer to 60% deionised water.

12ml of each solution was placed into a test tube and then suspended in a large beaker of calcium chloride, which was pre-cooled in the environmental chamber. This was used as a bath for the samples to help maintain the desired temperature.

The chamber was set up with the insulation as described for the ice melting test. During the test, the temperature of the samples and bath were logged every ten seconds using a data logger. The samples were stirred every minute to prevent the solutions from super-cooling. Pre-tests showed that the bath did not show any significant changes in temperature when the chamber door was opened and closed.

The test was stopped after 30 minutes and the data downloaded from the logger, where a graph was produced plotting temperature of the de-icer solution against time. The freezing point was taken as the temperature at which the cooling curve showed a definite plateau, the same principle as described in ASTM D1177.

2.5.2 Freezing point test results and review of assumptions

The freezing point temperatures for the de-icer solutions, calculated from the cooling curves, are shown in Table 20. Also shown for comparison, in brackets, are the freezing points calculated using the assumptions shown in Table 2, for solutions of rock salt pre-wetted with each liquid de-icer.

Table 20. Comparison of freezing points for de-icer solutions

Liquid component	Freezing point (°C)			
	Diluted liquid	15% Solution	20% Solution	25% Solution
Sodium chloride brine	-5.3 (-5.1)	-7.7 (-7.4)	-10.5 (-10.6)	-14.6 (-14.5)
Magnesium chloride brine	-13.5 (-11.6)	-8.5 (-8.0)	-12.2 (-11.7)	-16.3 (-16.3)
Calcium chloride brine	-11.3 (-8.2)	-8.5 (-7.7)	-11.6 (-11.1)	-15.5 (-15.3)
Brine with ABP – Sodium chloride brine with ABP	-6.1 (-6.6)	-7.9 (-7.7)	-11 (-11)	- 14.5 (-15.1)
Brine with ABP – Sodium chloride and calcium chloride brine with ABP	-6.5 (-6.6)	-7.9 (-7.5)	-11.2 (-11)	-14.7 (-15.1)
Brine with ABP – Sodium chloride brine with ABP liquid	-4.8 (-7.1)	-7.8 (-7.6)	-10.8 (-11.1)	-15.3 (-15.3)
ABP liquid	-5.2	-7.8	-	-15.4

The salt pre-wetted with the alternative de-icers shows the small reduction in the freezing point expected as compared to pre-wetting with sodium chloride brine. The reduction in freezing point is up to 1.8°C, 1.7°C and 1.7°C for the 15%, 20% and 25% solutions respectively.

The spread rates determined for the guidance were based on the freezing point curves for sodium chloride and the alternative de-icers, using the assumptions in Table 2. Accurate measurements are available in the literature for the sodium chloride phase diagram and as a result there was good agreement between the measured and calculated freezing points of the solutions shown in Table 20. The difference in the measured freezing points between the different de-icer solutions is small (less than 1°C) as the dominant factor is the amount of dissolved salt in the de-icer solution.

The freezing points of the diluted liquids showed greater variation from the assumptions, however the effect of this variation is limited when used for pre-wetting salt, where the liquid makes up 30% of the de-icer, as demonstrated by the results of the de-icer solution freezing point tests. The greatest discrepancy was measured for the calcium and magnesium chloride brine, which showed lower freezing point than assumed, and the ABP liquid, which showed higher freezing point.

2.6 Differential Scanning Calorimetry

2.6.1 Background

Previous research has suggested that some additives to salt suppress the freezing point of water but do not correspondingly increase the ice melting capacity. The laboratory testing reported in Section 2.3, 2.4 and 2.5 investigated if this effect is applicable to the de-icers included in the extreme cold guidance, by comparison of the freezing point suppression and ice-melting results for each de-icer type.

The use of Differential Scanning Calorimetry (DSC) has been reported to offer another potentially more reliable method of assessing the effective temperature and ice melting capacity of a de-icer (Akin and Shi, 2009).

DSC is a thermal analytical technique used to study phase transitions, energy changes and kinetics, by measuring the energy required to maintain the temperature of a material sample at the same temperature as a reference material during heating or cooling. The temperature and heat flow associated with material transitions involving the emission (exothermic) or absorption (endothermic) of heat or changes in heat capacity can be measured using DSC. When ice is melted, thermal energy is absorbed requiring an increase in energy to keep the material at the same temperature as the reference material. This produces a peak in the energy plot at the temperature at which the transition occurs. The addition of a de-icer decreases the temperature at which ice melts, which can be detected by the change in the position of the peak. The area under the peak can be integrated to give the amount of energy required for the transition and this is also decreased by the addition of a de-icer. Therefore the temperature of the peak and amount of heat flow allow the effective temperature and ice melting capacity of different de-icers to be compared.

The work carried by Akin and Shi found that DSC gave a better indication of the effective temperature of a de-icer than using the eutectic temperature and provided a more reproducible value for ice melting capacity than the conventional SHRP methodology. As part of the laboratory testing task in the work reported here, allowance was made for DSC analysis of samples containing the alternative de-icers included in the extreme cold guidance for comparison with the conventional laboratory test results.

2.6.2 Methodology

The Chemistry Department at the University of Sheffield was sub-contracted to carry out DSC analysis of the de-icers being studied. The methodology employed was based on the test procedure developed by Akin and Shi for using DSC to evaluate liquid de-icers.

An initial analysis was carried out of solutions for each de-icer formed with 20% de-icer to 80% deionised water by weight, where the de-icer consisted of dried rock salt and liquid de-icer in the ratio 70:30 by weight respectively.

The samples tested are as shown in Table 21.

Table 21. Details of DSC Samples for testing

Test Samples
Rock salt plus sodium chloride brine
Rock salt plus magnesium chloride brine
Rock salt plus calcium chloride brine
Rock salt plus sodium chloride brine with ABP
Rock salt plus sodium chloride and calcium chloride brine with ABP
Rock salt plus Sodium chloride brine with ABP liquid
Rock salt plus ABP liquid

10mg of each solution was analysed using a Perkin-Elmer Pyris 1 DSC. The de-icer solution was cooled slowly at a rate of 2°C per minute (to avoid super cooling) from room temperature to -60°C and then heated at the same rate back to ambient temperature. The scans produced show a number of peaks on both the heating and cooling cycles. Akin and Shi recommended using the heating cycle for the analysis as this was reported to be more reproducible. Three endothermic peaks can be identified in the heating thermogram in Figure 16; the first at ca. -18°C which is the eutectic melting peak, the second at ca. -7°C which is the ice melting peak and then there is an additional peak at around 5°C. This third peak is not present in the results reported in the literature and it may relate to an impurity. Triplicate runs were performed on each de-icer to provide an indication of reproducibility.

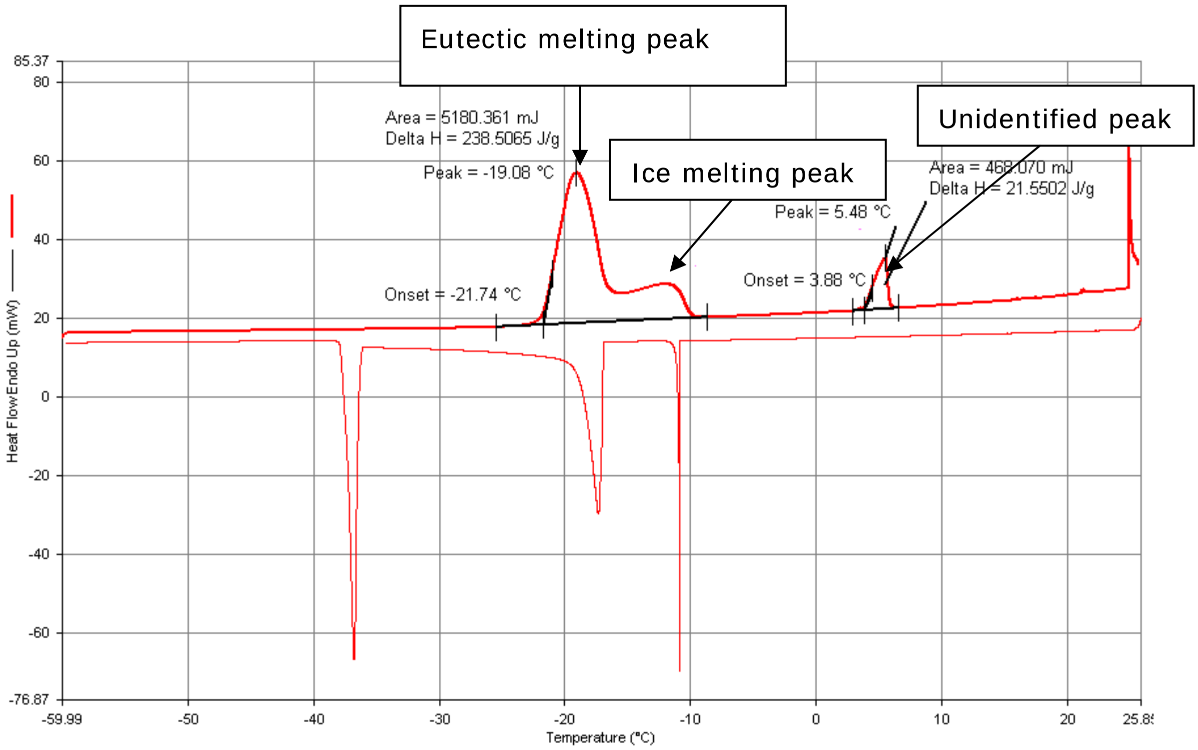

Figure 16. DSC scam, 2°C per min, 10mg sample, Sodium chloride solution (20% de-icer)

The ice melting peak, which is the peak associated with the de-icing process, closely follows the eutectic peak making it appear as a shoulder to the first peak. In an attempt to better resolve the peaks, a slower scan rate of 1°C per minute and smaller sample sizes (5mg and 2mg) were used, however this did not produce a significant improvement.

