ATOC Good Practice Guide
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ATOC

Association of Train Operating Companies

ATOC Train Operators Safety Group Good Practice Guide – De-icing Agents for On Station Use

Synopsis

This Guide provides advice on the selection of suitable de-icing agents for use on and about stations and station car parks, in particular with reference to the independent research undertaken on behalf of the TOC community during 2005.

Contents

Part A

Issue Record

This Good Practice Guide is intended as a one off stand alone document. It is not the intention that it will be reviewed, or that any amendments will be issued, on any systematic basis. As such it will not be subject to version control.

Responsibilities

This Good Practice Guide is made available to all member companies of the ATOC Train Operators Safety Group. Recipients should ensure that copies are made available as required to those within their own organisations for whom its content is relevant.

Explanatory Note

This Guide is intended to reflect good practice and is advisory only. The extent to which a receiving organisation chooses to comply with any or all of its contents is entirely at its own discretion.

Supply

This is not a Controlled document. Copies (both printed and electronic) may be obtained from the secretary to the ATOC Train Operators Safety Group.

Part B

1. Purpose

This document is intended to assist Train Operators in selection of de-icing agents for use on or about the stations for which they are responsible, taking into account effectiveness, corrosive properties, cost and environmental considerations and also practical factors such as ease of storage and application. It should be noted that different types/areas of application will generally require different types of product for optimum results.

2. Scope

This guide is produced for the benefit of all member organisations of the ATOC Train Operators Safety Group.

3. Currency

The greater part of this document comprises the findings and recommendations from the independent research conducted by RSSB on behalf of ATOC during 2005 for which TRL Limited were engaged.

It should be recognised that inevitably the currency of any such report will diminish through time - while much of the report focuses on the characteristics of particular groups of product, where conclusions are likely to remain valid, reference is also made to specific products, the composition and existence of which will clearly change through time.

When approached by potential suppliers introducing new products, Train Operators should seek to satisfy themselves as to the effectives and appropriateness of what is being offered based on their chemical composition (see Section 5 below).

4. Introduction

Train Operators are responsible for the safety of those areas for which they are responsible in and around stations and which are used by the public and/or staff. This responsibility includes treatment of such areas to mitigate against the effects of frost, snow and ice. A number of commercial products are available for these purposes, each with different characteristics in terms of cost, effectiveness, ease of use and impact on the environment. In parallel, the particular characteristics demanded of any de-icing product will themselves depend on the prevalent climatic conditions, the size and location of the area to be treated, the availability of (staff) resources to undertake the treatment and other such factors.

The main body of this Guide seeks to highlight the key factors to be considered when identifying suitable products - in each case detailed guidance is provided in Appendix A.

5. Categorisation of De-icing Agents

Existing de-icing agents may be categorised as follows based on their chemical composition:

Chloride based:	Sodium chloride (NaCl), magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$). These de-icers can also be mixed with corrosion inhibitors.
Acetate based:	Calcium magnesium acetate, potassium acetate and sodium acetate.
Formate based:	Potassium formate and sodium formate.
Urea based:	Urea (also called carbamide).
Glycol based:	Ethylene glycol, propylene glycol, diethylene glycol.

Products falling under the same category will tend to exhibit similar characteristics. For further details please refer in particular to Sections 3.2 and 3.9 of Appendix A.

6. Physical Form of De-icing Agents

Many products are available in a variety of physical forms. The most basic division is between liquid and solid, with various subdivisions of the latter e.g. granular, crystal, etc.). The form in which the product is supplied and/or applied will influence its effectiveness in terms of penetration, speed of action, longevity of effectiveness, susceptibility to dispersion (e.g. by wind or rain), etc.

Other factors which may influence preferred form include the availability and security of storage facilities, the availability of the equipment needed and the availability of competent staff.

7. Areas to be Treated

Areas requiring treatment can be similarly categorised, as follows:

7.1 Platform areas: Key concerns here are

- passenger safety
- minimisation of the risk of damage to track and signalling equipment as a result of the corrosive properties of any product used
- potential damage to train floors/fittings
- turbulence from passing trains

7.2 Station areas other than platforms (e.g. forecourts, concourses, waiting areas, footbridges, etc.): Key concerns here are

- presence of significant amounts of metal infrastructure means that corrosion is still an important consideration
- slip/skid resistance
- away from track, electrical conductivity is less relevant
- away from track, adhesive qualities are less relevant

7.3 Car Parks:

- Typically large areas well away from tracks and other infrastructure, cost and ease/speed of application becomes a prime consideration

8. Staffing Considerations

The following staff related factors should be taken into consideration when identifying the optimum product for use at a particular location:

8.1 Availability of staff:

Are staff generally available to repeat applications of the product at the necessary frequency needed to ensure continued effectiveness?

8.2 Training/Competence of staff:

Does the handling, preparation or application of the product require any specific competence on the part of staff? How will appropriate staff training be provided and by whom? How will competence be demonstrated and maintained?

9. Personal Protection and Equipment

The following product specific factors should be taken into consideration:

9.1 PPE

The potential need for and availability of Personal Protective Equipment in the handling, preparation or application of the product should be considered.

9.2 Specialist Equipment/Facilities

Are specialised facilities and/or equipment needed for the handling, preparation or application of the product?

See Section 7.7 of Appendix A for further details.

10. Environmental Impact

Most de-icing agents have the potential to cause environmental damage, particularly if they are either stored or used inappropriately or in contravention of manufacturer's instructions.

Specific recommendations concerning the storage and application of de-icing products and the need to appreciate the drainage arrangements for the area(s) being treated are included below - if these are followed, then any effects on the environment impact will be managed and minimised and the likelihood of a measurable environmental impact almost eliminated.

10.1 Storage

The availability, nature and security of storage facilities need to be taken into account, particularly in respect of the potential environmental impact. Specific products will generally have recommended instructions for safe storage.

All de-icing products should be stored under cover/in containers and on an impermeable surface to avoid any washing of the material into surface water drains or into the ground. There should be no public access to areas used for storage.

10.2 Application

The manufacturer's instructions for use of de-icing products should always be strictly followed. Over-application is financially wasteful, increases potential damage to the environment and may present a safety hazard to both the public and staff. Appropriate investment should be made in provision of suitable equipment and in the training of staff in its correct use (see Sections 8 and 9)

10.3 Drainage Issues

A clear understanding of the site drainage is a pre-requisite for good site management and appreciation of the potential impacts of the use of de-icing products. The Environmental Agency have made it known that they will be increasingly challenging owners of sites of all kinds to demonstrate that they understand their drainage.

11. Written Plans

It is recommended that TOCs have a written procedure for de-icing activity at each of their stations. This should include details of

- the various areas to be treated
- the products to be used
- when, how and by whom the products are to be applied
- how and where products are to be stored
- a site drainage plan
- a simple assessment of potential impacts on the water environment
- risks associated with all the above and how these are to managed

APPENDIX

Copy of RSSB/TRL Research Report 'Evaluation of Frost, Ice and Snow Precautions at Stations'

Evaluation of frost, ice and snow precautions at stations

by S J Reeves, M G Evans and M H Burtwell

TRL Limited

EVALUATION OF FROST, ICE AND SNOW PRECAUTIONS AT STATIONS

Version: 1.0

by S J Reeves, M G Evans and M H Burtwell (TRL Limited)

Prepared for:	**Evaluation of Frost, Ice and Snow Precautions at Stations, Project T532**
Client:	**Rail Safety and Standards Board**

CONTENTS

Executive summary

The Train Operating Companies (TOCs) in Great Britain have had various concerns over their current winter maintenance procedures. There is no guidance on de-icers in the Railway Group Standards, other than to be aware of corrosion issues when choosing a de-icer. The Association of Train Operating Companies (ATOC) approached the Rail Safety and Standards Board (RSSB) requesting some research to be carried out into the most suitable de-icing products for stations. In response to this, RSSB commissioned TRL to carry out project T532, entitled Evaluation of Frost, Snow and Ice Precautions at Stations. The aim of the project was to assess the various de-icers available and produce recommendations as to the most suitable de-icers for use at stations.

The project was divided into six tasks:

Task 1- to carry out a literature review on the available de-icers and their properties

Task 2- to review current Railway Group Standards

Task 3- to gather information on winter maintenance procedures currently performed at stations

Task 4- to obtain information on winter maintenance in other rail and transport sectors

Task 5- to analyse and evaluate all the information obtained from Tasks 1 to 4

Task 6- to produce recommendations and guidelines for winter maintenance at stations

Task 1 involved producing a separate report (Evans, 2005) on the types of de-icers available and their advantages and disadvantages. Tasks 2 to 4 involved gathering information on current winter maintenance practices both in the rail industry and other transport sectors, such as airport, light rail and tram. Task 5 was to analyse all the information obtained and Tasks 6 to distil some recommendations out of this. This is the final report on the project and summaries the findings from all six tasks.

The research has identified three distinct areas within stations with separate issues; car parks, concourse/forecourts and platforms. The most suitable de-icers for each of these areas were examined and then recommendations given. The cheapest option of rock salt was deemed appropriate for station car parks as they are large areas to treat and run-off would be unlikely to affect the track. The number of metal structures present is limited and the surface is normally tarmac, rather than concrete, therefore corrosion is not a priority in this area. However, it was suggested that a corrosion inhibitor might be added to the salt for treatment of concourses/forecourts, as here there is usually a large amount of metal infrastructure, but it is away from the track.

The most sensitive areas to treat are the platforms. For these it was suggested acetates would be the most suitable de-icers. A potassium acetate product applied in liquid form and a sodium acetate product in a solid form is most appropriate. These products should be less expensive and more effective than the present Kilfrost products, while also less damaging to the track and station infrastructure than rock salt. Although purchase price is an issue, when it comes to the sensitive platform areas, adverse effects (corrosion and conductivity) on the track and the safety of the public should be paramount. The harmful effects on the environment and station infrastructure of de-icer run-off should also be considered.

As well as the de-icer product, the application rate is also important. Therefore, it is recommended that appropriate spreading equipment is used rather than ad hoc hand spreading in order to control the spread rate of the de-icer. Health and safety requirements should be considered both during application of the product and also during storage. The correct storage of the chosen de-icer product is also important in order to maintain its effectiveness and ease of application.

1 Introduction

The Association of Train Operating Companies (ATOC) Safety Group requested the Rail Safety and Standards Board (RSSB) to sponsor research on their behalf to assess the de-icers available in the market and recommend those most suitable for use on station platforms. TRL was therefore commissioned by the Rail Safety and Standards Board (RSSB) in February 2005 to carry out this assessment. The project, entitled 'Evaluation of Frost, Snow and Ice Precautions at Stations', comprised six tasks. The first was a literature review on the various de-icers available and their properties and characteristics. This task involved gathering information about the de-icers available and the benefits and practical issues associated with each. A separate report was produced for this task (Evans, 2005) and a summary of the results is given in Section 0.

The second task of the project was to review current Railway Group Standards in order to discover how these might limit the choice of the de-icers. The third task was to gather information, from the train operating companies, via a questionnaire, to ascertain which de-icers are currently being used and any problems found with these. Task four was to gather similar information from other rail and transport sectors such as airports and the London Underground. Task five involved the analysis of the data obtained from tasks one to four and task six was to produce guidelines and recommendations for the RSSB in the light of this analysis.

This report summarises the information gained in all the tasks and aims to aid TOCs in finding the most suitable de-icer for their stations.

Weather precaution products (de-icers) are used at stations to prevent accidents to passengers or vehicles caused by frost, ice and snow. It is particularly important that the edges of platforms are not slippery as the consequences could be fatal. Chemical de-icers can be applied for anti-icing, to prevent ice formation, or de-icing, to melt ice and snow already present. De-icers may have different degrees of effectiveness for anti-icing or de-icing and different application rates may be required for the different situations. Anti-icing is normally performed when the road temperature is forecast to be below 1°C and is dropping, and the humidity is such that ice may form. This means for anti-icing to be effective up-to-date weather information needs to be obtained. Less product is normally required to prevent ice forming than to melt ice already present.

