SODIUM CHLORIDE (NaCl)

Description
Sodium chloride (also known as rock salt) is a naturally occurring mineral.

Health and Environmental Effects
The use of sodium chloride for de-icing can have adverse effects on vegetation, soil and water quality under specific conditions.

Vegetation
Roadside vegetation injury by salt spray and salt laden runoff has been documented and where widespread damage occurs can be a significant problem.

Soil
Infiltration of salt-laden runoff can cause some soil types to be less fertile, less permeable, have higher alkalinity and be more prone to erosion [Gales 1992 pg.141].

Water And Aquatic Life
Chloride ions are highly mobile and can contaminate surface water and groundwater under certain conditions. High chloride concentrations can, under specific conditions, affect water density thereby inhibiting seasonal mixing of lake water. Salt ions may liberate mercury and other heavy metals from lake sediments, although this hypothesis needs further evaluation. The impacts of de-icing salt on aquatic life are not usually significant but very high salt levels can stress aquatic environments.

Human And Terrestrial Wildlife Health
Sodium chloride, in high enough concentrations, can impart an unpleasant taste and odor to drinking water. Elevated salt levels in drinking water can be of concern to those individuals of the sensitive sub-population on sodium-restricted diets for hypertension treatment. On the issue of the health benefits of salt intake reduction, scientific data are becoming increasingly consistent in suggesting at most a small benefit from salt reduction. In many cases reviewed by Taubes [1998], little or no blood pressure benefit (lowering) was achieved by lowering dietary sodium.

The major documented wildlife impact related to road salting is the attraction of larger wildlife (particularly moose) to roadside pools of salt-laden water. Reported cases of ingested salt poisoning of smaller wildlife species are limited in extent and related to a combination of exceptional conditions. Researchers have concluded that saline drinking water for farm animals from road de-icing is not a water quality concern [D'Itri 1992]. If high salt loadings in small roadside ponds result in changes in pond chemistry, stress on breeding amphibians is possible. This potential requires further research.

Compatibility with Automotive and Highway Materials
Road salt use has vehicle and infrastructure implications. Effects occur from corrosion (from salt and other environmental causes) and other damage to surfaces in contact with salt materials

(slush, spray, mist, saline water). Studies in Toronto show that 50% of corrosion occurring on auto body steel was due to salt use during the winter months [Fromm 1984]. De-icing salts also contribute to the corrosion of reinforcing steel in concrete bridge decks and substructures. Costs are incurred to repair damaged surfaces and to develop and install protective measures to reduce salt corrosion. Future maintenance and repair costs can be expected to decline as vehicles, bridges and other infrastructure are constructed with better corrosion resistant materials.

De-icing Performance
The practical working temperature of sodium chloride is down to -9.4°C and its eutectic temperature (the lowest temperature at which the de-icer can suppress the freezing point of water) is -21°C at a mixture of 23.3% rock salt in water. As sodium chloride goes into solution it requires 39 British Thermal Units [BTU] from its surroundings. Sodium chloride is generally considered ineffective below -17°C.

Storage, Handling and Spreading Characteristics
Salt is easy to store, handle and distribute.

Additional Information
A sodium chloride application rate of 113 to 142 kg per 2-lane km is usually sufficient [Jones 1986 pg.111]. Salt costs approximately $33.05 U.S./tonne [Moran 1992, pg.357] which would be $1.86 to $2.34 per lane kilometer.

Sodium chloride is the most popular de-icer as it is inexpensive and highly effective when applied under proper climatic conditions.

CALCIUM CHLORIDE ($CaCl_2$)

Description

Calcium chloride is synthetic liquid brine in its natural state, but it is also available in solid flake and pelletized form. Calcium chloride absorbs moisture from the atmosphere and gives off heat (290 BTU) when converted to liquid so it works in lower temperatures than NaCl.