To further separate the ice melting and eutectic peaks, more dilute de-icer solutions with 15% de-icer to 75% deionised water were analysed, to move the ice melting peak closer to zero i.e. further to the right on the scan. None of these actions were entirely successful, but it was felt that using the more dilute samples gave some improvement. Consequently the scans were run with this concentration using 10mg samples and a 2°C per minute scan rate.

In addition, a second batch of de-icers was tested consisting of solutions of the same de-icer liquids, but without the rock salt component, as shown in Table 22. The liquid de-icers were mixed with deionised water in the ratio 1:1.5 by weight i.e. 40% liquid de-icer to 60% deionised water.

This allowed the peaks from the alternative de-icers to be analysed without being obscured by the sodium chloride peaks, although is not representative of how the de-icers would be applied in practice i.e. as the liquid component of pre-wetted salt.

Table 22. DSC Samples – dilute liquid de-icer solutions

Test Samples
Sodium chloride brine
Magnesium chloride brine
Calcium chloride brine
Sodium chloride bine with ABP
Sodium chloride and calcium chloride brine with ABP
Sodium chloride brine with ABP liquid
ABP liquid

2.6.3 Results

2.6.3.1 Analysis of thermograms

Analysis of a thermogram can provide the peak temperature, onset temperature and change in heat flow. The onset temperature is the point at which the ice crystals start to melt, the peak height indicates the temperature at which bulk ice melting occurs and the area under the curve the thermal energy required to initiate this change in state. However, even when the more dilute 15% de-icer solutions were analysed, as shown in Figure 17, it is difficult to identify the onset and peak area.

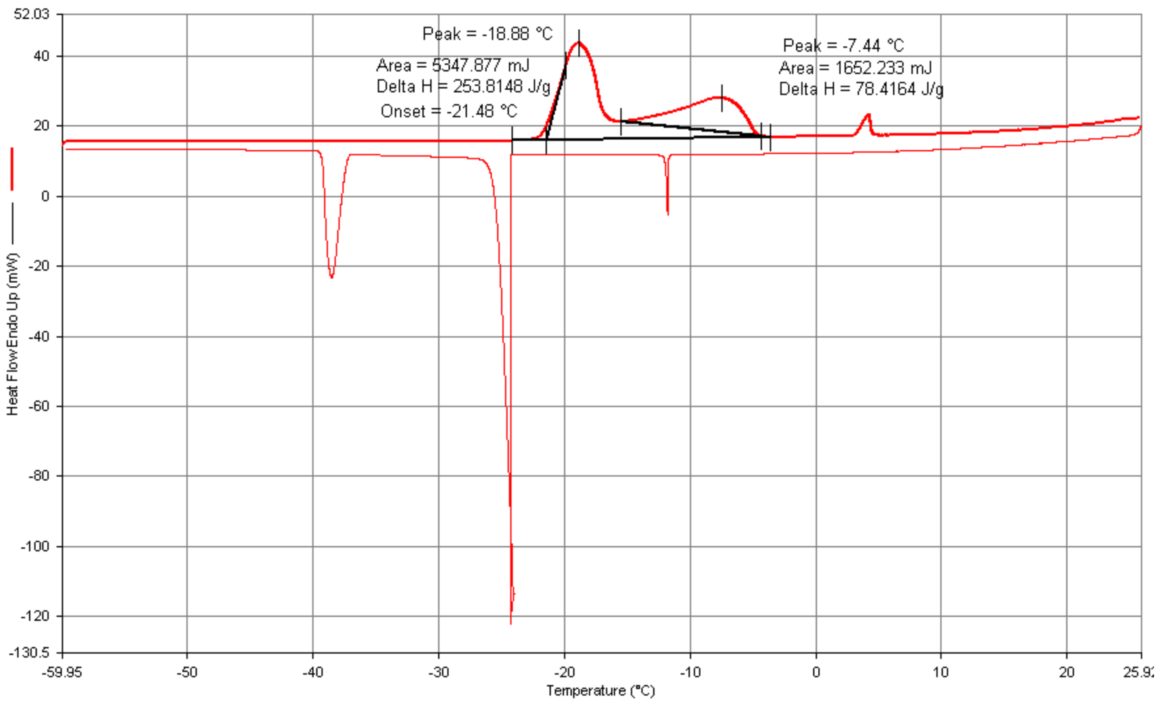

Figure 17. DSC scan of 10 mg of sodium chloride solution at a rate of 2°C per min

For the solutions of liquid de-icers, with the samples with only one peak around the temperature of interest, it was possible to obtain the area more accurately, as shown in Figure 18.

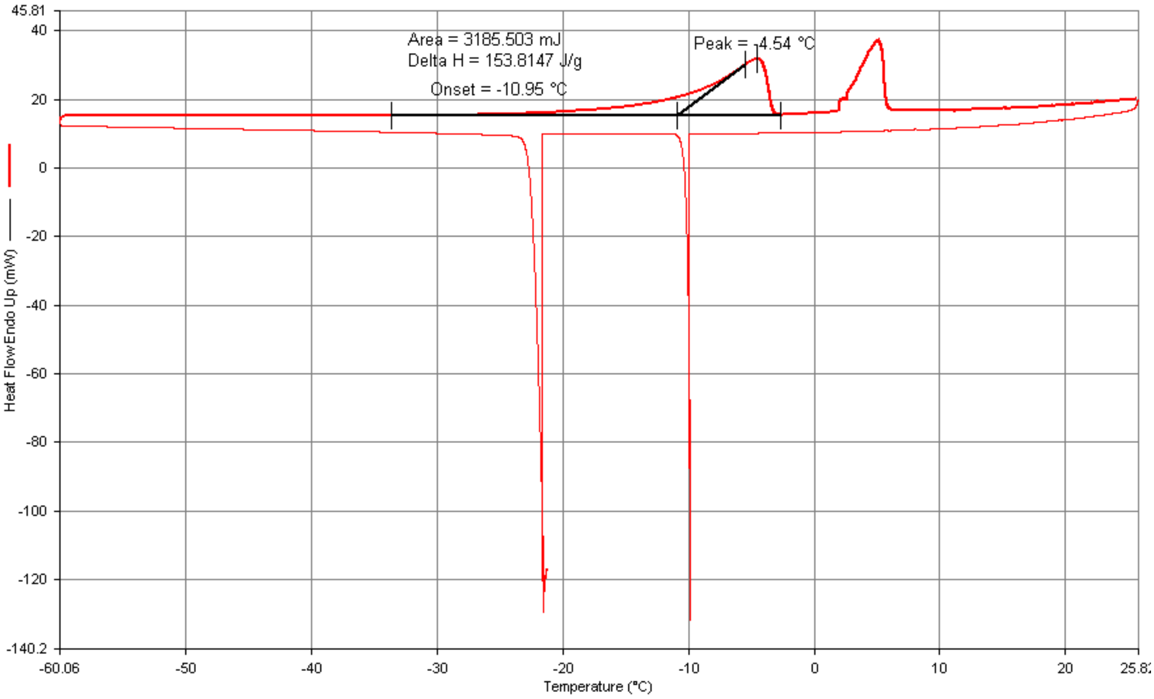

Figure 18. DSC of 10mg of ABP liquid (40% solution)

2.6.3.2 Effective temperature

The maximum peak height which corresponds to the effective melting temperature of the de-icer was measured in each thermogram. An average of the peak heights of the triplicate scans was taken to compare the effective temperature of the de-icers.

The effective temperatures are shown in Table 23 for the 15% de-icer solutions and diluted liquid de-icer solutions.

A comparison of these results with the freezing points measured in the laboratory tests are shown for the 15% de-icer solutions and diluted liquid de-icers in Figure 19 and Figure 20 respectively; the error bars indicate the standard deviation of the three runs.

Table 23. Comparison of freezing points for de-icer solutions

Liquid component	Freezing point (°C)	
	15% de-icer solution	Diluted liquid de-icer
Sodium chloride brine	-7.4	-4.6
Magnesium chloride brine	-8.4	-13.8
Calcium chloride brine	-8.2	-11.5
Brine with ABP – Sodium chloride brine with ABP	-7.8	-5.3
Brine with ABP – Sodium chloride and calcium chloride brine with ABP	-7.6	-5.8
Brine with ABP – Sodium chloride brine with ABP liquid	-7.6	-4.1
ABP liquid	-7.8	-4.4