Much research has been carried out into the use of various de-icing agents. This has been largely applicable to highways, but the experience gained from this research could also be successfully applied to station platforms

By far the most widely used means of de-icing pavements, highways and car parks, both in Britain and abroad, is by the use of chloride salts, the most common being sodium chloride (NaCl) in the form of rock salt. Rock salt is plentiful, cheap and a very effective de-icing agent. However, it causes corrosion of steel, both exposed and within reinforced structures, and its effect on the environment is also of increasing concern. As a consequence Network Rail has requested that other de-icing agents be employed on and around railway stations. There is concern within the industry, however, that alternative products may not be as effective as rock salt and are expensive.

This project aims to evaluate the de-icers available and to identify some suitable candidates that train operators may wish to consider using. Factors to be considered include their effectiveness at anti-icing and de-icing, the effective temperature, the effect on soft furnishings, cost, storage specifications, ease of application, comfort for passengers, i.e. no strong odour or staining of shoes and clothes and adhesion to the platform surface (e.g. when subject to draught from trains).

The information contained in this report was obtained from published and unpublished reports written by TRL, a review of recent literature, internet searches and from product manufacturers and distributors. Information on current de-icing practices was gathered from the TOCs and other transport sectors. The report aims to collate information from a range of sources, so that the above factors can be assessed for each de-icer and recommendations as to the most suitable de-icer for the application can be given.

2 Standards for station de-icing products

The standards governing the TOCs operations were examined for their specifications on de-icers. Very little guidance on de-icers is given in Railway Group Standards, but the information available is summarised in this section.

2.1 Railway Group Standard GI/RT7014

In Railway Group Standard GI/RT7014: Infrastructure Requirements at Stations it states that:

C4 Materials used for cleaning and de-icing

The effect that cleaning and de-icing materials have on the durability of platform surfaces shall be considered and only those that do not cause premature deterioration of the surface and adjacent track shall be used.

Corresponding to this are remarks that the materials used in platform surfaces, level crossings and bridges should also take into account the use of de-icers. This is the only reference to station de-icers in the standards and no advice on the types of de-icers which might fulfil this requirement is provided.

2.2 Network Rail guidance note

The only recommendation on appropriate de-icers provided to the TOCs originates from Network Rail, which has produced a guidance note, issued in September 2003, recommending the use of Kilfrost General De-icing Fluid (potassium formate solution) and Kilfrost Composite Ice Melter (granular sodium formate mixed with fine sand) on all station platforms. Network Rail insists that rock salt should not be used on platforms as it is concerned about the damage to concrete and corrosion of steel infrastructure. It also states that the grit in the salt can be transferred into the sliding door runners on rolling stock resulting in further damage.

The guidance note testifies that $300cm^3/m^2$ of Kilfrost GDF will de-ice down to -5°C, but that more severe conditions may require a higher application rate. It also suggests an application rate of Kilfrost CIM of $50g/m^2$ will provide protection down to –3ºC for anti-icing or when run-off would cause problems. At temperatures below this, a rate of least $100g/m^2$ is recommended. The guidance note states that these materials have been especially developed for Network Rail and have a low conductivity so as not to affect track circuits. However, no background information to support this or any comment on the product’s effectiveness at de-icing has been issued to the TOCs.

3 Summary of the types of de-icers available

A literature review (Evans, 2005) was undertaken on the types of de-icer available and their suitability for use in the station environment as part of Task 1. The parameters investigated included the effectiveness of the de-icer at melting ice and snow, slipperiness, corrosivity to metals and concrete, toxicity, impact on the environment and the cost of purchasing the products. The information contained in the literature review was obtained from published and unpublished reports written by TRL, a review of recent literature, internet searches and from product manufacturers and distributors. The information collated for the literature review is summarised in this section.

3.1 Mechanism of de-icing

Chemical de-icers melt ice and snow by depressing the freezing point of water to well below zero. The minimum temperature at which it is possible for a chemical to depress the freezing point is given by its eutectic temperature. This eutectic temperature is not reached in practice, as it only occurs at an exact concentration which cannot be maintained. However, the eutectic temperature is related to the practical effective temperature of the de-icer. For example, sodium chloride has a eutectic temperature of -21°C and is effective down to around -7°C, whereas calcium chloride has a eutectic temperature of -51°C and is effective down to about -31°C. In British climate, an effective temperature of -7°C is usually sufficient but, in Scotland, the use of de-icers with lower effective temperatures may be necessary.

Solid de-icers also need moisture in order to dissolve and start working. De-icers can be hygroscopic, absorbing moisture from the air and also deliquescent, dissolving in the absorbed moisture. This is dependant on the ambient humidity, for example sodium chloride absorbs moisture at a relative humidity over 75% and calcium chloride at a relative humidity of 29%. De-icers can also dissolve exothermically (releasing heat) like calcium chloride or endothermically (absorbing heat), such as sodium chloride.

Abrasives such as sand and grit may also be used. These do not remove ice and snow like chemical de-icers, but provide traction for feet and wheels. However, as they are not soluble they need to be removed afterwards or may be unsightly and cause problems by clogging drainage systems.

Although chloride de-icers, in particular sodium chloride, are the most commonly used products in Britain, non-chloride de-icing products are used in certain situations where corrosion of steel or aluminium infrastructure is a major concern and considered of greater importance than the more expensive purchase price. For example, due to their non-corrosivity, urea and glycol-based de-icers are employed by the Highways Agency for use on sensitive structures in the Midlands. However, there are concerns about the environmental effects of urea and it has been recommended by the Highways Agency and the Environment Agency that it is no longer used. Acetates/formates, glycols and urea are often used on airfield runways as they are less corrosive to aluminium and steel. The use of urea is also being phased out at British airports.

3.2 Categorisation of de-icers

The types of de-icer available can be categorised in terms of its active ingredient, e.g. chlorides, acetates, formates, urea and glycols. There is a range of proprietary products within each of these categories, which may have additives such as corrosion inhibitors, but have broadly the same properties. The benefits and possible problems due to each category of de-icer is summarised in **Table 3** to **Table 10** in Section 0. A more detailed description of the various de-icers is given in the literature review produced for Task 1 (Evans, 2005). Summary tables taken from the review are included in 0. The categories are:

Chloride based:	Sodium chloride (NaCl), magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$). These de-icers can also be mixed with corrosion inhibitors.
Acetate based:	Calcium magnesium acetate, potassium acetate and sodium acetate.
Formate based:	Potassium formate and sodium formate.
Urea based:	Urea (also called carbamide).
Glycol based:	Ethylene glycol, propylene glycol, diethylene glycol.

3.3 De-icing performance

The majority of the products available appear to be effective to temperatures well below the level achieved by either rock salt or urea. As far as the speed of their de-icing action is concerned, the information is not available for all de-icers, but what is obvious is that liquid de-icers perform better than solid and pre-wetted de-icers in this respect as they do not depend on climatic conditions (relative humidity) to initiate the de-icing action.

3.4 Corrosion characteristics

Rail infrastructure includes a large amount of metal which is naturally vulnerable to corrosion and which can be accelerated by exposure to de-icing chemicals. The rails are usually made of steel, as are the train wheels. Rail fastenings have components which are manufactured from cast iron and steel, dependent on the type of sleeper. Around 70 per cent of the track is supported by concrete sleepers, 25 per cent by timber and the remainder by steel. There is also a large amount of copper electrical cabling normally sheathed in plastic associated with switches, signals and train detection systems. Concrete or plastic conduits are laid alongside the track and also laid in the track are iron magnets for the automatic stopping systems. All these together with any utility pipes or wires running under or nearby the track could be affected by de-icer run-off from the platform.

The types of materials found on trains include steel, fibreglass, aluminium, a range of plastics, synthetic carpet, linoleum, wood, glass, Perspex, paints and lacquers. Finishes to the materials may be important, for instance brushed aluminium or polished, matt paint or gloss and metallic paints versus flat colours. These will be subject to de-icer walked in by passengers.

All chloride containing de-icers have corrosive effects, to different degrees, on both steel and aluminium. Chlorides also corrode the steel rebars in reinforced concrete causing spalling (chipping or flaking) of the concrete. Dissolved magnesium and calcium ions can also react with cement causing deterioration. All de-icers will increase the number of freeze-thaw cycles the concrete is subject to, which can exacerbate deterioration of poor quality concrete.

In comparison urea, glycol and acetate-based de-icers have considerably less corrosive effects than those containing chloride. Urea also reacts with concrete, and acetates and formates have some corrosive effect on galvanised steel as they react slowly with zinc. Acetates and formates should not be directly applied to materials made of galvanised steel or be stored in galvanised steel containers. This should not be a problem for components exposed to run-off as the de-icer will be diluted and exposure time is limited.

3.5 Conductivity effects

3.5.1 Vulnerability of electrical components

Corrosion is a particularly important factor in electric supply systems, as the electric current acclerates the electrochemical corrosion of the metal. At present around 40 per cent of the national rail network in Britain is electrified. Of this, around 7,578 single track kms of the network use 25,000 volt AC overhead electric cables as the power source. The current flows from the overhead cables to the train and is returned to the substation via the running rail and earth return circuit. Around 4,285 single track kms of the network is run using power supplied from a 750 volt DC electrified third rail laid at the side of the track. The DC system is more prone to corrosion than the AC system and the extra stresses at joints make these more prone to corrosion.

There are also other electrical components in the proximity of the track. Laid under the ballast or alongside the track are the electronics which control the switches, electric motors, communication cables to the switches and signals, transformers, circuit breakers, cables for train detection systems and emergency phones. Permanent and electromagnetic magnets, which are part of the automatic warning system (AWS) and track magnets to reduce arcing on the neutral sections of AC systems, are laid in the track. There may also be equipment not owned by the railway company such as utility pipes and cables lying under or alongside the track, which could also be corroded more quickly by stray currents.

Run-off from the station platforms onto the track has the potential to affect all this sensitive equipment. Both solid and liquid de-icers will dissolve in precipitation, or melting ice and snow, and the resultant solution may run on to the track. This run-off could have an adverse effect on the track components or leave a residue that may disrupt the connection between the train and track.

3.5.2 Stray current

Stray currents are those which have deviated from their intended course, for example flowing through the soil surrounding the electrified rail instead of the rail itself. If the conductivity of the soil has been increased by the presence of water and/or de-icing chemicals the probability of this occurring is increased. At the point the stray current leaves the metal infrastructure corrosion occurs. Stray currents may also be picked up by other metal structures nearby, for example utility pipes, and cause corrosion to these structures.

Stray currents also may interfere with the signals to and from the electronic components and the control centre. Stray current can reduce the electricity returned to the sub-station, increasing power costs. It may also heat up the electrical components causing further damage.

3.5.3 De-icer conductivity

All inorganic salts are electrolytes (conducting liquids); the conductivity is dependent not only on the type of dissolved material, but also on the concentration and temperature of the solution. The higher the concentration and temperature, the more conductive the solution is. The de-icer concentration will depend on the amount applied; the volume of ice and snow melted and the amount of precipitation. Sodium chloride solution is a strong electrolyte. The more conductive magnesium chloride solution is also reported to have damaged electrical systems and to cause arcing across electric insulators.

Acetates and formates are less conductive than chlorides, but they could still cause a problem if over applied. Potassium salts are more conductive than sodium salts. Urea is less conductive than both chlorides and acetates and the ammonia it forms is also weakly conductive. Glycol is the least conductive type of de-icer; it is less conductive than rainwater. The conductivity of the de-icers is given in Table 1. Unfortunately, the temperature and concentration of the conductivity measurements are not identical for all the de-icers (Flomotion Systems, 2004). Around a two per cent increase in conductivity is expected per 1°C increase in temperature.