Health and Environmental Effects

Some contradictory information regarding the environmental effects of calcium chloride was found in the literature. However, many sources report that calcium chloride can have a negative effect on the environment, similar to sodium chloride [Fromm 1984]. Excessive amounts of calcium chloride can produce an oily residue. When in solution calcium chloride has damaging effects on some (materials such as leather, rubber, metals, etc.).

Corrosion

Calcium chloride is more corrosive to metal than sodium chloride [Moran 1992, pg.346]. However, as calcium chloride is effective at lower temperatures it is less harmful to concrete.

De-icing Performance

Calcium chloride is a better de-icer than sodium chloride and it works at lower temperatures (-15°C or less). Its practical working temperature is -31.6°C and its eutectic temperature is -51.1°C at $CaCl_2$ concentration of 29.8% by weight [Kirchner 1998].

Storage, Handling and Spreading Characteristics

Calcium chloride is usually used as a pre-wetting agent, or mixed with sand to prevent freezing at low temperatures. It can also be used as an anti-icer. It is spread using the same technique and equipment as sodium chloride.

Additional Information

Calcium chloride is approximately $1811 per tonne [Moran 1992, pg. 357]. Suggested application rates for anti-icing range from are 28 to 55 kg of calcium chloride pellets per lane kilometer, and some estimates for de-icing range as high as 140 kg per lane kilometer [Kirchner 1998]. This would cost approximately $5 to $10 per lane kilometer for anti-icing or up to $25 per lane kilometer for de-icing.

POTASSIUM CHLORIDE (KCl)

Description
Potassium chloride is a common fertilizer and is often used as a low salt substitute in cooking. It is mined from sylvite deposits in New Mexico and Saskatchewan.

Health and Environmental Effects
Slightly less than sodium chloride. Corrosion similar to sodium chloride.

De-icing Performance
Potassium chloride is less active than NaCl and $CaCl_2$. It has a practical working temperature of -3.8°C and a eutectic temperature of -11.1°C at a concentration of 19.75% by weight in water. Potassium chloride requires 170 BTU's of heat (an endothermic reaction) as it goes into solution.

Storage, Handling and Spreading Characteristics
Potassium chloride is frequently packaged as an additive to other de-icers.

Additional Information
The cost is similar to NaCl.

MAGNESIUM CHORIDE ($MgCl_2$)

Description
Magnesium chloride is a hygroscopic chemical similar to calcium chloride. In its natural state it is a liquid but it is also sold as a solid flake de-icer.

Health and Environmental Effects
Similar to NaCl.

Corrosion
Similar to NaCl. Magnesium chloride is one of the only chemicals that can moderately deteriorate concrete but is listed as "slow to attack concrete" [Kirchner 1998].

De-icing Performance
Magnesium chloride has a practical working temperature of -15°C and its eutectic temperature is -33.6°C at a 21.6 weight percentage in water. Magnesium chloride has the ability to attract and retain moisture from its surroundings, but not as well as calcium chloride.

Storage, Handling and Spreading Characteristics
As a liquid magnesium chloride is used in the same way as calcium chloride to pre-wet road salt, sand and other de-icer mixes.

Additional Information
Magnesium chloride is only 48% active so it must be applied at twice the rate of $CaCl_2$.

CALCIUM MAGNESIUM ACETATE (CMA)

Description

CMA is calcium magnesium acetate, a synthetic powdered mixture of dolomite lime and acetic acid. It was first identified as an alternative to road salt by the U.S. Federal Highway Administration in the late 1970's. Since then extensive research and testing has been conducted on the corrosion impacts, environmental impacts and de-icing efficiency of the substance.

A granulated dry formulation of CMA is typically used for roadway de-icing. However, CMA can also be used in liquid form or combined with salt or sand. Liquid CMA can be formulated in the field from dry CMA and is generally used for anti-icing [Cryotech 1998].

Health and Environmental Effects

CMA is a biodegradable substance and has not been proven to have adverse effect on soils, water or vegetation.