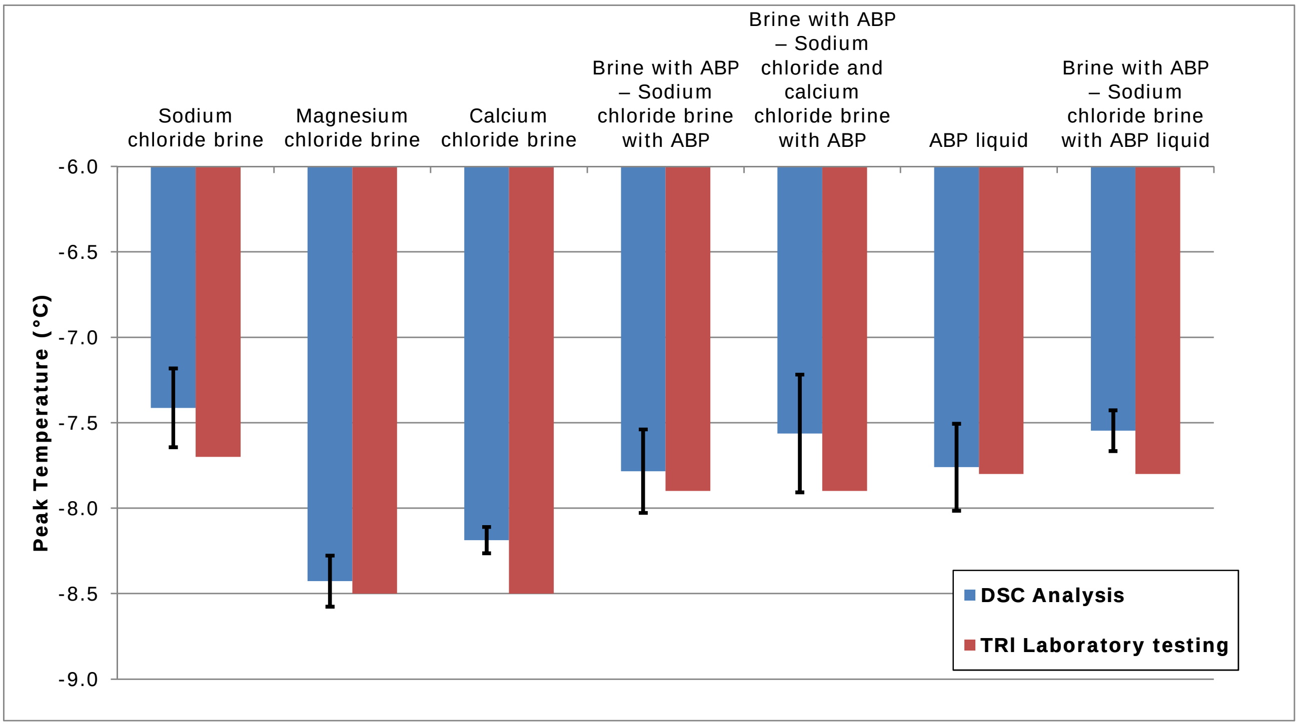

Figure 19. DSC peak temperatures for 15% de-icer solutions

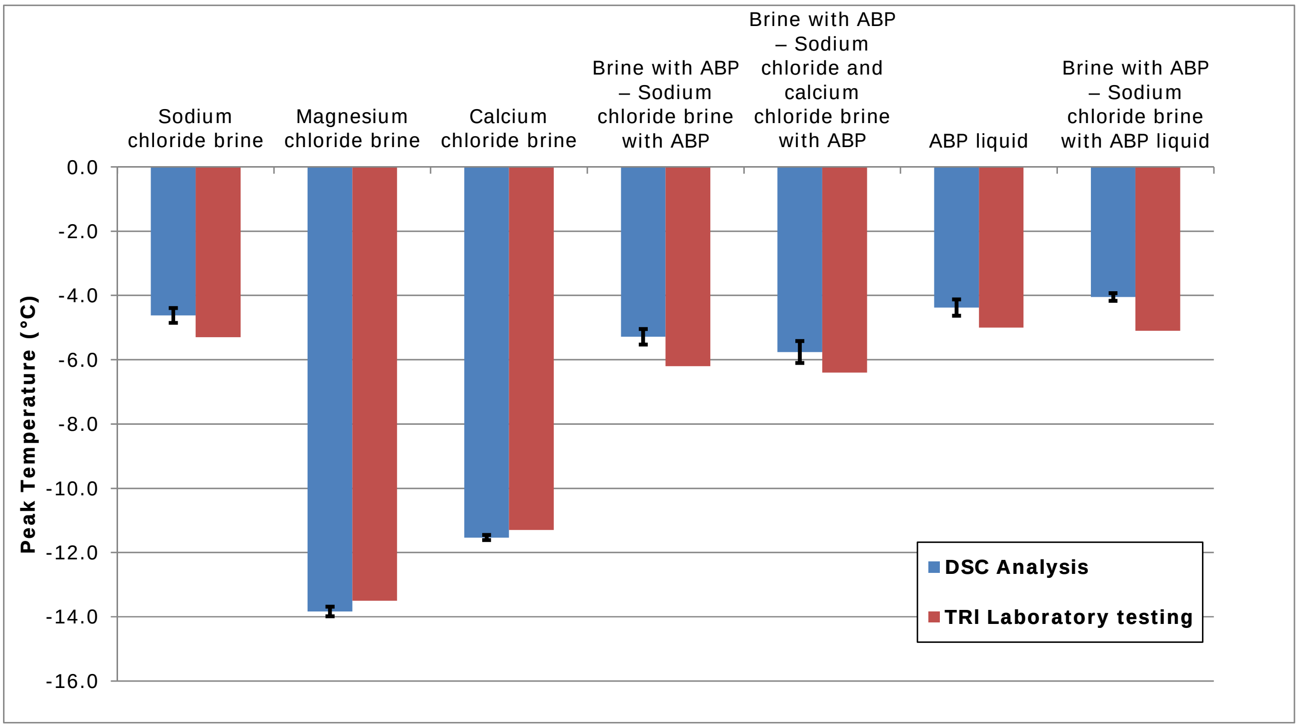

Figure 20. DSC Peak Temperatures diluted liquid de-icers

As shown, the DSC results correlated well with the freezing point temperatures obtained in the laboratory freezing point measurements reported in Section 2.5. DSC peak temperatures and the freezing point temperatures show a good correlation (R^2 = 0.84), although the correlation of the simple salts (NaCl, $MgCl_2$, $CaCl_2$) correlate much better than the de-icers containing ABPs (R^2 = 0.98).

The temperatures of the DSC peak was generally a small amount lower, typically by between 0°C and 1°C, than the freezing point measurements in the TRL laboratory tests.

2.6.3.3 *Ice melting*

Although the ice melting peaks for the 15% de-icer solutions could not be completely resolved, an attempt was made to measure the area under the ice melting peak and the heat flows obtained are plotted in Figure 21.

Similarly, the area under the ice melting peak was measured for the diluted liquid de-icers and is shown in Figure 22.