Table 1: De-icer conductivity (Flomotion Systems, 2004)

De-icer	Concentration % by weight	Temperature °C	Conductivity µS/cm
Sodium chloride	5 10 26	18	67200 121000 215000
Calcium chloride	5	18	64300
Magnesium chloride	5	18	68300
Potassium acetate	4.67 9.33	15	34700 62500
Sodium acetate	5	18	29500
Glycol	100	25	0.3
Urea	100	25	5000
Kilfrost CIM (sodium formate)	10	20	55000
Rainwater	100	25	30-100

As can be seen from the table, concentration has a large effect on conductivity. In addition to choosing the correct de-icer, it is important that the correct spread rate is applied. Over-application especially when there is little rainfall, increases the concentration of de-icer reaching the track. It should be noted that even if a product is lower in specific conductivity, if a higher dosage is required for it to be effective the resultant solution may actually be more conductive.

Rainwater itself is conductive, so the drainage around the track and electrical circuits is also important to prevent the potential for corrosion and damage from stray currents.

3.6 Frictional characteristics

There is limited information available regarding the slip resistance of de-icing products. However, the information that is available from the reported field and laboratory trials indicates a good degree of performance for a variety of de-icing products. Granular products may show better slip/skid resistance than liquid products, simply because they are granular, but this effect soon disappears once the grains go into solution.

Further testing would be required to confirm the slip resistance of any potential products (see Section 10).

3.7 Environmental characteristics

All categories of de-icers reviewed have, to varying degrees, adverse impacts on the environment. The most serious impact of chloride-based de-icers is vegetation and tree damage, although the rate depends on the amount of chloride each product releases to the environment. The common corrosion-inhibiters may have a tendency for oxygen depletion through high Biological Oxygen Demands (BOD) and Chemical Oxygen Demands (COD) and eutrophication[1] of the water environment.

Of all the categories considered, urea and glycol based products have the most adverse impact on the environment. Although these products do not have a serious impact on vegetation and trees, there are environmental concerns regarding the use of urea which releases ammonia to water courses and could cause toxicity to aquatic life at low concentrations. Glycols have very high BODs and CODs which has led to their reduced use as runway de-icers.

Among the de-icing categories considered, acetate-based de-icers appear to have less impact on the environment than urea and glycols, although the slight oxygen depletion they cause may be a potential toxicity problem for marine life. CMA causes less toxicity to marine life than potassium acetate, which is readily biodegradable, but moderately toxic to fish and invertebrates. One of the potential advantages of using of a potassium acetate product is the reduced frequency of application; hence less of the product contaminates the environment. Acetates are less toxic than formates.

3.8 Cost

The costs of the reviewed products, shown in Table 2, are given in pounds per tonne. An approximate cost is also given for both anti-icing and de-icing treatment of a 10 square metre area of platform over a 24-hour period. This is based on the recommended de-icer spread rates and frequencies given by the manufacturers.

[1] Eutrophication is the reduction of dissolved oxygen caused by algae blooms produced by the presence of excessive nutrients, such as phosphorous and nitrogen in the water system.

Table 2: Comparison of the costs of de-icers

De-icer		£/tonne	Cost in Pence (10 m²/24h)	
			Anti-icing	De-icing
Sodium chloride	Rock salt	25	0.3	1.0
	Safecote treated rock salt	35	0.4	1.4
Magnesium chloride	Ice Ban	180	4.5	9.0
Calcium chloride	SnoMelt	57	5.7	2.3
Sodium acetate	NAAC	1400	35.0	70.0
	Clearway 6s	1400	42.0	84.0
	Clearway 8s	1400	28.0	56.0
Potassium acetate	ApClear KA1	650	8.1	16.3
	Safegrip	400	6.0	20.0
	Cryotech E36	600	7.5	15.0
	Cryotech CF7	600	7.5	15.0
	NC-2000	600	3.6	7.5
	NC-3000	600	3.6	7.5
	IF32	900	22.5	45.0
	Isomex 1	900	13.5	45.0
Calcium Magnesium Acetate	CMA40	600	12.0	24.0
	CMA	600	12.0	24.0
	Clearway CMA Plus	1100	22.0	44.0
Sodium Formate	Kilfrost CIM	1250	62.5	125.0
Potassium Formate	Kilfrost GDF	1250	62.5	125.0
	Clearway F5	1000	20.0	50.0
Urea		650	26.0	65.0
Glycol		990	9.9	39.6

It can be seen that rock salt is by far the cheapest de-icer available and Kilfrost CIM and GDF are amongst the most expensive. However, it is also important to consider the indirect costs associated with the effect of the de-icer product on the station infrastructure and the wider environment. Another increasingly important factor to consider is the legal cost from public and employee accident claims that could be incurred if an ineffective de-icer is applied.

3.9 Summary of de-icer properties

The advantages and disadvantages of the different categories of de-icers are summarised in Table 3 to Table 10.

3.9.1 Chlorides

Chloride based de-icers are the most commonly used type of de-icer. The most used of these are sodium chloride, magnesium chloride and calcium chloride.

3.9.1.1 Sodium chloride

Sodium chloride is the most commonly used de-icer. In Great Britain, the predominant form is rock salt as this is the cheapest and is readily available. Sodium chloride can also be applied in solution as brine or pre-wetted to decrease the time it goes into solution, especially if applied in low humidity conditions. Pre-wetting also increases the de-icer's adhesion to the platform surface. The main benefits and possible problems of sodium chloride as a de-icer are given in Table 3.

Table 3: Benefits and problems of sodium chloride

Benefits	Possible problems
• Cheapest of the options in the form of rock salt • Effective de-icer down to -7ºC • Easily applied • Non-toxic to humans	• Corrosive to steel and aluminium and re-reinforced concrete • Harmful to vegetation • Leaves a white residue on soft furnishings and floors

3.9.1.2 Magnesium chloride

Magnesium chloride is often used in the USA because it has a lower effective temperature than sodium chloride. It is not normally used in Great Britain because it chemically attacks concrete and the climate does not necessitate its lower effective temperature. The main benefits and problems associated with using magnesium chloride as a de-icer are summarised in **Table 4**.

Table 4: Benefits and problems of using magnesium chloride as a de-icer

Benefits	Possible problems
• Effective de-icer down to -15ºC • Can be used as a solid or a liquid	• Corrosive to steel, aluminium and chemically damages concrete • Damaging to vegetation • May leave an oily residue

3.9.1.3 Calcium chloride

Calcium chloride is also a de-icer more often used in the harsher USA climate. Its benefits and possible problems when used as a de-icer are given in Table 5.

Table 5: Benefits and problems of using calcium chloride as a de-icer

Benefits	Possible problems
• Effective de-icer to -31ºC • Can be used as a solid or a liquid	• Corrosive to steel and aluminium and reinforced concrete • Damaging to vegetation • Potential irritant to skin, eyes and respiratory tract • May leave an oily residue

3.9.1.4 Additives

Recently a number of agricultural based salt additives have come onto the market. These are based on by-products of the sugar beet industry and are brown viscous liquids which are often mixed with salt. The salt may also be bought already mixed with the additive. Safecote is the most used product of this type in Britain. The benefits and problems of using an additive such as Safecote, with sodium chloride, are given in Table 6.

Table 6: Benefits and problems of using a salt additive

Benefits	Possible problems
• Enhanced performance at low temperatures • Reduced corrosion • More adhesion to the platform surface	• Still contains sodium chloride (although 23 per cent less) with all the environmental and conduction problems that entails • Strong odour • Brown staining of soft furnishings and flooring

3.9.2 Acetates

Acetates, in particular potassium acetate, are frequently used on airport runways because they are less corrosive to aluminium than salt and more environmentally friendly than urea and glycol. Their benefits and possible problems when used as a de-icer are given in Table 7.

Table 7: Benefits and problems of using acetates as de-icers

Benefits	Possible problems
• Essentially non-corrosive to most metals and surfacing materials • Environmentally benign	• Moderately corrosive to galvanised steel • Approx 20-30 times more expensive than rock salt/tonne

Calcium magnesium acetate is considered the most environmentally benign de-icer. It is less corrosive to steel, aluminium and reinforcement bars in concrete than sodium chloride, but it is expensive. It is less effective than salt below -5° C, acts less quickly and requires a greater application rate. However it lasts longer, so requires fewer applications (TRB, 1991).

Sodium acetate is effective down to -13°C and spread at 15-25g per m^2. It has only a slightly higher density than urea, so may require pre-wetting if used near high-speed trains.

3.9.3 Formates

Formates are similar to acetates and are often used at airports in mainland Europe because they have a weaker odour than acetates. Kilfrost CIM and GDF, the products recommended by Network Rail, contain sodium formate and potassium formate respectively. Clearway F5 and Aviform L50 are also potassium formate solutions, which have lower BOD and COD values than potassium acetate. Potassium formate has a low corrosive affect on steel but, similarly to potassium acetate, a moderate corrosive effect on galvanised steel, zinc, silver and solder. Around $25g/m^2$ is normally applied.

Peak SF and Aviform S-solid are other granular sodium formate products also with low corrosion to steel, copper and aluminium, but moderate corrosion to galvanised steel, zinc and solder. The benefits and possible problems of using formates as a de-icer are given in Table 8.

Table 8: Benefits and problems of using formates as a de-icer

Benefits	Possible problems
• Essentially non-corrosive to most metals and surfacing materials • Environmentally benign	• Moderately corrosive to galvanised steel • Approx 20-30 times more expensive than rock salt/tonne

3.9.4 Urea

Urea used to be applied to airport runways and on sensitive highway structures such as bridges, but its use is being phased out due to environmental concerns over the ammonia produced. The benefits and problems of using urea as a de-icer are summarised in Table 9.

Table 9: Benefits and problems of using urea as a de-icer

Benefits	Possible problems
• Non corrosive to metals and surfacing materials • Low conductivity	• Releases ammonia and nitrates to water courses • Approx 20-30 times more expensive than rock salt/tonne • Ineffective below about -7 °C • Light-weight granules are readily blown away by passing trains

3.9.5 Glycol

Glycols are viscous liquids used in the air industry for de-icing aircraft. They have high BOD and COD values, so give rise to environmental concerns. The airport run-off is often collected and treated to mitigate this. Ethylene glycol is toxic to mammals (including humans) even at low levels, but propylene glycol is not, so despite its higher BOD, is normally preferred. The benefits and problems of using glycol as a de-icer are given in Table 10..

Table 10: Benefits and problems of using glycol as a de-icer

Benefits	Possible problems
• Non corrosive to metals and surfacing materials • Not easily washed away • Low conductivity	• Large oxygen demand on environment • Some glycols are toxic • Approx 40 times more expensive than rock salt/tonne

3.10 Conclusions of the review

From the literature review it can be seen that the products in the different de-icer categories have varying properties which will affect their use at stations. Some of the relevant properties are summarised below:

1. All chloride containing de-icers have corrosive effects, to different degrees, on both steel and aluminium and their solutions are highly conductive, which may affect electrical components on the track. Magnesium and calcium chloride can also damage concrete.
2. Acetate and formate based de-icers have considerably fewer corrosive effects than those containing chloride and are less conductive. They have a low impact on the environment, but have a higher purchase price.

3. There are potential environmental problems associated with urea, as ammonia is released by urea in watercourses. It causes toxicity to aquatic life even at low concentrations. It is not corrosive or highly conductive.
4. Although glycols are reasonably non-toxic to aquatic life and biodegrade rapidly, they exert a large oxygen demand on water systems. Some glycols are toxic to humans. They are low in corrosivity and conductivity.
5. The choice of a solid or liquid de-icer may depend on the type of treatment (anti-icing or de-icing) required.