Soils

CMA has no effects on soil compaction or strength and may increase the fertility and permeability of some soils. CMA may contribute nutrients (calcium and magnesium) while displacing iron, aluminum, zinc and copper. [Gales 1992, pg.173].

Water

CMA is biodegradable and exhibits poor mobility in soils, so it is not likely to reach groundwater. It is more hygroscopic than NaCl (greater tendency to absorb moisture) so it is less susceptible to leaching action. Concern has been raised over the potential of CMA to extract heavy metals in soils and cause trace metal contamination of ground water. However, McFarland [1992, pg. 202] found that CMA was not found to mobilize preexisting heavy metals from a variety of roadside soils compared to water or NaCl.

Vegetation

No detrimental effects on roadside plants have been recorded when CMA was tested at concentrations likely to be generated by highway de-icing [NRC 1991, pg. 129].

Aquatic And Terrestrial Wildlife

No deleterious effects on aquatic organisms have been recorded when tested at concentrations likely to be generated by highway de-icing. CMA may reduce dissolved oxygen levels as it decomposes, hence heavy CMA treatments near small poorly flushed or poorly diluted ponds and streams may require special monitoring and further study. CMA smells like vinegar, so unlike salt it is not attractive to animals. It has been used in Scandinavia in deer management areas as a means of preventing vehicle/animal accidents.

Human Health

Some workers have complained of chemical irritation from CMA unless they wear protective clothing [Hanneman 1992, pg. 433]. CMA powder has a tendency to create nuisance dust that may require the use of dust masks and well-ventilated storage and handling areas. However, new pelletized versions are less prone to dusting and blowing, and are better able to penetrate packed snow than the early powdery CMA products.

Corrosion

CMA is less corrosive to metals found in automotive steels, aluminum alloys, stainless steels, combined metals, bridges, roadways, parking garages and other steel and concrete systems than NaCl. The corrosion rates of steel tested in tap water were equal to or slightly higher than those of steel tested in CMA solutions [NRC 1991, pg. 131]. CMA does not contribute to spalling and scalling on new reinforced concrete and does not accelerate corrosion of older chloride contaminated concrete. However, there is insufficient evidence that CMA reduces the rate of corrosion of steel in concrete that is already contaminated with chlorides.

De-icing Performance

Although CMA is effective at the same temperatures as salt it has different performance characteristics. CMA does not melt ice and snow but turns it into an oatmeal texture. It performs best when accompanied by plowing or traffic activity, and when it is applied at the outset of a storm before significant snow and ice accumulation. When applied early CMA is able to mix with the falling snow and inhibit the ability of snow particles to adhere to each other or to the pavement (NRC 1991, pg. 122). CMA does not produce a running brine and so it does not move off the surface like other de-icers, nor can its performance be measured in the same way (penetration, undercutting etc.).

CMA ions are larger than those of NaCl so the rate of diffusion into a liquid film surrounding ice is slower. When applied after the onset of a storm CMA takes longer to start working than NaCl (about 20 min) and is less successful in penetrating heavy snowpack and ice [NRC 1991, pg.114].

Practical Working Temperature is -6°C, and the eutectic Temperature is -27°C at a concentration of 32.5% CMA by weight in water [Kirchner 1998].

Storage, Handling and Spreading Characteristics

When CMA was used in powdered form it was dusty, difficult to handle and there were some reports of CMA spray adhering to windshields and body parts and causing skin irritation [NRC 1991 pg. 120 and 133]. When exposed to moisture CMA frequently cakes and clogs. Some inconvenience has occurred with CMA clogging and sticking to spreading equipment. New pelletized versions have alleviated most of these earlier problems.

CMA needs to be kept dry during storage, preferably in enclosed, well-ventilated shelters. Since CMA is less dense than salt it requires 60% more space [NRC 1991, pg. 123]. Regular salt spreading equipment is used for CMA.