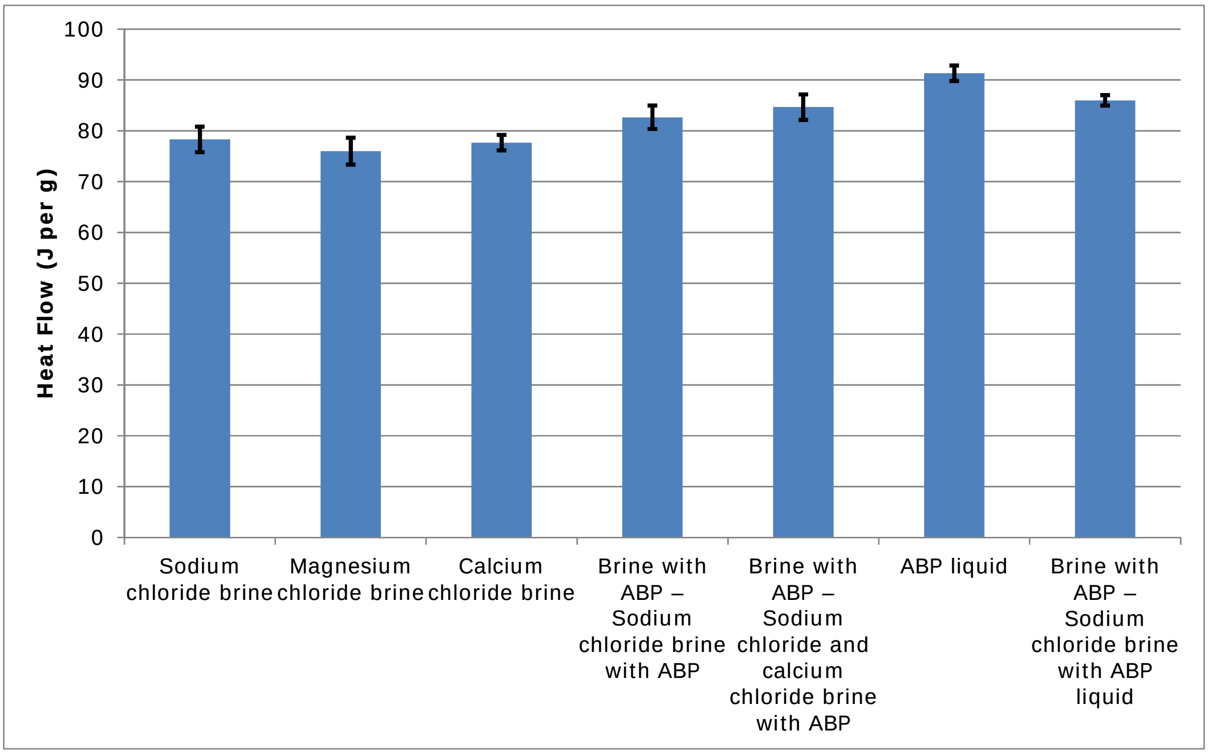

Figure 21. DSC heat flow – 15% de-icer solutions

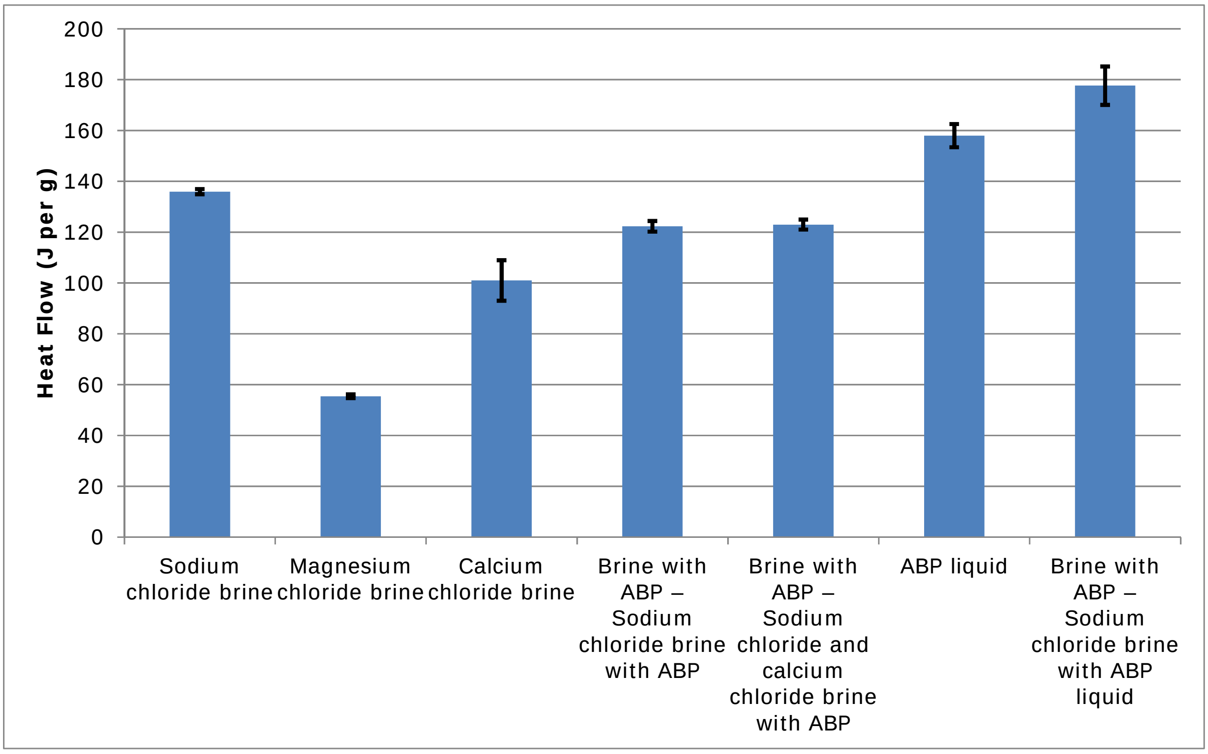

Figure 22. DSC heat flow – diluted liquid de-icers

The heat flow should correspond to ice melt results, with de-icers exhibiting a lower heat flow generating more ice melting. However, little correlation was obtained with the heat flows and ice melting results at -7°C, likely due to the difficulties resolving the peak areas. The same analysis was carried out for the diluted liquids, where a higher but still low correlation was found (R^2 = 0.46). For the simpler salts the correlation was much higher (0.99), suggesting a much more complex relationship in the ABPs.

2.6.4 Summary

DSC can be used as an analytical tool for de-icers, but there are some difficulties surrounding the analysis. The scan rate and sample size used greatly affect the result and it can be difficult to identify and resolve the different peaks. However, the results obtained do appear to support the freezing point depression results, with magnesium chloride decreasing the freezing point by 14%, calcium chloride by 10% and Safecote and Ecothaw by 5%.

The use of DSC to measure melting capacity was less successful. The heat flow values for the ABPs do not appear to correspond to the ice melting results, as they show larger heat flows than sodium chloride in the DSC analysis, but more volume of ice melted in the ice melting tests. This is contrary to the results reported by Akin and Shi, who found a very good correlation between ice melting and DSC results. The lack of correlation may be due to difficulties resolving the DSC peaks and warrants investigation beyond that which was possible during this project.

3 Effects of alternative treatment materials on skid resistance

3.1 Background

Surfaces that have an applied de-icer solution have the potential to have less skid resistance than an untreated surface. Some alternative de-icers can be classified as hygroscopic so untreated surfaces may also dry more quickly than those surfaces that have been treated. There is anecdotal evidence that some of the materials used as de-icers, particularly calcium chloride and magnesium chloride, can make road surfaces slippery by leaving an oily residue.

Understanding and quantifying any effects on the skid resistance of typical road surfacings after application of certain de-icers is important in assessing the appropriateness of using these de-icers on the road network. However the tests carried out here do not replicate actual road/tyre interaction at traffic speed and can only be considered indicative of potential issues. For a definitive view on the effects of the de-icers testing would need to be carried out at a range of representative traffic speeds on typical road surfaces and using suitable test equipment.

3.2 Introduction

Laboratory tests were carried out to show the extent to which skid resistance is affected on typical road surfacings after spreading the alternative liquid de-icers. Comparisons were made between wet skid resistance values for typical road surfacing materials when treated with the liquid de-icers as supplied and when in solution.

Testing was carried out of all the alternative de-icer types included in the guidance:

- Magnesium chloride brine
- Calcium chloride brine
- Sodium chloride brine with ABP
- Sodium chloride and calcium chloride brine with ABP
- ABP Liquid
- Sodium chloride brine, for comparative purposes

3.3 Methodology

3.3.1 Portable Skid-Resistance Tester

Tests were carried out in the laboratory using a portable Skid-Resistance tester, as developed by TRL, to determine Skid Resistance Values (SRVs) when the different liquid de-icers are applied to stone mastic asphalt (SMA) (i.e. a thin surface course system).

The detailed operation of the equipment is described in Road Note 27 (Road Research Laboratory, 1969). It is generally used to check the resistance of wet roads and other surfaces to skidding. It was designed to represent as far as possible the friction between a patterned vehicle tyre and a wet, medium-textured road surface at 50km/h.

The tester essentially comprises a pendulum arm carrying a rubber slider that is arranged to swing so that the slider contacts the surface under test over a distance of 125mm. The friction between the slider and the test surface reduces the speed of the swinging arm and the maximum swing is recorded against a scale that is marked to indicate SRV. This value represents the skid resistance for that surface. As temperature has an effect on rubber resilience, in the UK results on site are corrected to a standard temperature of 20°C. The tester used in the tests was calibrated by the British Standards Institute (BSI).

3.3.2 Test surfaces

Testing was carried out on 300mm diameter cores taken from trafficked surfacings on the Agency’s network.

The surfacing materials tested were:

- 14mm SMA
- 6mm SMA

3.3.3 Test procedure

The asphalt cores to be tested and the skid tester were set up on a jig to control the level of the core so that no movement could take place between the asphalt section and the tester once the rubber arm made contact with the surface. The contact point between the rubber arm and the surface of the core was measured to be as flat as possible with a spirit level so an equal distribution of force was applied.

The asphalt specimen was removed after each test and cleaned with warm running water before being replaced in its original position. This is viewed as an acceptable method for cleaning the core of any chemical residue from the test as chemicals such as sodium chloride (NaCl) have a strong attraction between its components and water having a strong polar value can dissolve these chemicals allowing for it to run off the core.

The tester was set up and the zero setting adjusted before each test. A number of swings were made with the asphalt surface wetted with water until the readings stabilised. Skid resistance values were then measured for each of the de-icers, wetting the surface between each swing. Both the core surface and the rubber slider on the pendulum arm were wetted with the de-icer solution before each swing, so that they were copiously wet and thus all contact points between the core and the rubber were wet.

For each measurement, 10 consecutive readings were taken at each of 4 separate points on the core to provide an average value for the surface under test. The average skid resistance value for each core was calculated from the average of these 4 points tested.

Periodic checks of the wet skid resistance were made with water to ensure that there was no change in the skid resistance of the asphalt surface as the testing progressed. This also allowed checks to be made on the condition of the rubber slider to make sure there was not sufficient wear that might be affecting the results.

The test programme was as follows:

1. Initial measurement of wet and dry skid resistance for each core, at 20°C.
2. Liquids tested as supplied (i.e. no dilution), for each core at 20°C
3. Diluted solutions of liquids with deionised water in a 1:1 ratio by weight (no salt added).
4. 25% by weight solutions of de-icers tested, for each core at 20°C – de-icer consists of salt and liquid de-icer in the ratio 70:30 by weight.
5. Calcium chloride and magnesium chloride liquids tested after leaving for set periods after application.

3.4 Results

3.4.1 Wet and dry skid resistance of test surfaces

The wet and dry skid resistance was measured for each surfacing as shown in Table 24.

Table 24. Wet and dry skid resistance of surfacing

Surfacing	SRV	
	Wet	Dry
6mm SMA	58	89
14mm SMA	54	85

For high-speed roads and sites such as roundabouts values of 55 and 65 would be required. The values measured for the test surfacings are therefore consistent with the values expected for surfacings on the Agency's network.

3.4.2 Liquids tested as supplied

Table 25 and Figure 23 show a comparison of SRVs measured for the test cores treated with the liquid de-icers as supplied.

Table 25. Comparison of skid resistance of liquids as supplied

Liquid de-icer	SRV		% change from wet SRV	
	6mm SMA	14mm SMA	6mm SMA	14mm SMA
Sodium chloride brine	58	51	-1	-5
Brine with ABP – Sodium chloride with ABP	54	49	-7	-9
Brine with ABP – Sodium chloride and calcium chloride with ABP	54	49	-7	-9
Calcium chloride brine	48	42	-18	-21
Magnesium chloride brine	43	38	-26	-29
ABP liquid	43	37	-27	-31