4. De-icers currently used by TOCs

In order to understand the current situation with regard to winter maintenance at stations and the issues which are faced at stations, information was sought from the TOCs. To facilitate this, a questionnaire was devised and sent to the 25 TOCs. A copy of the questionnaire is given in 0, together with a list of all the TOCs that replied. There were 17 replies giving a good representation of the range of de-icers currently used. In some companies, separate replies were received from the different regions. The information they provided on their current de-icers is summarised in Table 11. The responses are given as received and are the opinions of the TOCs. The products would need to be properly tested before conclusions on specific products could be reached (see Section 10).

Table 11: Summary of de-icers used by TOCs

De-icer product (active ingredient)	Product description	No. of TOCs applying on platforms	Summary of TOC comments
Salt (sodium chloride)	Granular solid, >90% sodium chloride	8	Some TOCs use the purer marine salt rather than rock salt to limit staining to train flooring. The majority of TOCs that use sodium chloride were satisfied with its effectiveness. It is often used in car parks, but in a number of cases also on platforms. Little was mentioned about any significant corrosion of station infrastructure, but Network Rail is more likely to be aware of this issue.
Procoat (sodium chloride)	Safecote and Peacock marine salt (purer than a rock salt)	1	Additives are relatively new to the de-icer market, although Safecote has been trialled on highways. The additive acts as a corrosion inhibitor to the salt. The TOC has been using it for 4 months and was satisfied with its performance. Although no comments were given on the smell and colour of the product, it could be a possible problem. Another TOC also mentioned looking into the use Safecote.
Kilfrost CIM (sodium formate) Kilfrost GDF (potassium formate)	Granular sodium formate plus fine grade sand Potassium formate solution	9	Most TOCs using the Kilfrost products were dissatisfied with their effectiveness and were only using them because of the Network Rail guidance note. A number of TOCs commented on refreezing causing slipperiness (see Section 3.6) and the high cost of the product

De-icer product (active ingredient)	Product description	No. of TOCs applying on platforms	Summary of TOC comments
Ice Melt (urea)	White crystals or "prills" of urea coated in 1% formaldehyde as an anti-caking agent	3	Most TOCs using Ice Melt were satisfied with its effectiveness. Some commented on staff complaints about the ammonia smell and white residue left on soft furnishings and train flooring.
Thaw (urea)	Red brown granules of 70-100% urea	6	Quite a few TOCs are using this product and most seem reasonably satisfied with it. They commented that its low density made it subject to draughts from trains. Also it has an ammonia smell and leaves a white residue on trains and platforms. One TOC said it was only effective at anti-icing not de-icing.
Clearway (potassium acetate)	Solution of 50% potassium acetate and corrosion inhibitors	1	There are a number of Clearway products, which one was used was not specified, although the TOC stated that it was potassium acetate based and both liquid and granules were used. Clearway 1 and 3 are potassium acetate solutions. Clearway S6 and S8 are sodium acetate granules. The TOC had been using it for six years and was satisfied with its performance.
Ice Clear (urea)	White "prills" of urea	1	The TOC had only been using Ice Clear for a year. They thought its effectiveness was satisfactory, but it was slippery (see Section 3.6), so an alternative de-icer is being sought
SupaThaw (calcium chloride)	White powder of calcium chloride (80-100%) and a mineral anti-slip additive	1	The TOC trialling this product said it was extremely slippery (see Section 3.6) and coincided with a high number of accidents. Its use has been stopped after less than a month.
Cryotech NAAC (sodium acetate)	Spherical white/grey pellets of 97% anhydrous sodium acetate with <1% corrosion inhibitors	1	The TOC has only been trialling it for two months, but was satisfied with its performance.

The information gathered showed that a variety of de-icers are being used on station platforms, the most prevalent being salt and Kilfrost. A significant number of TOCs in Great Britain are applying urea based products such as Ice Melt, Thaw and Ice Clear. A number of companies have tried Kilfrost products, but were dissatisfied with the results, and were therefore trialling other products or returning to using salt.

The solid products were applied either by hand, shovel/scoop or by hand-pushed hopper spreaders. The liquid products were sprayed by hand and generally thought more difficult to apply. The application rates were often uncontrolled especially when applied by hand or shovel, so TOCs were unable to provide spread rates. When rates were given, they were around 50g/m^2 for salt and Thaw, and 50-100g/m^2 for Kilfrost.

As part of the questionnaire, the TOCs were asked to rate their current de-icers in terms of effectiveness, ease of application and coverage. In order to consolidate the results, very poor was given a value of -2, poor -1, satisfactory 1, good, 2 and excellent 3. The total for each de-icer was combined and the percentage of the maximum score calculated. The results are summarised in Figure 1, with the number of replies the score is comprised from indicated (where more than one questionnaire was returned per TOC this is included). It should be noted that de-icers only used by one TOC, such as Procoat, Clearway and NAAC show only one company's view on the product. Kilfrost was split into CIM and GDF when specified, but if not, is shown on the graph under Kilfrost. Again it should be noted the ratings are based on the views of the TOCs, not experimental evidence.

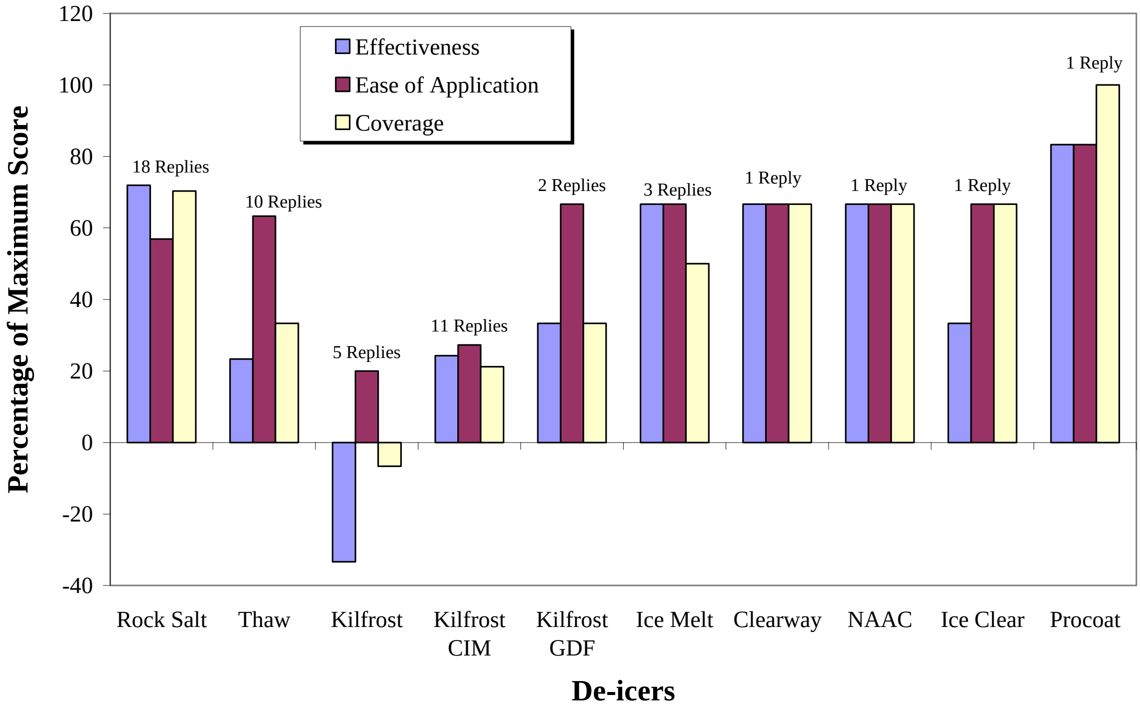

Figure 1: Graph of TOCs ratings for currently used de-icers

From Figure 1, it can be seen that Kilfrost was particularly poorly rated. Rock salt was thought to perform well by all who used it and the TOCs that used NAAC, Clearway and Procoat were satisfied with these products.

Network Rail

The questionnaire was also sent to Network Rail managed stations. These are:

Birmingham New Street
Cannon Street
Charing Cross
Edinburgh Waverley
Euston
Fenchurch Street
Gatwick Airport
Glasgow Central
King's Cross
Leeds
Liverpool Lime Street
London Bridge
Manchester Piccadilly
Paddington
Victoria
Waterloo

One reply was received within the timescale of the project; this was for Edinburgh Waverley station. They have been using Kilfrost CIM for five months, before that they used Peacock marine salt. They state Kilfrost is more effective than salt and less needs to be applied.

NB. Although the Network Rail guidance note recommends Kilfrost GDF for the platforms and Kilfrost CIM for footbridges and barrow crossings a significant number of people are using the solid product for the platforms. Using the liquid de-icer prevents the loss of product from wind and draughts from trains that they mentioned.

5 Problems identified with currently used de-icers

Problems identified by TOCs with their current de-icers were:

- *Slip resistance* - Slipperiness caused by the de-icer itself (Ice Clear and Supathaw), an oily residue produced by the de-icer or from re-freezing (Kilfrost).
- *Adhesion to platform surface* - Low density granular de-icers are blown away by winds and draughts from high-speed trains (Kilfrost CIM and Thaw granules)
- *Cost* - The high purchase price of the product and its availability from only one supplier was a particular issue with the Kilfrost products.
- *Staining of train flooring and soft furnishings* - Some products left a white residue (Thaw and salt).
- *Unpleasant odour* - Staff complained about the smell of ammonia from the urea based products Ice-melt and Thaw.
- *Health and safety* - Staff complaints over skin irritation from applying Kilfrost CIM.
- *Application* - Difficulty in applying the product (Kilfrost GDF) and difficulty in spreading as the product forms a paste when damp, which can even be straight from the bags (Kilfrost CIM). The need to apply high doses (Kilfrost).

- *Rural stations* - Impractical to re-treat rural stations with products that need frequent applications (normally a de-icer product is applied once to three times per week routinely during winter to rural stations whatever the weather). One TOC said Kilfrost needed to be applied every two hours.
- *Effectiveness* - The product was only effective at anti-icing and not de-icing (Thaw). Kilfrost was generally thought to be ineffective. Salt was said to be the most effective.

Corrosion

Little was mentioned about corrosion by the TOCs and most of those that did comment said they had not observed corrosion to either metal or concrete structures. Some TOCs mentioned minor damage to concrete platforms and steel platform structures. Only one TOC mentioned significant corrosion of steel platform infrastructure when using rock salt. However, it would be expected that Network Rail would be more aware than the TOCs of corrosion problems, especially with regard to the track.

6 De-icers used by other transport sectors

Other transport sectors face similar problems to the rail industry. For example they also possess large amounts of metal infrastructure and sensitive electronic equipment that could be vulnerable to accelerated corrosion caused by de-icers. Therefore, the questionnaire was also sent to representatives of the light rail, tram, London Underground and air industries in order to discover how they dealt with these issues.

6.1 Other rail sectors

Trams, light rail, Northern Ireland Rail and London Underground Limited (LUL) were contacted for their views on winter maintenance of their networks. However, many of the tram systems are new, so no long-term data on corrosion etc. are available. Trams also tend to travel along streets, so will be subject to any de-icer applied by the local council (usually rock salt).

Information on de-icers used by London Underground Limited was requested, but indications from the internet suggest Kilfrost is used on their platforms. There are also eight tram/light rail systems in the UK, these are:

Tyne and Wear Metro

Docklands Light Railway

Metrolink Manchester

Croydon Tramlink

Midland Metro

Nottingham Express Transit

Sheffield Supertram

Blackpool (historic trams)

Unfortunately, only one reply was received in the time scale of the project. This was from Nottingham Express Transit, which applies Thaw with a spread rate of 50g/m^2 on their platforms. The local council apply rock salt to their car parks and depots. Nottingham Express Transit said Thaw was effective even on snow, but was easily blown away and expensive. Their network is too new for corrosion effects to be apparent.