Additional Information

Typical application rates of CMA are 20 to 40 grams per square meter or 70 to 113 kg per lane kilometer [Cryotech 1998]. CMA is lighter than salt. The theoretical amount of CMA relative to salt needed for comparable ice melting is 1.7 to 1 by weight. However Michigan reported having to use about 2.6 times as much CMA as salt to attain dry pavement conditions [Gales 1992, pg. 171].

Cost is approximately $716 U.S. per tonne (based on $650.00 per imperial ton [NRC 1991, pg. 135] which would be $50 to $80 U.S. per lane kilometer. Acetic acid represents about 80% of the cost (of CMA. It is synthesized from natural gas or through fermentation of feedstock (corn, dairy or whey).

To date the prohibitive cost of CMA has limited its principal uses to address particularly sensitive environmental or corrosion situations.

POTASIUM ACETATE

Description

Potassium acetate is a liquid formulation that is generally considered a better ice melter than CMA. It has been used primarily as a runway de-icer but products are also designed for roadway use. Potassium acetate can also be used to coat rail and truck beds, non-porous roofs and road signs to prevent the adhering of snow and ice. Potassium acetate has also been used to keep rail switched open, free manhole covers and truck scales and keep conveyors ice free and as an antifreeze in toilet water [Cryotech 1998].

Potassium acetate can be used as a pre-wetting agent for CMA, road salt, and other solid de-icers and sand. It has also been used as an anti-ice to keep bridge decks from freezing and as a roadway de-icer.

Health and Environmental Effects

Potassium acetate is biodegradable, and decomposes to potassium and acetate which exerts a slight BOD (Biological Oxygen Demand) as it is metabolized to carbon and water. The BOD of Potassium acetate at 2°C is 0.30 gram O_2 per gram. Potassium acetate is toxic to fish at elevated concentrations (LC50 at 1500 mg/L) [Cryotech 1998].

Corrosion

Potassium acetate is generally considered non-corrosive, however it is not recommended:

- for use on low quality or non-air entrained concrete;
- to be in contact with galvanized metals; or
- to be mixed with liquid chloride de-icers like $CaCl_2$ and $MgCl_2$.

De-icing Performance

Potassium acetate has a freezing point of -60°C and a practical working temperature of -26°C [Cryotech 1998].

Storage, Handling and Spreading Characteristics

If potassium acetate is not stored in a clean sealed container it can begin to prematurely biodegrade and exhibit biological growth.

Additional Information

On thin ice liquid potassium acetate can be applied at 50 g/m^2. On thicker ice (2.5 cm) the manufacturer recommends an application rate of 150 g/m^2 [Cryotech 1998].

SODIUM ACETATE (NaAc)

Description

Anhydrous sodium acetate has recently been introduced as an alternative de-icer. Successful trials were conducted over the 1997-98 winter season at Vancouver International Airport. Sodium acetate is a solid spherical pellet. It has been designed for airport runway use but it may also be applied to roads, parking garages and walkways.

Health and Environmental Effects

Sodium acetate readily degrades at low temperatures and has a relatively low biological oxygen demand [Cryotech 1998]. Contact with skin or eyes may cause irritation and inhalation of dust may irritate the upper respiratory tract.

Corrosion

Sodium acetate is not corrosive to metals like chlorides but it is more corrosive than CMA.

De-icing Performance

Anhydrous grade sodium acetate is exothermic so it gives off heat as it dissolves.

Storage, Handling and Spreading Characteristics

Sodium acetate may be spread with existing solid de-icer spreading equipment. It requires flat bulk storage and requires care to avoid caking caused by excessive moisture. Excessive handling may cause dustiness and suitable ventilation is required. It can be pre-wetted with liquid potassium acetate.

Additional Information

Sodium acetate can be applied at about two thirds the rate of urea to achieve similar effectiveness [Cryotech 1998].

Sodium acetate was successfully used at the Vancouver International Airport in 1997/98 on roads, bridges and parking surfaces.