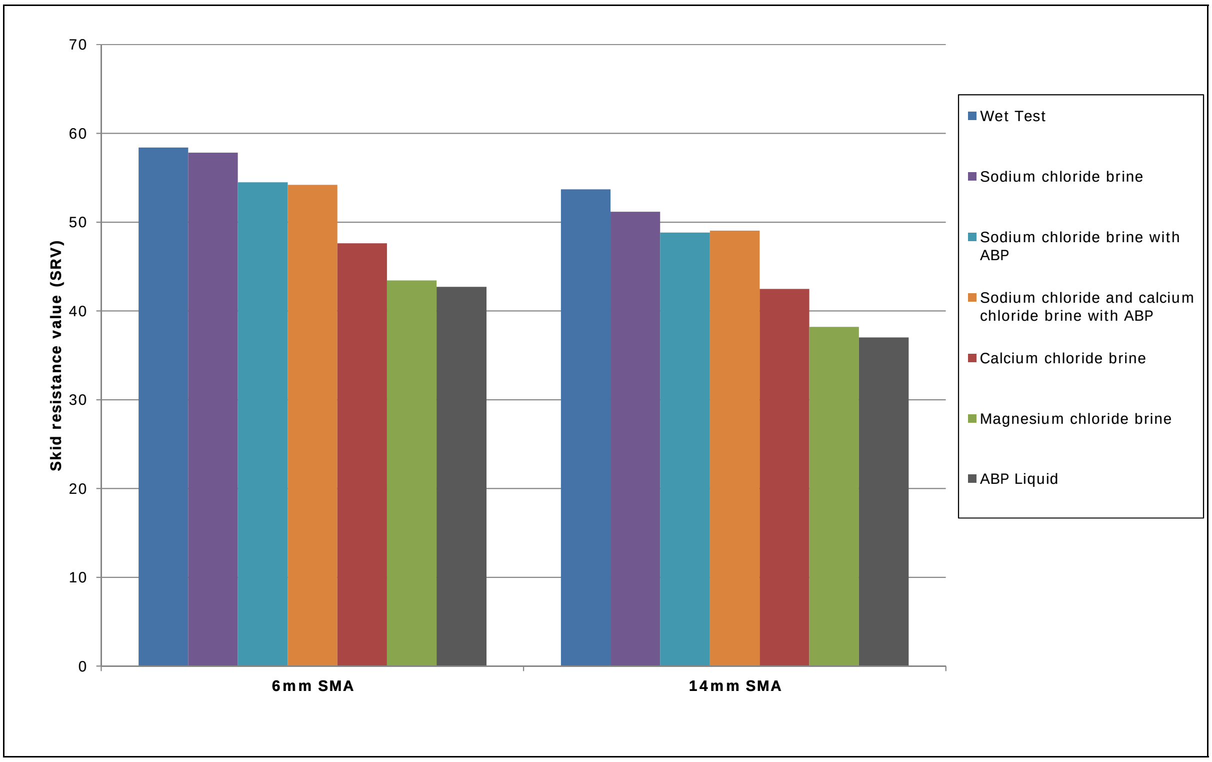

Figure 23. Comparison of Skid Resistance Values (SRV) for liquids as supplied (not diluted in solution)

Application of sodium chloride brine or brine with ABP did not show a significant reduction from the untreated wet skid resistance. Application of calcium chloride brine, magnesium chloride brine and ABP liquid resulted in greater reductions of up to 31% from the untreated wet skid resistance as shown in Figure 23.

3.4.3 Diluted liquids

Table 26 and Figure 24 show a comparison of SRVs measured for the test cores treated with liquid de-icers diluted 1:1 with de-ionised water.

Table 26. Comparison of skid resistance for diluted liquids

Liquid de-icer	SRV		% change from wet SRV	
	6mm SMA	14mm SMA	6mm SMA	14mm SMA
Calcium chloride brine	55	54	-6	0
Magnesium chloride brine	56	50	-4	-7
ABP liquid	56	51	-3	-5

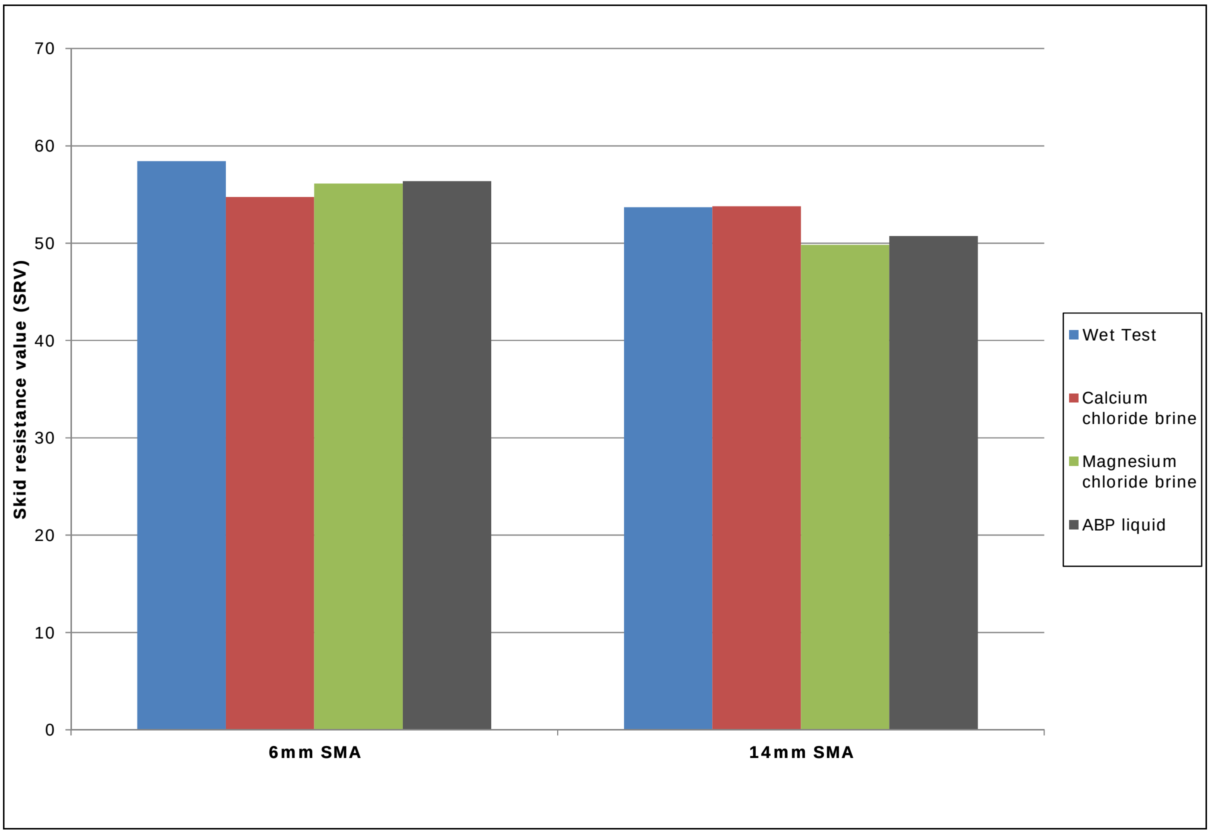

Figure 24. Comparison of Skid Resistance Values (SRV) for diluted 1:1 de-icer solutions

Dilution of the liquids resulted in skid resistance values similar to the untreated wet skid resistance.

3.4.4 25% de-icer solutions

Table 27 and Figure 25 show the comparison of SRVs measured for the test samples treated with 25% solutions of de-icer.

Table 27. Comparison of skid resistance for 25% de-icer solutions

Liquid de-icer	SRV		% change from wet SRV	
	6mm SMA	14mm SMA	6mm SMA	14mm SMA
Sodium chloride brine	57	49	-2	-9
Brine with ABP – Sodium chloride with ABP	54	49	-8	-9
Brine with ABP – Sodium chloride and calcium chloride with ABP	56	52	-4	-3
Calcium chloride brine	54	50	-8	-7
Magnesium chloride brine	55	49	-6	-9
ABP liquid	54	50	-8	-7

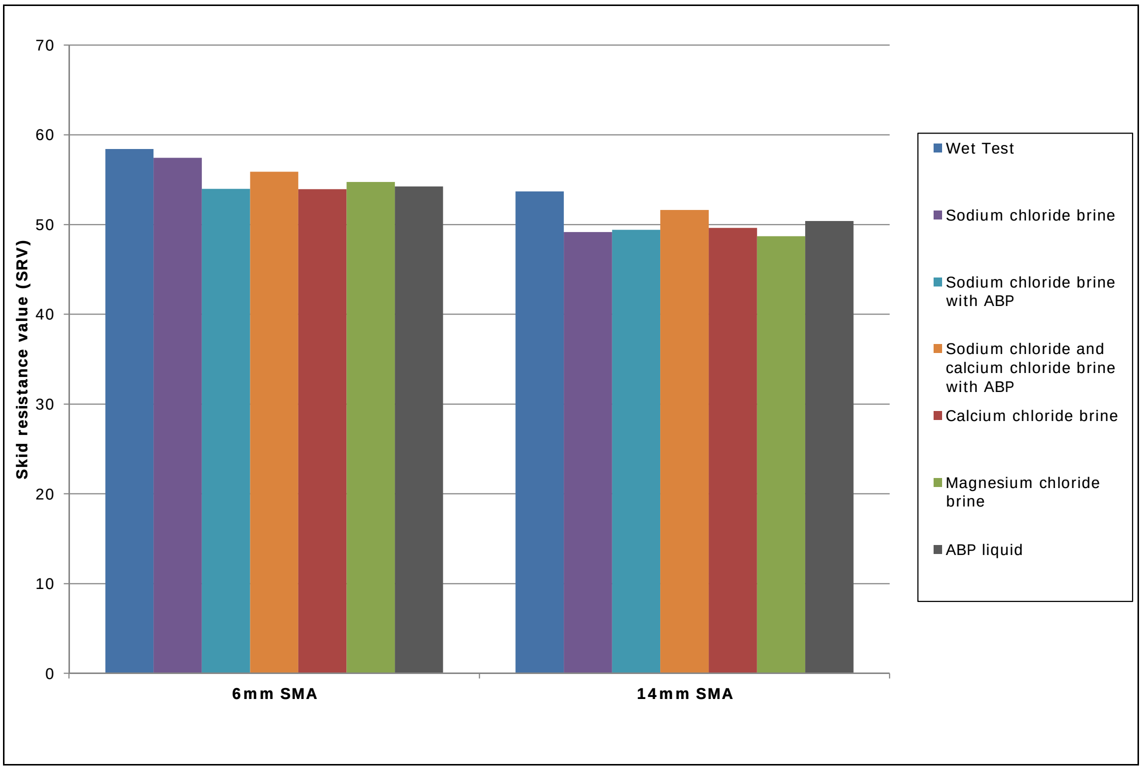

Figure 25. Comparison of Skid Resistance Values (SRV) for 25% de-icer solutions

3.4.5 Testing of liquids after leaving for set periods after application

Tests were carried out to measure the SRV of the test surfaces, following application of calcium and magnesium chloride brine as supplied and leaving for 12 and 48 hours after application before testing.

When carrying out the test, no liquid was applied before each swing to either the surface or the rubber slider i.e. a dry skid resistance measurement.