6.2 Airports

Airports suffer from similar problems to railways, as they too have metal structures (primarily aluminium) and electronics to protect against corrosion. Skid resistance is extremely important on a runway due to the high speeds involved during take off and landing. Airports are also becoming increasing aware of the environmental impact of their de-icing activities.

British Airports Authority (BAA) is responsible for the largest airports in Britain- Heathrow, Gatwick, Stansted, Glasgow, Edinburgh, Aberdeen and Southampton. BAA has been using potassium acetate based de-icers since 1986/1987. Glasgow Airport is the only exception; Konsin (ethylene glycol) is used because of the high rainfall experienced. The more viscous fluid is less easily washed away and as potassium acetate is applied as a 50 per cent solution it is already diluted, whereas glycol is applied neat. Glycol is also used at Manchester Airport.

Acetates are normally favoured over glycols because they have much lower BODs and CODs. Urea has been banned by the BAA because the ammonia it releases is environmentally damaging and is only effective down to -5°C. However, some airports still use it, for example in the USA it is still widely used because they have less stringent environmental regulations. Propylene glycol is still used to de-ice aircraft.

The Aerospace Material Specification (AMS) 1435 issued by the G-12 Aircraft Ground De-Icing Steering Committee Society of the Automotive Engineers (SAE) sets the specifications for runway de-icers to be used on all international airports (see 0). Acetates meet these specifications.

European airports tend to use formates because of their weaker formic acid odour rather than the acetic acid (vinegar) odour of acetates. The potassium acetate product Clearway 3 has been used by the BAA since the 1990s. This has been modified to be more viscous than the previously used Clearway 1, so it is not so easily washed away by rainfall. Their current supplier is Vedugt, on a three year contract. There are six suppliers in the UK. The normal spread rate is 20g/m^2 for anti-icing treatment and 40g/m^2 for de-icing treatment, but these are dependent on the weather. They state that there is no gain in applying more than 50g/m^2. The only deterioration BAA has observed is a few cracks on the edges of the runway due to freeze-thaw action.

7 De-icers that might address the TOCs' problems

To satisfy every situation found at a station and meet all the needs of the public, TOCs and Network Rail a de-icer would need to have the following characteristics:

- Effective in the British climate (an effective temperature of -10°C is probably suitable to include Scotland)
- High skid resistance
- Non-corrosive to steel and concrete infrastructure
- Low conductivity

- Low environmental impact
- Easily applied
- Low in cost
- Require a low application rate
- Leave no residue on soft furnishings and flooring of trains
- Not be blown away by wind or the draught from high-speed trains
- Long lasting
- Capable of being used as both for anti-icing and de-icing

However, no de-icing product is perfect; therefore no one product will meet all requirements for all situations. Different station areas have different priorities for these characteristics, so it may be most effective to use different products in each area. The areas identified are car parks, station areas (other than platforms) and platforms. In this section the issues of each area are outlined and possible de-icers for each are given.

7.1 Car parks

Car parks are normally a large area of asphalt with limited metal infrastructure such as signs and barriers. Some degree of trafficking is present in order to crush a granular de-icer and aid it to enter solution. The run-off is unlikely to affect the track and passengers are unlikely to walk the de-icer onto the trains. The prime concern for car parks is treating a large area as cheaply as possible. Corrosion, conductivity and residue are not such large concerns so the cheapest option may be the best.

7.2 Station areas other than platforms

Areas such as forecourts, footbridges, waiting areas and concourses often have passenger/luggage and catering vehicles and a large amount of pedestrian traffic. There is a significant amount of metal infrastructure, such as information signs, barriers, seating and lighting. There is less probability of de-icer run-off reaching the track and being walked onto trains than on the platforms. Therefore, the most important issues here are skid resistance (vehicles) and slip resistance (pedestrians) and protection of the station infrastructure. Conductivity and surface adhesion are not major concerns.

7.3 Platforms

Platforms are the most difficult areas to treat. Not only is passenger safety a prime concern, with slips at the edges of platforms having possibly fatal results, but this area is the closest to the track. De-icer can run-off the platform causing damage to the track or electrics. There is also a high probability that a de-icer will be walked onto the trains by passengers causing damage to train flooring and soft furnishings. Adhesion to the platform when subjected to the strong draught from high-speed trains is also an important factor. Therefore, any de-icer has to be effective, low in corrosivity and conductivity and unlikely to be blown off the platform by passing trains. Also, as the de-icer is likely to be walked onto the trains, it should not stain or damage train flooring or seating. For the public’s comfort in the enclosed area of the train, a strong odour is also best avoided. Cost is obviously an issue, but TOCs are probably prepared to pay more for a suitable de-icer for this sensitive area.

7.4 Other issues

Rural unmanned stations can provide a particular problem. A long lasting de-icer is required that does not need frequent applications and which can be applied on minimal visits by maintenance personnel.

Winters are hasher in Scotland than in the rest of Great Britain and a de-icer with a lower effective temperature may be required.

The environmental impact of the de-icer is important in all the areas to be treated.

7.5 Summary of de-icer products

There is a large range of de-icers available that can be put into categories of their active ingredients. Each category has its benefits and potential problems and the products in the category may have slightly different characteristics. A summary of the main characteristics is given in Table 12.

Table 12. Summary of de-icer characteristics

De-icer type	Product	Effective temperature	Purchase price	Corrosion	Environment	Other
Chlorides	Sodium chloride	-7°C	Cheap	Very corrosive to metals and concrete	Damages vegetation	Highly conductive
Acetates	Potassium acetate Sodium acetate Calcium magnesium acetate	-15°C -15°C -6°C	20 to 50 times more expensive than rock salt	Moderately corrosive to galvanised steel. Considered least corrosive de-icer	Slightly high BOD, but relatively environmentally benign Considered the least environmentally harmful de-icer	Less conductive than chlorides
Formates	Potassium formate Sodium formate	-15°C -5°C	20 to 50 times more expensive than rock salt	Moderately corrosive to galvanised steel	Slightly lower BOD than acetates	Less conductive than chlorides
Glycol	Propylene glycol	-15°C	40 times more expensive than rock salt	Moderately corrosive to galvanised steel	High BOD and COD damages water systems	Viscous so not easily washed away
Urea		-5°C	25 times more expensive than rock salt	Not corrosive	Forms ammonia which is toxic to aquatic life	Low density means easily blown away

7.6 Form of the de-icers

In addition to the choice of active ingredient in the de-icer, its physical form will also have an effect. There are advantages and disadvantages to applying a product as a solid or liquid, these are summarised below:

Liquid de-icers

- Most suitable for anti-icing as they do not need time to go into solution
- Not blown off the platform by high-speed trains
- Do not block sliding train doors
- No re-crystallised residue to stain train floors and seats as with some solid de-icers

However,

- Spray equipment is needed to apply the products
- Treated surface may become slippery
- Easily washed away if not viscous

Solid de-icers

- Penetrate snow and ice better than liquids
- Provide traction until granules go into solution
- Are easier to apply than liquid de-icers

However,

- Light solids may be blown away by the draught from trains
- They take time to go into solution especially in low humidity conditions or with low pedestrian flows provide limited crushing of the grains
- Granules may disrupt sliding door mechanisms

The choice between liquid and solid de-icer depends on the situation. For example, if sliding doors are commonly used or high-speed trains are the primary service causing strong draughts, a liquid may be most appropriate. Whereas if the station experiences a lot of snow or rain, a solid de-icer may be best. Also, for anti-icing a liquid may be more effective, whereas for de-icing a solid may be more effective. It is likely that to have both de-icers available would be the best option.

7.7 Spreading equipment

There are a number of options available for spreading both solid and liquid de-icers that would be suitable for a station environment. These range from small, manually operated spreaders and backpack sprayers through to larger, towable spreaders and small vehicles.

7.7.1 Solid material spreaders

Equipment discussed in this section would be suitable for spreading solid materials such as urea, sodium acetate, calcium magnesium acetate and sodium formate as well as traditional rock salt.

Manually operated spreaders are often recommended for spreading solid de-icers over small areas and will deliver a more even and accurately dosed spread as compared to hand spreading. For example, the *Cruiser Turbocast 300* from Glasdon U.K. Ltd can hold around 70kg of material and costs approximately £800. The spread rate and width can be controlled and both dry and wet solid material can be used. The *Dolomite* from JC Peacock Ltd can hold 50kg of solid material and costs around £500. For a typical precautionary treatment, applying 20g/m^2 of solid de-icer, one 50 kg load of a spreader would cover 2500 square metres.

Examples of larger, towable spreaders are the *Gladiator* from JC Peacock Ltd and the *Cruiser Towable 80* from Glasdon UK Ltd. These spreaders can hold around 250kg of material and can be towed using the traditional ball hitch mechanism. The gladiator, which uses a spinner mechanism, has an adjustable spread width of between 2 and 12m and costs around £2000. The *Cruiser Towable 80* provides distribution of material via a rotating shaft with rubber plates rather than the spinner. The rotating shaft mechanism distributes material more evenly over a narrower spread width of 0.8m and can spread both wet and dry material.

Bunce (Ashbury) Ltd distribute a range of EPOKE towable spreaders, from the *EpoMini* series through increasing capacity to the SKE series. These spreaders have an agitator which helps to break up the material and a roller which empties the hopper over the full width of the spreader. Depending on the model selected, spread widths of 0.5m to 2m can be achieved.

7.7.2 Liquid spreaders

Spreading equipment in this section would be suitable for spreading liquid materials such as brine, APCLEAR KA1 and Cryotech CF7/E36.

For use on smaller areas a backpack or pushable sprayer would be recommended, due to ease of use and ability to reach less accessible areas. Backpack sprayers have capacities of up to approximately 20 litres which, for a standard precautionary treatment of 20 ml/m^2, would be enough to cover 1000 square metres although precise control of spread rate would be difficult. Pushable sprayers enable more accurate control of the de-icer coverage and have capacities of approximately 25 litres, for example the *Groundsman* and *Professional* from Allen Power Equipment Ltd

For larger areas, Bunce (Ashbury) Ltd distribute the EPOKE *HCW City Sprayer* which can hold up to 300l with a spreading width of 1-3m. The spreading quantity can be adjusted from 5-50 ml/m^2. EPOKE also manufacture a towable spreader, the *City Sprayer*, which can hold up to 1000 or 1500 litres depending on the model. It features a 1 metre wide spreading boom with a side nozzle that can be directed to increase the spreading width to two metres.

Holder distribute small articulated tractor units which are manufactured in Germany. The *C240 Multipark has* an anti-icing and dust control pack with a 375 litre tank. This machine is extremely versatile and could be put to other uses such as sweeping.

7.8 Storage

The storage of salt can lead to the contamination of local soils, trees, vegetation and watercourses. Therefore, a substantive move has been made to the use of covered storage facilities (including purpose built and bespoke barns and domes), which have obvious environmental benefits when compared to the use of uncovered stockpiles. The move to covered storage may well be linked to some extent by the Environment Agency showing increasing interest in the methods of storage of salt adopted by road authorities and in particular the controls applied to mitigate the risks to the environment associated with uncovered stockpiles. For Health and Safety reasons all de-icing chemicals should be stored away from public access.

All de-icers should be stored according to the manufacturers-specifications which should be contained on the Material Data Specification (MDS) sheets provided with the product. De-icers are often delivered in suitable containers for storage, but the MDS sheet should list suitable materials the product can be stored in. Solid de-icers are normally hygroscopic in order to enter solution quickly and therefore need to be stored away from moisture. Damp products may be more difficult to spread, as ‘clumping’ can occur.