UREA CO $(NH_2)_2$

Description

Urea is a common fertilizer (46% nitrogen) that comes as solid small white pellets or in liquid form. It is synthesized from ammonia and carbon dioxide.

Health and Environmental Effects

Soil

Moran (92) claims no negative effects on soil quality and being a form of nitrogen it may Actually Improve Soil Quality.

Vegetation

Urea is reported as having no negative effects on vegetation [Moran 92]. However, as urea is a common fertilizer overuse will cause vegetation burn.

Water And Aquatic Life

Urea degrades by hydrolysis to ammonia and is subsequently converted to nitrate by nitrifying soil organisms. Ammonia and nitrate are of high environmental concern [Sills 92, pg. 328]. Nitrates stimulate the eutrophication process and can contaminate drinking water. Ammonia is acutely toxic to aquatic life.

Human Health

Biodegradation of urea may result in objectionable odours due to the release of aldehydes.

Corrosion

Urea is less corrosive than the chlorides. For this reason it is a popular runway de-icer. However urea has a detrimental effect upon concrete as it causes severe scaling at 2% wt. concentration [Kirchner 1998].

De-icing Performance

Urea is less active than NaCl and $CaCl_2$. The practical working temperature of urea is -3.8°C and its eutectic temperature is -11.6°C [Kirchner 1998]. Urea requires heat to be effective (an endothermic reaction of 106 BTU).

Additional Information

Urea costs approximately $200/imp ton [Gales 1992]. It must be used in quantities twice as great as NaCl to be as effective (which would be approximately 113 to 142 kg per lane km). Urea costs approximately $22.60 to $28.40 per lane kilometer.

GLYCOLS

Description
Glycols are dihydroxy alcohols similar to the material used in anti-freeze. It is typically found as ethylene glycol or propylene glycol. It is commonly mixed with urea for use as a runway de-icer but it is not commonly used on roadways.

Health and Environmental Effects
Glycols are highly biodegradable under normal conditions and therefore do not persist in the environment.

Human And Terrestrial Wildlife Health
When ingested by humans and animals toxicity can be significant (has an attractive sweet taste). Propylene glycol is less poisonous than ethylene glycol but is a more potent skin irritant and sensitizer. Glycols do not bioaccumulate in organisms. Technical grade ethylene glycol contains the known carcinogen I,4-dioxane. Biodegradation may result in objectionable odours due to the release of aldehydes.

Water And Aquatic Life
The acute and chronic aquatic toxicity of ethylene and propylene glycol is relatively low [Sills 1992 pg. 326]. Glycols biodegrade rapidly and exert extremely high BOD even in cold temperatures. This can deplete dissolved oxygen in water and negatively affect aquatic life. BOD of diluted ethylene glycol is 5000 mg/l (compared with domestic raw sewage which has a BOD of 200 mg/l) [Sills 1992, pg. 328].

Corrosion
Glycols are non-corrosive liquids.

De-icing Performance
Glycols are effective but short-lived de-icers.

Storage, Handling and Spreading Characteristics
Glycols are liquids and therefore require tanks and spray equipment for application.

Additional Information
Glycol is used in airport runway de-icing at a rate of 4.88 $kg/100m^2$.

Glycols are more effective when applied as an anti-icer in which case less can be used. Glycol is more expensive than salt.

METHANOL (CH_3OH)

Description

Methanol (or methyl alcohol) is sometimes used as an antifreeze. In its natural state it is a liquid and is commonly used as an important fuel source.

Health and Environmental Effects

Methanol is highly volatile, flammable and toxic [Bryan 1992 pg. 464]. It is lethal to humans and animals if ingested. The break down products of methanol contribute to ozone pollution in the lower atmosphere [Gales 1992 pg. 167]. Methanol is highly volatile so it evaporates before it can deplete oxygen from aquatic environments. However, methanol vapors are toxic and due to its high volatility ambient air quality can easily be degraded.