Table 28 and Figure 26 show the comparison of SRVs measured for the test surfaces.

Table 28. Comparison of skid resistance

Liquid de-icer	Time after application (hrs)	SRV		% change from wet SRV	
		6mm SMA	14mm SMA	6mm SMA	14mm SMA
Calcium chloride brine	12	53	46	-9	-14
	48	51	47	-13	-12
Magnesium chloride brine	12	50	43	-14	-20
	48	56	48	-4	-11

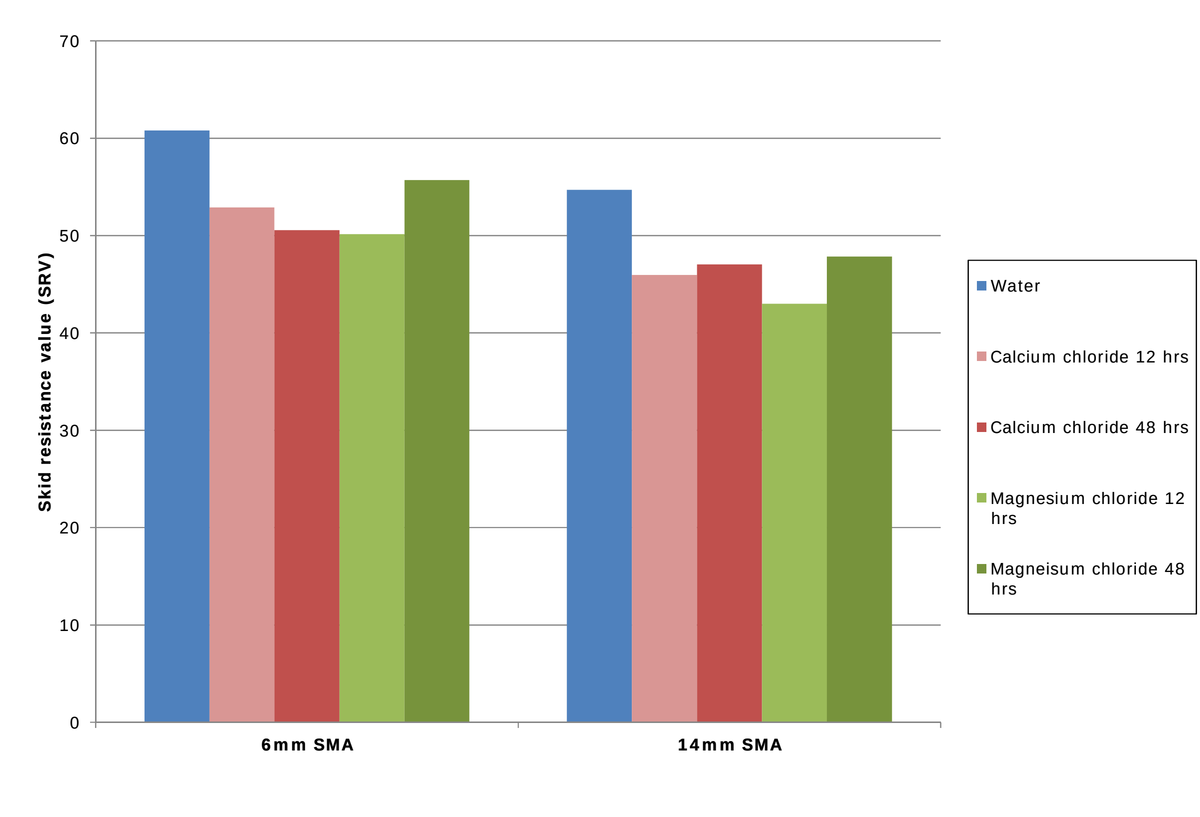

Figure 26. Comparison of Skid Resistance Values (SRV) for de-icer solutions

The surfaces of the cores were observed to remain damp, for both calcium and magnesium chloride, when testing 12 and 48 hours after spreading.

3.5 Discussion

If the alternative liquids have an adverse effect on the skid resistance of the test surfaces, the greatest effect will likely occur after application of the undiluted liquids (as supplied), when the concentration of the de-icers will be greatest. The results obtained for application of the undiluted liquids showed that all de-icer solutions tested have a SRV less than the wet skid resistance value with just water. Application of sodium chloride brine or brine with ABP did not show a significant reduction from the untreated wet skid resistance. Application of calcium chloride brine, magnesium chloride brine and ABP liquid resulted in greater reductions of up to 31% from the untreated wet skid resistance.

While there is clearly a significant reduction for the calcium chloride brine, magnesium chloride brine and ABP liquid, the concentrations of the liquids when tested undiluted are significantly higher than would be present on the road surface in practice. For precautionary treatments in conjunction with rock salt, and based on the expected amount of water present and typical losses after spreading, the concentration of the resulting solution of de-icer (salt and liquid de-icer) will be approximately 25%. Tests of the 25% solutions resulted in skid resistance values for all the de-icers within 10% of the level measured with water.

If applying ABP liquid for treating ice and snow, the de-icer will be significantly diluted by the melt water. Test of the 1:1 diluted liquids represented a concentration higher than can be expected under any reasonable spreading scenario and the skid resistance was again measured to be within 10% of the level measured with water.

When drawing conclusions form the laboratory tests, it must be noted that the Pendulum Tester results do not relate directly to the actual coefficient of friction experienced by a particular tyre in a particular situation, i.e. the actual coefficient of frictions at traffic speeds. It is also not possible to directly extrapolate the results to cover other types of surfacing than those tested, or the behaviour of the test surfaces on site. While the test results cannot be considered conclusive, they enable an initial check to be made of any significant differences in the skid resistance occurring from the use of the alternative de-icers compared with standard de-icing practices.

The alternative de-icers are only intended to be used when spreading is required when temperatures have already fallen below -7°C (or -5°C in low humidity conditions). If spreading is carried out above this temperature standard treatments should be used. The de-icers are therefore most likely to be used for isolated treatments rather than successive treatments over several days. For solutions of the alternative de-icers a small reduction in the skid resistance was measured in comparison to a wet road. Overall, the results have given some indication that the amount of the alternative de-icers present on the road surface may not produce a significant drop (i.e. greater than 5 to 10%) in the skid resistance compared to a wet road. However, this could only be proven by appropriate tests at traffic speed.

For higher concentrations of de-icers, in particular calcium chloride brine, magnesium chloride brine and ABP liquid, there was a more significant drop in skid resistance measured. In sustained Extreme Cold conditions, where successive treatments are made with the alternative de-icers over more than one day, there is the potential for residual levels of the de-icing chemicals to build up on the road surface and more concentrated solutions to be formed when small amounts of water are present. In these circumstances, it is recommended that Service Providers take appropriate action on routes where skid resistance is close to the minimum permitted level.

In considering possible adverse effects from the alternative de-icers, it must be considered that ice formation on the road surface will result in a far more adverse effect on skid resistance than the effect of the alternative de-icers.

4 Monitoring and reporting on the use of alternative treatment materials

4.1 Background

For the 2011/2012 winter period, Service Providers in Highways Agency Area 4 (South East and Kent) and 14 (North East and Northumberland) procured alternative liquid de-icers, for use in extreme cold conditions on selected routes of their network. Transport Scotland also procured a range of alternative materials during the previous winter for use on their network.

The materials procured for use on the Agency network were:

- Magnesium chloride brine (Area 14)
- Calcium chloride brine (Area 4)

There is limited operational experience of the use of the alternative de-icers in the UK and it was considered important that any use of the materials was carefully monitored, to assess the effectiveness of the treatments and to identify any practical issues related to storage and spreading of the materials.

4.2 Monitoring requirements

The Service Provides in both Areas had selected a route prone to low temperatures for trialling the alternative de-icers. Weather station and road sensor information was available for these routes.

A reporting form was produced for Service providers, to specify the types of information to be recorded each time treatments were made. The form is included in Appendix A.

Evidence of the effectiveness of the treatments was sought from service providers. Wherever possible this included quantitative data together with qualitative data from observations of performance and sensor data.

The quantitative weather and road condition data specified included:

- Temperature when treatments were carried out and the minimum temperature reached after treatment.
- Humidity levels during and after treatment
- Conditions at time of spreading, including type and amount of precipitation, wind strength
- Road surface conditions – bare pavement, ice, snow or slush

General feedback was sought from Service Providers regarding any practical issues with delivering the treatments, including:

- Storage
- Loading and unloading de-icers to/from spreaders
- Calibration of spreaders with the alternative de-icers (i.e. whether done, how and when)

4.3 Summary of treatments

4.3.1 Overview

Generally milder conditions prevailed during the 2011/12 winter period, resulting in limited opportunities to trial the use of the alternative de-icers in extreme cold conditions. Colder conditions occurred during early February 2012, and a small number of precautionary treatments were carried out using the alternative de-icers in both Areas as detailed in Section 4.3.2.

4.3.2 Details of spreading runs

Table 29 and Table 30 show the precautionary treatments carried out using rock salt pre-wetted with calcium chloride and magnesium chloride brine respectively.

Table 29. Precautionary treatments carried out in Area 4 using rock salt pre-wetted with calcium chloride

Date	Time	Spread rate g/m²	RST when spreading (°C)	Air temperature when spreading (°C)	Minimum temperature after spreading (°C)	Relative Humidity (%)
10/02/2012	21.00	18	-2.7 to -3.9	-2.7	-7.5	-
12/02/2012	05.00	18	-5 to -7	-5 to -7	-7	-

Table 30. Precautionary treatments carried out in Area 14 using rock salt pre-wetted with magnesium chloride

Date	Time	Spread rate g/m²	RST when spreading (°C)	Air temperature when spreading (°C)	Minimum temperature after spreading (°C)	Relative Humidity (%)
01/02/2012	14.00	14	>-5	>-5	-6.5	-
02/02/2012	22.00	16	>-5	>-5	-8	-
03/02/2012	15.00	16	>-5	>-5	-7	-

4.4 Effectiveness of treatments

At present there are only very limited data and observations available, due to the small number of treatments carried out. All treatments carried out have been precautionary and the majority of treatments have also been carried out when spreading at temperatures greater than -5°C, with the minimum temperature after spreading around -7°C.