8 Conclusions

As no de-icing product is perfect, no one product can meet all requirements for all situations. The purchaser must consider the benefits and problems associated with each product and choose the most suitable de-icer for their particular situation. It was found that the station environment could be separated into three main areas, i.e. car parks, concourses and platforms, each having different priorities for de-icer treatments in winter. The risks for each area should be examined and a suitable product chosen which minimises these risks.

The choice of de-icer products falls into two categories, namely liquid and solid, which have different benefits and disadvantages. The active ingredient dictates the main characteristics of each de-icer product and its effectiveness at preventing ice forming, melting ice that has already formed, and treating snow. Although cost is an issue, when it comes to the sensitive platform area, adverse effects (corrosion and conductivity) on the track and the safety of the public should be paramount. The harmful effects on the environment and station infrastructure of de-icer run-off should also be considered.

Solid and liquid products require different spreading equipment. The equipment will also depend on the size of the area to be treated. Spreading equipment will produce a controlled application rate rather than ad hoc application by hand. Effects on the track and environment as well as de-icer effectiveness depend on a correct application rate, in addition to the use of the most appropriate product.

Health and safety requirements should be considered during application of the product and also during storage. The correct storage of the chosen de-icer product is also important in order to maintain its effectiveness and ease of application.

9 Recommendations

This report has sort to identify the de-icer characteristics that may influence the use of a de-icer at stations and describes how well the de-icers available fulfil these characteristics. Based on the results of this some recommendations for suitable de-icers for the three areas identified, i.e. car parks, concourse/forecourts and platforms, are provided.

9.1 Car parks

The de-icers best suited for station car parks should be cheap and effective in the British climate. The presence of metal infrastructure, such as signs and barriers is limited, therefore corrosion is unlikely to be such a prime concern. Also the de-icer is unlikely to reach the track, so high conductivity is not a concern. Therefore, the cheapest option of salt is probably most appropriate. The use of a purer salt, such as marine salt would prevent pedestrians walking marl clay and other impurities into the station and staining the flooring. The recommended de-icers are summarised in Table 13.

Table 13: Recommended car park de-icers

Category	Products	Reasons
Chlorides	Rock salt	Low cost
Chlorides	Marine salt	Slightly higher cost, but with less potential for staining

9.2 Station areas other than platforms

Station areas other than platforms, such as concourses and forecourts, have more metal infrastructure than car parks, such as information signs, barriers around ticket machines and gates, and seating. Therefore, a TOC may wish to use a less corrosive product than salt. However, these areas are quite large so cost might be an important issue. It may be desirable to use a salt additive, which will reduce the corrosion level but keep costs low. This would be more expensive than salt alone, but less expensive than other de-icing products. De-icer is unlikely to reach the track so the high conductivity of sodium chloride solution would not be a concern. A recommended de-icer for station areas other than platforms are given in Table 14.

Table 14: Recommended forecourt de-icers

Category	Products	Reasons
Chlorides	Additive treated salt	Adding a corrosion inhibitor to the salt, means the de-icer will cause less damage to metal and concrete than salt alone. Although more expensive than rock or marine salt it is less expensive for a large area than other de-icing products.

9.3 Platforms

Platforms are the most difficult areas to treat. The run-off could damage the track and switches and the de-icer is very likely to be walked onto the trains with the potential to damage flooring and soft furnishings. A product is required that is less corrosive and conductive than chlorides, but that is still effective and is not blown off the platform by passing trains. Urea, glycols, acetate and formates are all less corrosive than chlorides. There are additives, which reduce the corrosivity of salt, but the resultant solution would still be conductive and have some corrosivity. Glycols are the least conductive de-icers, but have high BODs and CODs. Some glycols are also toxic. Urea is environmentally damaging and is easily blown off platforms, it has an effective temperature less than rock salt, produces an ammonia smell and leaves a white residue. Acetates and formates are less conductive than chlorides and are not corrosive to steel and concrete. A product with a zinc corrosion inhibitor may be used if large quantities of galvanised steel are present.

Although potassium acetate solution is less viscous than glycols, a product which has been enhanced to produce a high viscosity could be used, so it is less easily washed away. Potassium formate solution is less viscous than potassium acetate solution, so despite its lower BOD and COD values is unlikely to be appropriate for the high rainfall in Great Britain. Although quite expensive, potassium acetate has a long lasting effect, so fewer applications are required.

Sodium acetate has a specific gravity of 1.53 compared to 1.32 for urea, so the granules are less likely to be blown off the platform, especially if an angular granule is used. It is however lighter than sodium chloride (2.17) and sodium formate (1.92). It may be pre-wet with potassium acetate solution if required. Sodium acetate is reported to work faster than salt as it exothermically dissolves, and it is effective down to lower temperatures. The recommended de-icers for platforms are given in Table 15.

Table 15: Recommended platform de-icers

Category	Products	Reasons
Acetates- Potassium acetate (liquid)	Clearway 3	Clearway 3 is a 50% potassium acetate solution with added corrosion inhibitors. It is a viscous liquid with a consistency similar to glycol, developed so it is not easily washed off by rain. It is used on most airport runways in UK. As it is a liquid it will not block train doors. It has a low corrosivity to steel and aluminium; however moderate corrosive effect on zinc, galvanised materials, solder and silver. It should not be directly applied to galvanised steel or near unprotected electrical systems as it is conductive. Application rates of around $20g/m^2$ are used and it is long lasting. It has a slightly high BOD, but otherwise is environmentally friendly.
	CF7	CF7 is also a 50% potassium acetate solution with added corrosion inhibitors.
	Clearmelt	Clearmelt also has added corrosion inhibitors. The manufacturer claims these reduce corrosion to galvanised steel by eight times that of other potassium acetate de-icers.
Acetates- Sodium acetate (solid)	NAAC	Sodium acetate has a similar density to urea, so might be blown off if used on platforms at stations passed by high-speed trains. It can be pre-wetted with a potassium acetate product (10%) to reduce this. NAAC has corrosion inhibitors of <1%. A spread rate of around $25g/m^2$ is used. Like potassium acetate it is not corrosive to steel and aluminium, but is moderately corrosive to galvanised steel and solder and should not be used on poor quality concrete.
	Clearway 8s	Clearway 8s does not have corrosion inhibitors. The irregular shape of the Clearway 8s granules makes it less easy for them to roll off platforms than the spherical NAAC pellets.

10 Next steps

The properties of the suggested de-icers need to be examined more closely. There is information available on sodium chloride and some trials on Safecote coated salt have been performed. One aspect of these that has not been fully investigated for any of the de-icers is skid resistance/slip resistance. This is obviously an important factor for any de-icer used. Comparison between corrosivity to different metals and concrete is another aspect that could be investigated further.

Trials could be performed on a small number of stations over the next winter to determine the effectiveness of the candidate de-icers. Particular attention should be given to the run-off rates, surface adhesion of the de-icer, application frequency, ease of use, corrosion effects and any residue left on trains. The accident records could be compared with previous winters and the users and public questioned on their views on the de-icers.

Acknowledgements

The work described in this report was carried out in the Sustainability Group of TRL Limited. The authors are grateful to Marilyn Burtwell who carried out the quality review and auditing of this report. They would also like to thank all those who aided the project by completing the questionnaire, including the TOCs, BAA and Nottingham Express Transit.

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Appendix A. Questionnaire sent to TOCs

Train Operating Company:	
Stations Responsible for:	
Name of Contact: **Tel. Number:** **Email:**	

1. Which de-icing products are currently used at your stations *(if more that one product is used please specify the areas where each de-icer is applied)*?

2. How long have you been using this product(s)?

Product **Time (years)**

3. What are the reasons for using this product(s)?

Product **Reasons**

4. Please provide details of de-icer supplier(s) and contact details.

5. What methods of de-icer application are used at your station(s)?

6. What is the rate and frequency of de-icer application?

(a) As a precautionary measure (g/m²)? …………………………………………..

(b) After the weather event (g/m²)? ……………………………………………

7. How would you rate:

(a) the effectiveness of the product(s):

Product	**Very poor**	**Poor**	**Satisfactory**	**Good**	**Excellent**
……….…	☐	☐	☐	☐	☐
…………	☐	☐	☐	☐	☐
…………	☐	☐	☐	☐	☐

(b) the ease of application:

Product	**Very poor**	**Poor**	**Satisfactory**	**Good**	**Excellent**
……….…	☐	☐	☐	☐	☐
…………	☐	☐	☐	☐	☐
…………	☐	☐	☐	☐	☐

(c) the coverage:

Product	**Very poor**	**Poor**	**Satisfactory**	**Good**	**Excellent**
……….…	☐	☐	☐	☐	☐
…………	☐	☐	☐	☐	☐
…………	☐	☐	☐	☐	☐

8. Have you observed any corrosion or damage, e.g. cracking, spalling (chipping or flaking of concrete), loss of material, bending or discolouration as a result of using this product?

(a) On platform infrastructure: (please ring to indicate degree of damage)

Steel	None	Minor	Significant	Severe
Aluminium	None	Minor	Significant	Severe
Concrete	None	Minor	Significant	Severe
Other	None	Minor	Significant	Severe

(b) On the rail track: (please ring to indicate degree of damage)

Steel	None	Minor	Significant	Severe
Aluminium	None	Minor	Significant	Severe
Concrete	None	Minor	Significant	Severe
Other	None	Minor	Significant	Severe

(c) Areas outside the track: (please ring to indicate degree of damage)

Steel	None	Minor	Significant	Severe
Aluminium	None	Minor	Significant	Severe
Concrete	None	Minor	Significant	Severe
Other	None	Minor	Significant	Severe

(d) Rolling stock: (please ring to indicate degree of damage)

Steel	None	Minor	Significant	Severe
Aluminium	None	Minor	Significant	Severe
Soft Furnishings	None	Minor	Significant	Severe
Other	None	Minor	Significant	Severe

9. Do you have any other comments on winter maintenance, for example on de-icer performance or cost?

TRL are grateful to the following TOCs who completed the questionnaire:

Arriva Trains Northern

Virgin Trains: West Coast Trains Ltd

South Eastern Trains

Chiltern Railways

Northern Rail

Merseyrail Electrics

One

Midland Mainline

First ScotRail

c2c Rail Ltd

Southern- Brighton

Southern- Redhill

Southern- New Cross Gate

Southern- East Coast

Southern- Dorking

GNER

Thameslink

Silverlink County

Silverlink Metro

TransPennine Express

Arriva Trains Wales

Wessex Trains

Also, Nottingham Express Transit and Edinburgh Waverley Station.

Appendix B. International airport regulations on de-icers

The Aerospace Material Specification (AMS) 1435 issued by the G-12 Aircraft Ground De-Icing Steering Committee Society of the Automotive Engineers (SAE) sets the specifications for runway de-icers to be used on all international airports. An extract from the document is given below:

1. Liquid de-icers

(i) Glycol base fluids

Composition of proprietary solutions meeting this specification varies with the manufacturer, though the glycol-base content is approximately 50 percent. Application rates range from 1-2 gal/1000 ft^2 for de-icing and from 0.2-0.5 gal/1000 ft^2 for anti-icing. While the specification only requires a eutectic temperature of -10 F (-23 °C) or less, proprietary products are available with eutectic temperatures as low as -75 F (-59 °C). Ethylene glycol, $(CH_2)(OH)(CH_2)(OH)$, has a eutectic temperature of approximately -58 F (-50 °C) for an aqueous solution of 58-78 weight percent of ethylene glycol and a freezing point of approximately 8.6 °F (-13 °C) for the pure fluid. Propylene glycol, (CH2) (OH) (CH) (OH) (CH3), has a eutectic temperature of approximately -75 °F (-59 °C) for an aqueous solution of 60 weight percent of propylene glycol. Propylene glycol in its pure form does not have a freezing point per se, but sets to glass below -60 °F (-51 °C).