Corrosion

There is evidence of deleterious effects of methanol on asphalt concrete [Bryan 1992 pg. 464].

De-icing Performance

The eutectic point of methanol is -125°C at 83% concentration by weight in water. This makes methanol particularly effective at low temperatures. Methanol also works much more rapidly than salt.

Storage, Handling and Spreading Characteristics

Methanol's volatility, flammability and toxicity make it very difficult to handle.

Additional Information

Methanol is short lived (it evaporates quickly) and requires re-application within a few hours. It is approximately 5.5 times the cost of salt [Gales 1992, pg. 167].

SODIUM FORMATE (HCOONa)

Description
Sodium formate is produced as a by-product or waste product of other chemical processes. It is a solid de-icer. Very little information is available and much of the available information is contradictory.

Health and Environmental Effects
Both sodium formate and sodium chloride have similar environmental effects relating to sodium (can damage soil structure, and contributes to roadway vegetation burn). Sodium formate has a lower oxygen demand compared to other de-icing compounds.

Compatibility with Automotive and Highway Materials
Sodium formate does not contain chloride and so it is non-corrosive to steel. Some reports indicate that sodium formate has a neutral pH while others indicate a pH of 10 to 12 [Gales 1992, Old World 1998]. Sodium formate causes no more damage to concrete than salt.

De-icing Performance
Sodium formate is similar to salt in terms of de-icing speed, temperature range and endurance of de-icing effect [Gales 1992 pg. 167]. It has a eutectic point of -18°C.

Storage, Handling and Spreading Characteristics
Sodium formate can be applied with conventional equipment.

Additional Information
Sodium formate costs 13 times more than salt [Gales 1992, pg. 167].

ORGANIC COMPOUNDS (SUGAR BY-PRODUCTS)

Description

Sugar byproducts have been developed that may reduce the environmental issues connected with salts and may have longer residual effects when spread on roadways.

The organic compounds used for de-icing are typically byproducts of agricultural operations such as refining sugar beets or corn, or the ethanol distillation process. One of the most common is beet juice (left-over from the process of extracting sugar from sugar beets). Sugar byproducts are not de-icing material. While there is no consensus regarding to what degree beet juice and other sugar by-products depress freezing temperatures, sugar by-products alone are very poor ice melters. Instead, they are treated in alkali to increase the ionic strength of the liquid, which when mixed with brine lowers the freezing point of the de-icing solution. However, Fay [2007] found that, based on preliminary data, there was no significant difference in the ice-melting capacity of the tested chloride-based deicers, and the sugar by-product.

Most commonly, sugar byproducts are blended with brines of magnesium chloride, sodium chloride, calcium chloride and potassium chloride and the mixture is applied to dry roads as an anti-icing agent, or as pre-wetting agent.

Health and Environmental Effects

No long-term research yet exists, but Sugar by-products / brine liquid products are generally believed to be less harmful to infrastructure and the environment. Some commercially available products are recognized by the U.S. Environmental Protection Agency as being safe for human health and the environment. However, aesthetics may be a drawback. For example, beet juice can potentially stain carpets and exteriors.

Corrosion

While sugar by-products / brine liquid sugar by products have the potential to reduce corrosivity of deicers to metal, preliminary research by Fay [2007] indicated chloride-based deicers and the sugar byproduct-based deicer were similarly very corrosive to mild steel.

De-icing Performance

Sugar byproducts are not de-icing material. As such, the performance will depend on the brine with which the sugar byproducts are blended. Johnson [2005] reports that a commercially available sugar by-product / $MgCl_2$ brine liquid has the freezing point of -65° C.

Additional Information

Prices for the types of organic compounds described here are typically more than ordinary rock salt, although generally less is required. However, pilot programs (e.g., City of Montreal, Niagara Region and City of Barrie) are underway at the time of writing to determine if mixtures can reduce the number of applications by sticking longer to roadways, which it could offset its higher price point by reducing labor costs.

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