Overall, the service providers did not encounter any issues with the effectiveness of the treatments. Road sensor data and observations from cameras did not indicate any significant effect to the carriageway state when the alternative de-icers were spread on dry roads. i.e. salt going more quickly into solution

In Area 4, snowfall occurred on the 12th February at 9.00, following the treatment at 05.00. The sensor data showed a freezing point of -20°C indicating the formation of a concentrated solution of de-icer on the road surface from melted snow. Camera images also showed a comparison between the main carriageway, which had been treated using the alternative de-icer, and a slip road which had undergone conventional treatment with sodium chloride. In the view of the Service Provider, the alternative de-icers had increased the melting of the snow compared to sodium chloride.

In Area 4, the Service Provider also noted that the residual effects of the treatment were still evident 36 hours later, despite a number of light rain showers after the last treatment.

In summary, at present there is insufficient evidence from trials on the network to draw firm conclusions on any greater effectiveness from treatments with the alternative de-icers. There is some indication, at present anecdotal, that the alternative de-icers resulted in snow melting more quickly, when applied as a precautionary treatment before snowfall, and that the residual effects of the treatments are longer lasting after treatment.

4.5 Practical issues

There have been no issues reported with storage or spreading of the de-icers by either Area.

The main practical issue reported related to the need to load and unload the spreader each time a treatment with the alternative de-icer is required. One Area noted that a spreader had been dedicated solely to the use of the alternative de-icers, such that it could remain filled with the de-icer and not require emptying after each treatment. The other Area stored the de-icers in the spreader so effectively had the same arrangement.

4.6 Recommendations

It is recommended that further monitoring of the use of the alternative de-icers is carried out in the next winter season, to provide more extensive data on the effectiveness of the treatments in a range of conditions.

Monitoring procedures should be in place before the start of the season, as opportunities to test the de-icer in appropriate conditions may be limited.

The reporting form included in Appendix A specifies the types of information to be recorded each time treatments are made.

Test locations on the network should be selected that allow quantitative weather and road condition data to be collected, as discussed in Section 4.2. Test locations will also ideally allow comparison of treatments with the alternative de-icers to standard treatments with sodium chloride at the same location. Examples are application of different treatments for each carriageway on a dual or motorway section.

Testing on the network is likely to indicate the effectiveness of pre-cautionary treatments e.g. how quickly the salt enters solution and longevity of the treatments.

Opportunities should be sought for testing the effectiveness of the treatments on snow and ice. It is recommended that a suitable site be identified off the network that can allow the testing of different application strategies e.g. liquid only treatments.

5 Review of current guidance

5.1 Precautionary treatments before frost

In calculating spread rates for precautionary treatments, the key assumptions tested were:

- Increased dissolution of the dry salt component of the pre-wetted salt i.e. a higher proportion of salt in solution due to the effect of the more hygroscopic de-icers (e.g. magnesium and calcium chloride) attracting moisture and facilitating the dissolution of salt
- A small reduction in the freezing point of the solution formed on the road surface (As none of the pre-wetting solutions proposed contain much alternative de-icer their effect on the freezing point suppression is small compared to the dry salt component)

As discussed in this report, the freezing point tests have provided assurance that the correct freezing point values have been used in the calculations.

The results of the dissolution testing have indicated that the use of the alternative de-icers, in particular de-icers that contain magnesium and calcium chloride, can increase dissolution compared to rock salt and rock salt pre-wetted with sodium chloride brine. It has also been demonstrated that the effect of trafficking and additional water on the road surface significantly increase the amount of dissolution.

Overall, it is considered that the results have demonstrated that the assumptions are valid when there is sufficient traffic and water to help dissolve the salt. (Lack of traffic to aid dissolution is also recognised in guidance for salt spreading without alternative de-icers)

Without the effects of added water and crushing of the salt, lower levels of dissolution were measured in the laboratory than assumed when calculating the spread rates. However, when less water is present less salt is required to dissolve to lower the freezing point of the water so the effects of low dissolution are not a major concern.

Another key consideration is that the spread rates in the current guidance were calculated assuming no residual salt is available from previous treatments to form a salt solution on the road surface. During the testing, it has become apparent that this does not represent a realistic condition that would be encountered on the road. If spreading salt on damp or wet roads in extreme cold temperatures, there must be sufficient residual salt available to have formed a salt solution and prevented ice formation at the time of spreading. If roads were damp or wet without any salt available, ice would already have formed before spreading.

An example is given as follows, to demonstrate the residual salt levels that could be expected when carrying out precautionary treatments in extreme cold. In this example, a treatment has been carried out spreading 9g/m² of standard pre-wetted salt, on a damp road, to prevent freezing down to -5°C. It is assumed that about 50% loss of salt occurs before the temperature reaches -5°C. The temperature continues to fall below -5°C and a further treatment is subsequently made (within 6 hours) spreading rock salt pre-wetted with an alternative de-icer (e.g. calcium chloride) on a damp road, for a forecast minimum temperature between -7°C and -10°C. For the treatments made with the alternative de-icer the guidance is currently for spreading at 17g/m², assuming a 45 to 50% loss after spreading which would result in 9g/m² residual salt.

Taking into account the residual salt levels from the previous treatment at 9g/m², there is approximately 4 to 5 g/m² of residual salt already present at the time of spreading. There will be further loss in this residual salt to around 2 to 3g/m² by the time the minimum temperature is reached. Hence, spread rates with the alternative de-icer can be reduced by approximately 5 to 6g/m², the equivalent amount needed to be spread to achieve the 2 to 3 g/m² of residual salt. Hence, only approximately 11 to 12g/m² of salt pre-wetted with calcium chloride would need to be spread in this scenario i.e. around a 33% reduction.

Overall, the laboratory testing has indicated that spread rates in the current extreme cold guidance do not need to be revised to prevent ice forming in extreme cold temperatures. While the levels of dissolution measured in the laboratory testing were low, it was considered that in practice the effects of traffic and additional moisture will increase the dissolution, if spreading at the correct rates, to sufficient levels to provide an effective treatment. The expected residual salt available in damp or wet conditions in extreme cold will provide further assurance that the current spread rates are adequate. There may be scope to reduce the rates, however it is considered that further site trials are needed before this could be implemented.

The use of the alternative de-icers may also offer advantages in terms of lower losses during and after spreading, and these have still been assumed when reviewing the rates. Some feedback from the site testing has indicated that the use of the alternative de-icers may increase the longevity of the treatments, however there has not been an opportunity to carry out significant monitoring of use on the network to confirm these assumptions due to the lack of extreme cold temperatures over the winter 2011/12.

The testing has reinforced the importance of trafficking to aid the salt dissolution. The current NWSRG guidance already contains the following note in the precautionary spread rate matrix:

'A follow-up treatment of 50% of the recommended rate should be considered in lightly trafficked areas at the lower end of temperature bands indicated'

It is considered important that the issue of trafficking is retained in the guidance. The current guidance is very prescriptive regarding the increase in spread rate and it is recommended that a small amendment is made to the note:

'In lightly trafficked areas, the effectiveness of the treatments should be closely monitored and follow up treatments considered'

When accounting for residual salt, there are two main scenarios to consider.

Case 1: There are one-off treatments made in extreme cold e.g. when treating in early morning, during periods when temperatures rise above the extreme cold range during the day.

Case 2: There can also be periods of sustained freezing in extreme cold conditions i.e. temperatures remaining below -7°C, over 12 hours or more, where there would have been continuous treatments using the alternative de-icers over this period.

Regarding residual salt, the current NWSRG guidance and draft AMM contain the following note:

'To take account of residual salt during periods of sustained freezing, when surfaces are well drained and there is no melt water or ice present, rates of spread for treatments carried out within 6 hours of previous treatments may be 50% of the rates in the table.'

The current note relates to Case 2 above. It is recommended that it be made clearer that sustained freezing in this recommendation refers to sustained **extreme cold** conditions i.e. temperatures remaining below -7°C over 12 hours or more and successive treatments made with the alternative de-icers.

A suggested amendment is as follows:

'To take account of residual salt during periods of sustained extreme cold temperatures, where temperatures do not rise above extreme cold over 12 hours or more, rates of spread for successive treatments, carried out within 6 hours of previous treatments using alternative de-icers, may be 50% of the rates in the table.'

For case 1, it is recommended that a general guidance note be added regarding assessing and accounting for residual salt. A suggested note is as follows:

'Where Service Providers are confident of significant levels of residual salt, spread rates may be reduced by an appropriate amount'.

To be more cost effective, the priority should always be to treat before extreme cold conditions occur, using standard treatments. When necessary, the alternative de-icers should be used only when spreading is required in extreme cold temperatures.

The greatest benefit in using alternative de-icers for precautionary treatments would appear to be for spreading on drier road surfaces, conditions most similar to the laboratory tests carried out with no additional water or crushing of salt. An important consideration for further site testing could be the benefit from use of the alternative de-icers before heavy hoar frosts in the early morning, and not just for extreme cold temperatures, where it is necessary to spread salt on a dry surface with little traffic. This scenario has been highlighted by Service Providers as particularly problematic.

5.2 Treatments on snow and ice

As previously discussed, the spread rates for treatments on ice and snows have been calculated based on the assumption that 20g/m^2 of dry salt is suitable for treating a thin layer of ice down to -5°C. This assumption was based on the current HA treatment matrix, which specifies the use of 20g/m^2 dry salt for treating ice at temperatures above -5°C.