(ii) Potassium acetate base fluids

Application rates range from 1-2 gal/1000 ft^2 for de-icing and from 0.3-0.5 gal/1000 ft^2 for anti-icing. While the specification requires a eutectic temperature of -10 °F (-23 °C) or less, proprietary products are available with eutectic temperatures as low as -76 °F (-60 °C).

2. Solid de-icers

(i) Generic solid

The approved specification is SAE AMS 1431A, Compound, Solid Runway and Taxiway De-icing/Anti-icing. Approved solid compounds include airside urea, calcium magnesium acetate (CMA), sodium formate, and sodium acetate. The specification requires a phase diagram relating product dilution to freeze point. The delivered product is effective within +7 °F (+4 °C) of the preproduction temperature value established by the manufacturer. Application rates for a specific product are based on manufacturer recommendations.

(*ii*) *Airside urea (also called carbamide)*

The approved specifications are SAE AMS 1431A, Compound, Solid Runway and Taxiway De-icing/Anti-icing and MIL SPEC DOD-U-10866D, Urea-Technical. Agricultural grade urea that meets any of these specifications, termed airside urea, is acceptable. Production of this non-toxic solid white chemical, chemical formula $(NH_2)_2CO$, is in either powder or "shotted" ("prilled") form. The latter form's shape is small spheres of about 1/16 inch (1.5 mm) diameter. Both forms are primarily for de-icing where powdered urea is frequently mixed with sand. Hot mixtures of powder or "shotted" urea and sand serve two purposes: (1) immediate increase in braking action and; (2) retention of chemical over the pavement area until it initially dissolves some of the ice and then melts the remainder. The urea de-icing function is practical only at temperatures above approximately 15°F (-10 °C) because of the decreasing melting rates below this temperature value. The decreasing melting rate is a result of urea's eutectic temperature, defined in paragraph 2(f), which is approximately 11.3 °F (-11.5 °C). However, the presence of solar radiation assists urea in the melting action. Pavement surface temperature and ice thickness determine the urea application rate.

Table 16. Application rate of airside urea

Ice Thickness (mm)	**Application Rate (g/m^2)**		
	-1.1°C	**-3.9°C**	**-6.7°C**
< 0.8	78	110	290
0.8 ≥ < 3.2	150	290	610
3.2 – 6.4	610	860	1340

Landside chemicals

The most effective landside chemicals used for de-icing/anti-icing based on both cost and freezing point depression are from the chloride family, e.g. sodium chloride (rock salt), calcium chloride, and lithium chloride. Unfortunately, these chemicals are known to be corrosive to aircraft and therefore are prohibited from use on aircraft operational areas. Although classified as salts, CMA, sodium formate, and potassium acetate are approved for airside use because they comply with an SAE specification. When any corrosive chemical is used, precautions should be taken to ensure that vehicles do not track these products onto the aircraft operational areas.

Appendix C. Summary tables of de-icers

Table C1. Sodium chloride (NaCl) and corrosion inhibited sodium chloride

<table>
<tr><th>De-icer product/properties</th><th>Rock salt</th><th>Safecote treated road salt</th><th>Ice Slicer®</th><th>Meltdown™ Zero</th><th>CG-90</th><th>Geomelt® S</th></tr>
<tr><td>US/UK distributor</td><td>Various</td><td>Safecote Ltd provides the Safecote liquid</td><td>Envirotech Services, Inc.</td><td>NA</td><td>Cargill Inc.
Salt Division</td><td>Grain Processing Corporation, USA
Sales@grainprocessing.com</td></tr>
<tr><td>Composition</td><td>NaCl</td><td>NaCl pre-mixed with 3% of Safecote (sugar based molasses). Also as pre-wetting agent with/without brine</td><td>Complex Chloride</td><td colspan="2">NA</td><td>NaCl brine + an ag. product as inhibitor</td></tr>
<tr><td>Method of application</td><td>Solid</td><td>Pre-coated or pre-wetted solids</td><td></td><td>Granules</td><td>NA</td><td>Liquid</td></tr>
<tr><td>Effective temperature</td><td>-7ºC</td><td>Slight improvement to salt</td><td colspan="3">NA</td><td>-34.8ºC</td></tr>
<tr><td>Range of spread rates (g/m^2)</td><td>10-40</td><td>Similar to untreated rock salt</td><td>6 - 9</td><td colspan="3">NA</td></tr>
<tr><td>Frequency of application</td><td>24 hrs</td><td>Assumed 24 hrs</td><td colspan="4">NA</td></tr>
<tr><td>Ice melting capacity</td><td>Immediate</td><td>25% improvement to salt at -6ºC</td><td colspan="3">NA</td><td>Immediate. At 32% concentration as effective as salt brine</td></tr>
<tr><td>Skid resistance characteristics</td><td>No change to the skid resistance characteristics of the surface</td><td>No detrimental effects on the skid resistance (pre-wetted option)</td><td colspan="4" rowspan="2">NA</td></tr>
<tr><td>Cost per tonne of product</td><td>£25</td><td>Not finalised yet. Approx. £35 for premix option</td></tr>
<tr><td>Relative corrosion to salt, %</td><td>Highly corrosive to steel/aluminium</td><td>Pre-wetted option has 55% of the corrosiveness of rock salt</td><td>26.6</td><td>Not approved by PNS</td><td>27</td><td>Not approved by PNS</td></tr>
<tr><td>Storage and handling</td><td>Undercover or in dry environment</td><td>Plastic container</td><td colspan="4">NA</td></tr>
<tr><td>Appearance</td><td></td><td>Brown liquid, with molasses odour</td><td>Reddish to white</td><td colspan="3">NA</td></tr>
</table>

Environmental impact	Damaging to vegetation and pollutant of watercourses	Similar to rock salt, with reduced effect due to less Chloride used	NA

Note: ® - Registered Trademark; ™ - Trademark

Table C2. Chloride based: Corrosion inhibited liquid magnesium chloride ($MgCl_2$)

De-icer product/properties	**FreezGard Zero with Shield LS Inhibitor**	**Hydro-Melt liquid de-icer**	**Caliber**		**IceMelt**
			M1000	**M2000**	
US/UK distributor	IMC Kalium	Cargill Incorporated	Envirotech Services Inc.	Envirotech Services Inc.& Glacial Tech.	Iceman http://www.gertens.com/articles/iceman2.html
Composition	$MgCl_2$ (25%-35%) + H_2O	$MgCl_2$ (29.5%-32%) + H_2O	$MgCl_2$ (30%) + Caliber de-icer (corn extract)	$MgCl_2$ (30%) + Caliber de-icer (corn extract)	100%
Method of application	As liquid de-icer or a pre-wetting agent		Precautionary salting /pre-wetting agent	Stockpile treatment of sand or for pre-wetting	NA
Effective temperature	NA	-17.8ºC	-16ºC	-16ºC	NA
Range of spread rates (g/m^2)	NA	NA	8-21 (32 over snow) 35-105kg/tonne for pre-wetting	75kg/tonne salt for stockpile treatment 50-84 kg/tonne for pre-wetting	NA
Frequency of application	NA	NA	4 days www.gertens.com/articles/iceman.html	NA	4 days
Ice melting capacity	NA			20% faster than NaCl at -7ºC during the first 15 minutes	NA
Skid resistance characteristics	NA	Over-application could cause slippery conditions during precautionary treatment	Friction coefficient slightly less than wet surface	NA	
Cost per tonne of product	NA		Price at US plant: £112	£51.33 for treated product (US)	£643
Relative corrosion to salt	21	23.4	22.3	8.1	Not approved by PNS
Storage and handling	Avoid contact with skin or clothing (using rubber gloves); wash hands after handling		No special handling requirements	NA	
Appearance	Brown opaque solution	NA	Translucent tan to dark brown		
Environmental impact	NA				

Table C3. Chloride based: Corrosion inhibited liquid magnesium chloride ($MgCl_2$), Cont'd

De-icer product/properties	Ice Ban			Secusal	Secucal + Eco-Thaw	Mag	Geomelt® M
	Ultra M	Summit	Performance Plus M				
US/UK distributor	Earth Friendly Chemicals Inc., US			Nedmag Industries, UK	Nedmag/ Eco-Thaw	NA	Grain Processing Corporation, USA
Composition	25.2% $MgCl_2$ solution	15% $MgCl_2$ solution + 35.5ppm Phosphorus	26% $MgCl_2$ solution + 14.2ppm Phosphorus	$MgCl_2$ (30%) + H_2O	$MgCl_2$ (50%) + Eco-Thaw (50%)	$MgCl_2$ (22%) + H_2O	$MgCl_2$ + an agricultural. inhibitor
Method of application	Liquid			Pre-wetting with NaCl (70:30) or liquid application	Liquid		
Effective temperature	-55ºC	-43ºC	- 61ºC	-17ºC	-32ºC	-25ºC	-40.8ºC
Range of spread rates (g/m^2)	27 to 42 g/m^2 (depending on surface temperature)			Pre-wetting: 6-20 for HRA (equiv. to 10-25 for thin surfaces	NA		
Frequency of application	NA			Liquid spray: 7-30 for HRA and 10-35 for thin surfaces	NA		depending on whether used for pre-wetting, or stockpile treatment
Ice melting capacity	At -17.8ºC, 70 to 76% more effective than salt 2 to 8 hrs after application	N/A					When diluted to 55% capacity, performs as well as brine
Skid resistance characteristics	Frictional value is 85% of wet tined concrete surface	NA	Frictional value is 82% of wet tined concrete surface	NA		NA	NA
Cost per tonne of product	£180 (conventional Ice Ban product in 1997)	NA		£62	NA	£75	NA
Relative corrosion to salt	17.1	13.2	8.4	Not approved by PNS	Not approved by PNS		14.2
Storage and handling	NA						
Appearance	NA					Liquid	NA

Environmental impact		3 times less toxic than table salt	

Note ® - Registered Trademark

Table C4. Chloride based: Calcium chloride ($CaCl_2$) with/without inhibitors

De-icer product/ properties	**LiquiDow* Armor***	**Tetra 94™**	**Tetra 80™**	**Roadmaster™**	**Winter Thaw® DI**
US/UK distributor	The Dow Chemical Company http://www.dow.com/	Tetra Chemicals, Tetra technologies Inc. http://www.tetratec.com/business_units/chem_index.html			
Composition	30% $CaCl_2$ + corrosion inhibitor	94-97% $CaCl_2$	77-82% $CaCl_2$		32% $CaCl_2$ + corrosion inhibitor
Method of application	Liquid	Pellets	Pellets	Liquid	Liquid
Effective temperature	-29 °C	-17.8°C	-17.8°C	-32°C	-32°C
Range of spread rates (g/m^2)	12.5-25 as liquid. Pre-wetting rate is 2.5-3% by weight of solids	49 over ice	49 over ice	NA	
Frequency of application	NA				
Ice melting capacity					
Skid resistance characteristics	Comparable to wet surface. Excessive application rate reduces skid resistance	NA			
Cost per tonne of product	NA				
Relative corrosion to salt	26	Not approved by PNS		Not approved by PNS	16.5
Storage and handling	Protective clothing recommended. Mix only prior to application. Slight agitation needed.	Protective clothing should be worn during handling		Protective clothing, rubber gloves and safety goggles recommended. May cause minor irritation. To be stored in tightly closed containers	
Appearance	Brown liquid	White granule	White pellet	Clear	Clear light yellow to dark amber
Environmental impact	NA	Non-toxic to humans, other mammals, aquatic life and vegetation			

Note: * - Trademark of the Dow Chemical Company; ® - Registered Trademark; ™ - Trademark

Table C5. Chloride based: Calcium chloride ($CaCl_2$) with/without inhibitors, cont'd

De-icer product/ properties	SnoMelt	Geomelt™ C	IceBan + Cal Ban
US/UK distributor	Standard Tar Products Co. Inc. Standtar@aol.com	America West http://www.america-west.net/ americawest@prodigy.net	
Composition	$CaCl_2$	32% $CaCl_2$ + an inhibitor	$CaCl_2$ (30-42%) + IceBan
Method of application	Pellets	Liquid	
Effective temperature	-45 °C	NA	
Range of spread rates (g/m^2)	Assume 10-40		
Frequency of application	Assume 24 hrs		
Ice melting capacity	5.3 times faster NaCl at -17 °C after 20 minutes		
Skid resistance characteristics			
Cost per tonne of product	£57 (US delivery)		
Relative corrosion to salt	40 Not approved by PNS	21	Ice Ban Performance Plus M (8.4%); Cal Ban (26%)
Storage and handling	NA		
Appearance			
Environmental impact	Gentle on grass and other vegetation	NA	

Note: ™ - Trademark

Table C6. Chloride based: Corrosion inhibited (NaCl +$MgCl_2$) and ($CaCl_2$ + $MgCl_2$)

De-icer product/properties	Meltdown 10™ and 20™	CG-90® Surface Saver™	Magic Salt	Road Crew
US/UK distributor	Envirotech Services, Inc.	Cargill Inc. Salt Division	Standard Tar Products Co. Inc. standtar@aol.com	
Composition	N/A	77.1% NaCl 21.9% $MgCl_2$ 1.0% corrosion inhibitor	NaCl treated with Magic Minus Zero™ liquid (an agricultural by-product mixed with $MgCl_2$)	$CaCl_2$ pellets treated with $MgCl_2$
Method of application	NA		Solid	
Effective temperature	NA	-9.5°C	-17.8°C	-17.8°C
Range of spread rates (g/m^2)		Same rate as regular highway de-icing salt	60-80ml/m^2 on ice/snow in driveways	NA
Frequency of application	NA		24 hrs	
Ice melting capacity			NA	
Skid resistance characteristics			NA	
Cost per tonne of product	NA	£270 (US price)	£140 (US price)	£143 (US price)
Relative corrosion to salt	30 (for Meltdown 10) 27 (for Meltdown 20)	15 (for Saver 10) 26 (for Saver 22)	Not approved by PNS	Not approved by PNS
Storage and handling		Avoid humid or wet conditions	NA	
Appearance	Solid, light brown to greyish white	NA	White powdery residue	
Environmental impact	NA		Harsh on vegetation and grass	Caution advised near vegetation and grass

Note: ® - Registered trademark; ™ - Trademark

Table C7. Acetate and formate based de-icers

De-icer product/properties	CMA40®	CMA®	ApClear KA1	Clearway CMA Plus	Safegrip and Safegrip Plus
US/UK distributor	Cryotech De-icing Technology	various UK distributors	AP Chemicals	Univar Ltd	Brotherton Speciality Products Ltd
Composition	40%CMA + 60%NaCl	96% CMA min. 4% inert material	Potassium Acetate with corrosion inhibitors	Calcium Acetate & Magnesium Acetate	50% Potassium Acetate with less than 1% inhibitor
Method of application	Granules	Granules	Liquid	Solid (pellets)	Liquid
Effective temperature	-7°C	-7°C	-15°C	-15°C	At 50% concentration effective to -22°C
Range of spread rates (g/m^2)	20-40	20-40	25-50	20 – 40	15-50. Rate may decrease with Safegrip Plus (assume 10 – 40)
Frequency of application	Assume 24 hrs		48 hrs	24 hrs	24 hrs (Safegrip) 48 hrs (Safegrip Plus)
Ice melting capacity	NA		Immediate	NA	Immediate
Order of skid resistance to salt: the lower the better (salt = 1)	NA		3	2	NA
Cost per tonne of product	£600	£600	£650	£1100	£400 for both types
Relative corrosion to salt	-7.0 to 0.0 (non corrosive)		Essentially non-corrosive	Essentially non-corrosive	Essentially non-corrosive, but requires laboratory qualification
Storage and handling	It should be stored indoors or in weather-proof containers. Covering bulk piles is advised in high humidity areas.		In stainless steel or HDPE containers	Plastic containers or bags in dry environment	In stainless steel or HDPE containers
Appearance	NA				Clear liquid
Environmental impact	Little impact	Little impact COD 0.75 g O_2/g	NA		Water quality: Potential oxygen depletion, eutrophication plus slight increase in metals. Aquatic environment: AS CMA products but moderately toxic to fish and invertebrates Terrestrial vegetation: Environmentally benign and not harmful at concentrations typically used. There is evidence that CMA may improve plant growth

Note: ® - Registered Trademark

Table C8. Acetate and formate based de-icers

<table>
<tr><th>De-icer product/properties</th><th>Cryotech E36®</th><th>Cryotech ® CF7</th><th>Cryotech ® NAAC</th><th>NC-2000</th><th>NC-3000</th></tr>
<tr><td>US/UK distributor</td><td colspan="2">Cryotech De-icing Technology</td><td>Omex Environmental Ltd</td><td colspan="2">Envirotech Services, Inc.
www.envirotechservices.com</td></tr>
<tr><td>Composition</td><td colspan="2">50% by weight Potassium Acetate in water + corrosion inhibitors</td><td>Sodium Acetate (NaAc)</td><td colspan="2">From processing of starches and sugars. 10-50% Potassium Acetate, 10-50 % complex carbohydrate, plus water</td></tr>
<tr><td>Method of application</td><td colspan="2">Liquid</td><td>Spherical pellets</td><td colspan="2">Ready to use de-icing fluid in particular for bridge automatic de-icing and parking structures</td></tr>
<tr><td>Effective temperature</td><td>-28°C</td><td>-26°C</td><td>-18°C</td><td>-54°C at 100% concentration</td><td>-38°C at 50% concentration</td></tr>
<tr><td>Range of spread rates (g/m^2)</td><td>50 – 150 (de-icing)
25 (anti-icing)</td><td>50 – 150 (de-icing)
25 – 50 (anti-icing)</td><td>15 - 25</td><td colspan="2">12 -25 for precautionary salting. 25-37 on thin ice</td></tr>
<tr><td>Frequency of application</td><td colspan="2">Assume 48 hrs</td><td>NA</td><td colspan="2">As any other liquid de-icer</td></tr>
<tr><td>Ice melting capacity</td><td colspan="3">NA</td><td colspan="2">Immediate</td></tr>
<tr><td>Skid resistance characteristics</td><td colspan="3">NA</td><td colspan="2"></td></tr>
<tr><td>Cost per tonne of product</td><td>£600</td><td>£600</td><td>£1400</td><td colspan="2"></td></tr>
<tr><td>Relative corrosion to salt</td><td>Not tested by PNS</td><td>0.0</td><td>Not tested by PNS</td><td colspan="2">(less corrosive than water)</td></tr>
<tr><td>Storage and handling</td><td colspan="2">No special storage requirements</td><td>Store in original containers. Suitable protective clothing needed</td><td colspan="2">No special storage requirements</td></tr>
<tr><td>Appearance</td><td>Clear colourless liquid (can be dyed blue)</td><td>Clear colourless liquid</td><td>NA</td><td>Clear with mild odour</td><td>clear, green/blue with mild odour</td></tr>
<tr><td>Environmental impact</td><td>Non persistent and biodegradable
BOD=0.14 COD=0.3</td><td>Non persistent and biodegradable
BOD=0.15 COD=0.3</td><td>BOD=0.58 COD=0.98</td><td colspan="2">Low BOD. Contains no phosphates or nitrogen</td></tr>
</table>

Note: ® - Registered Trademark

Table C9. Acetate and formate based de-icers

De-icer product/properties	Kilfrost CIM	Kilfrost GDF	IF32	Isomex 1	Clearway F5
US/UK distributor	Kilfrost Ltd	Kilfrost Ltd	Omex Environmental Ltd	Omex Environmental Ltd	Verdugt b.v. (Manufacturer)
Composition	Sodium Formate	Potassium Formate	Solution of Potassium Acetate and Urea	Potassium Acetate with corrosion inhibitors	55% potassium formate solution with corrosion inhibitors
Method of application	Solid granules	Liquid	Liquid	Liquid	Liquid
Effective temperature	10% by wt. Solution -4.5^oC 20% by wt. Solution -10^oC	Undiluted solution less than -25^oC	NA	NA	Diluted(1:1) -15^oC
Range of spread rates (g/m^2)	50	For frost: 30 – 70 ml/m^2	20-25 ml/m^2	15 ml/m^2	15-30(anti-icing) 25-50(de-icing)
Frequency of application	NA	NA	NA	NA	NA
Ice melting capacity	Agitation may be required	Immediate	Immediate	Immediate	Immediate
Skid resistance characteristics	Not tested	Not tested	Not tested	Not tested	Not tested
Cost per tonne of product	£1250	NA	£10/10l drum	£20-25/20l drum	NA
Relative corrosion to salt	NA	NA	NA	NA	NA
Storage and handling	Tightly sealed containers	Tightly sealed containers	NA	NA	NA
Appearance		Clear liquid	Clear liquid	Clear liquid	Clear liquid
Environmental impact	COD=0.3	BOD=0.05 COD=0.1	BOD=0.36 COD=0.47		BOD=0.09 COD=0.12

Table C10. Acetate and formate based de-icers

De-icer product/properties	Clearway 6s	Clearway 8s
UK distributor	Verdugt b.v. (Manufacturer)	Verdugt b.v. (Manufacturer)
Composition	Sodium acetate	Sodium acetate
Type	Granules	Granules
Effective temperature	-15 ˚C	-15 ˚C
Range of spread rates (g/m^2)	30-60	20-40
Frequency of application	NA	NA
Ice melting capacity	Agitation may be required	Agitation may be required
Skid resistance characteristics	Not tested	Not tested
Cost per tonne of product	NA	NA
Relative corrosion to salt	NA	NA
Storage and handling	In original containers	In original containers
Appearance	White, irregular granule	White, irregular granule
Environmental impact	BOD=0.32 COD=0.56	BOD=0.38 COD=0.83

Note: ® - Registered Trademark; ™ - Trademark

Table C11. Urea and glycol based de-icers

De-icer product/ properties	Thaw Granules	Urea	Konsin	Urea mixed with Konsin
UK distributor	Arrow Chemicals Ltd	Univar Ltd	Univar Ltd	
Composition	[$CO(NH_2)_2$] or carbamide	[$CO(NH_2)_2$] or carbamide	Glycol blend with corrosion inhibitor	Products mixed during spreading
Type	Solid (pellets)	Solid (pellets)	Liquid	Combination
Effective temperature	-7^{o}C	-7^{o}C	-12^{o}C	-7^{o}C
Range of spread rates(g/m^2)	20 – 50	20 – 50	10 – 40	20–50 (Urea) 1.5–10 (Konsin)
Frequency of application	12 hrs	12 hrs	24 hrs	18 hrs
Ice melting capacity	Delayed - agitation required	Delayed - agitation required	Immediate	Possibly some delay
Skid resistance characteristics				
Cost per tonne of product		£640	£990	£640 (Urea) £990 (Konsin)
Relative corrosion to salt	Essentially non-corrosive			
Storage and handling	In containers (dry, cool environment)	In containers (dry, cool environment)	In stainless steel containers	Separately
Appearance	White solids with slight, specific odour	White solids with slight, specific odour	Typical alcoholic fermentation odour	NA
Environmental impact	Substantially biodegradable but may cause damage to aquatic life	Substantially biodegradable but may cause damage to aquatic life	Substantially biodegradable – low toxicity	As separate products

Note: ® - Registered Trademark; ™ - Trademark