The spread rates in the guidance were calculated assuming all the salt dissolves and forms a solution with concentration equivalent to the concentration on the eutectic curve for that temperature. i.e. allowing unlimited time after spreading. The results of the ice melting tests have shown that all the salt did not dissolve after 1 and 2 hours, even at -5°C, and that the use of the alternative de-icers has increased the rate of ice melting compared to dry rock salt or rock salt pre-wetted with sodium chloride brine. The increase in ice melting for alternative de-icers after both 1 and 2 hours was greater than assumed in calculating the spread rates in the guidance. This improved ice melting could allow de-icers to penetrate ice layers more quickly or allow slightly thicker layers of ice to be penetrated, per gram of de-icer.

Based on this increased ice melting, there is some scope to reduce the spread rates for the alternative de-icers relative to sodium chloride. However, it should be reiterated that the basis for the current spread rates for treating ice is that spreading 20g/m² of dry salt is effective for treatments at -5°C. The absolute amount of de-icer needed is dependent on the thickness of the ice layer for undercutting, if thick ice, or melting of thin ice layers. The rates have been developed to provide the same relative performance in terms of time and number of treatments that may be required. It is therefore considered that monitoring of treatments in site trials is important to verify the effectiveness of the proposed spread rates.

For the treatments on snow and ice, the effectiveness of the dry rock salt and salt pre-wetted with sodium chloride brine decreases relative to salt pre-wetted with the alternative de-icers as the temperature decreases. Dependent on further site testing, the results indicate that for equivalent performance the spread rates for the alternative de-icers, and also rock salt pre-wetted with sodium chloride brine, could be 20% lower between -5°C and -10°C. For treatments carried out between -10°C and -12°C, to provide an effective treatment in the same time scale, the results would indicate the spread rates for use of dry salt should be increased by about 20%, while the rates for use of alternative de-icers and sodium chloride brine remain unchanged.

The ice melting tests carried out with liquid only have demonstrated the risks of spreading liquids on sheet ice. The liquids were observed to spread out evenly over the surface, even when viscous liquids were applied in lines. This spreading out could result in a more slippery surface forming. The amount of ice melted per gram of de-icer was also measured to be significantly less than for dry or pre-wetted rock salt. The laboratory testing was on compacted sheet ice and therefore represents an extreme case compared to conditions on the network. If applying liquids on sheet ice, consideration should be given to closing the roads to allow the de-icer to melt the ice sufficiently. The use of liquids in lines could offer benefits on less compacted surfaces e.g. snow layers where the liquid could penetrate more easily before spreading out. These could potentially be more effective than the use of pre-wetted rock salt, where the salt grains may be encapsulated within the snow rather than melting and penetrating the layer. Again, site trials in extreme cold conditions would be recommended to confirm the effectiveness of these treatments.

6 Conclusions

Review of assumptions

1. The testing shows that the freezing points of the de-icer solutions are in good agreement with the assumed values. However, because the active alternative de-icer component of the de-icer was small compared to the dry salt component, differences in the freezing points were small.
2. The alternative de-icers are shown to be highly effective in ice melting tests. Rock salt pre-wetted with the alternative de-icers shows an increased rate of ice melting per gram of de-icer compared to dry rock salt or pre-wetted with sodium chloride brine. This ice melting is achieved with 70% of the de-icer comprising dry salt.
3. The increased ice melting of rock salt pre-wetted with the alternative de-icers means that they can penetrate and undercut ice layers more quickly or, potentially, thicker ice layers than rock salt or rock salt pre-wetted with sodium chloride brine. Also, the alternative de-icers are better able to fully melt thin ice layers, and do this more quickly.
4. The results of the ice melting tests show more ice melting than assumed, in developing the NWSRG guidance, relative to use of dry salt alone when using the alternative de-icers in pre-wetted salt. As a result there is potential to change the spread rates.
5. The alternative de-icers are hygroscopic and so attract water from the atmosphere or from the road. In this way, more water may be available to dissolve the dry salt component. There was possible evidence of this phenomenon in some dissolution tests, with the salt appearing visibly wetter when pre-wetted with the alternative de-icers.
6. The results of the dissolution tests show that, with no additional water or trafficking, the salt pre-wetted with the alternative de-icers has greater dissolution relative to salt pre-wetted with sodium chloride brine than was assumed in developing the NWSRG guidance. There is therefore potential to reduce the spread rates.
7. Testing with additional water and crushing of the salt resulted in significantly increased levels of dissolution, to the levels assumed in the guidance. There was also indication that the use of calcium and magnesium chloride brine increased the dissolution relative to sodium chloride brine when tested under conditions more representative of those encountered on the network.
8. Overall, it is considered that the results have demonstrated that the assumptions in developing the NWSRG guidance regarding dissolution are valid when there is sufficient traffic and water to help dissolve the salt.

Monitoring of use of alternative de-icers

9. There has been very limited use of the alternative de-icers on the network in the winter 2011/12 due to the limited occasions of extreme cold conditions. Based on this use, there has been some anecdotal evidence from Service Providers that the alternative de-icers provided a more effective treatment.

10. Due to the limited use, no firm conclusions can be made and there is a need for further monitoring to confirm the findings from the laboratory test program for precautionary and post treatments.

Effects of alternative de-icers on skid resistance

1. Samples of asphalt wetted with undiluted sodium chloride brine or brine with ABP did not show a significant reduction in skid resistance from samples wetted with water alone. Application of undiluted calcium chloride brine, magnesium chloride brine and ABP liquid resulted in greater reductions of up to 31% from the skid resistance with water alone.
2. Tests of 25% de-icer solutions, representative of concentrations expected after spreading, resulted in skid resistance values for all the de-icers within 10% of the level measured with water alone.
3. Overall, the results have given some indication that the amount of the alternative de-icers present on the road surface may not produce a significant drop (i.e. greater than 5 to 10%) in the skid resistance compared to a wet road. However, this should be verified by appropriate tests at traffic speed.
4. In sustained Extreme Cold conditions, where successive treatments are made with the alternative de-icers, there is the potential for residual levels of the de-icing chemicals to build up on the road surface and more concentrated solutions to be formed when small amounts of water are present. In these circumstances, it is recommended that Service Providers take appropriate action on routes where skid resistance is close to the minimum permitted level.

Review of current guidance (issued February 2012)

1. Laboratory testing has provided confidence that the current spread rates are effective for both precautionary treatments and treatments for snow and ice.
2. Taking account of the expected levels of residual salt, it is considered that precautionary spread rates could be reduced if previous treatments have been made before the extreme cold conditions and no precipitation had occurred to wash off the salt.
3. The greatest benefit from the alternative de-icers would appear to be for spreading on drier road surfaces
4. There is scope for changing the spread rates in the current guidance for the treatment of ice and snow, down to -10°C to reflect improved performance with the alternative de-icers.
5. It is recommended that spread rates are not reduced at this stage without more extensive monitoring of the effectiveness of the current rates in site trials.
6. An important consideration for further site testing could be the benefit from use of the alternative de-icers before heavy hoar frosts in the early morning, where it is necessary to spread salt on a dry surface with little traffic. This scenario has been highlighted by Service Providers as particularly problematic.

7 Recommendations

Overall, the work has provided assurance that the current spread rates are adequate to provide effective treatments.

Recommendations have been made for additional guidance, or where there is scope to reduce spread rates. Before reducing spread rates, it is recommended that more comprehensive monitoring is carried out of the alternative de-icers in site trials

It is recommended that the results are disseminated to the NWSRG working group on Extreme Cold Treatments.

8 Acknowledgements

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Appendix A Alternative de-icer reporting form

General information	
Road / Route	
Date	
Time of spreading	

Road information	
Predominant road type (1 lane / 2 lane / 3 lane)	
Surface type (SMA / HRA / Concrete)	
Length of road treated	

Spreading vehicle information	
Type of spreader (e.g. Schmidt 4x4, 6x4 or Romaquip 4x4, 6x4)	
Vehicle registration	

Treatment information	
Alternative de-icer used (Magnesium chloride / Calcium chloride)	
Type of Treatment (Precautionary before frost/ Precautionary before snow/ Reactive on snow or ice)	
Reason for using alternative de-icer? (Low temperature / Low humidity)	
Method of spreading (Pre-wetted or liquid only)	
Spread rate	
Length of road spread	

Environmental conditions	
Forecast minimum RST	
RST at time of spreading	
Forecast minimum air temperature	
Air temperature at time of spreading	
Road surface state (Dry / Damp / Wet)	
Humidity	

Performance reporting
Please comment on the de-icer performance, in particular in comparison to standard pre-wetted treatments. The following points are included for guidance:

- The road surface state after spreading e.g.
  - Bare/bare and wet pavement
  - Bare/bare and wet wheel tracks
  - Amount of ice or compacted snow
- Where possible information should be recorded from sensors e.g.
  - Surface state – Wet / Dry / Snow / Ice
  - Residual salt (Low / Medium / High)
  - Freezing point of solution on road (active sensors)
- Time for salt to enter solution for precautionary treatments?
- Time to become effective if applied to ice and snow?

General feedback

Performance

1. Were you able to visibly compare your treated road surface to another where the alternative chemical was not being used? **Yes / No**

2. Do you believe that the performance was better using the alternative chemical, compared to standard pre-wetted salting? **Yes / No / No difference**

Comments:

3. Was there any evidence that roads remained wetter after spreading (because of residual de-icer) compared to standard pre-wetted salting? **Yes / No / No difference**

Operational issues

4. Were the alternative de-icers spread using standard settings for pre-wetted salt? **Yes / No**

5. Were there any issues with spreading? e.g. poor spread distribution, blocking of nozzles **Yes / No**

Comments:

6. Were there any issues with storing the de-icers? e.g. crystallisation in storage tanks **Yes / No**

Comments:

7. Were there any issues loading and unloading de-icers to/from spreaders e.g. ability of conventional pumps to transfer de-icer from storage to spreader **Yes / No**

Comments:

8. Please comment on any other practical issues regarding the use of the alternative de-icers e.g. storage of sodium chloride brine removed from spreader tanks

Comments: