Methods and Materials for Snow and Ice Control on Roads and Runways: MINSALT Project

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The harm caused by salt can be reduced by using methods and materials, both chemical and mechanical, that more effectively counteract slippery conditions. New deicing methods and agents have been tested in several different projects in the Swedish MINSALT project in efforts to find ways of improving skid resistance that do not have the negative effects of salt. In regard to chemical deicing—that is, salting—methods have progressed from spreading dry salt to spreading prewetted salt and saline solutions, and from spreading curative when icy conditions have already formed to spreading preventive as an anti-icing measure. Spreading prewetted salt or a saline solution has been done for many years, and it is now a fairly well known technique; test results are mostly positive. The methods are presented, and results and experience from some winter use are shown. Several deicing agents were tested as alternatives to sodium chloride, but calcium magnesium acetate was investigated most intensively. The studies were concerned with melting properties, corrosion to metals, and effects on cement concrete. For runway deicing there is a search for alternatives to urea, which has a negative effect on the environment. Liquid potassium acetate has been tested in the laboratory and the field, and the experience is mostly positive; it is now used on some airports in Sweden.

The harm caused by salt can be reduced by using methods and materials, both chemical and mechanical, that more effectively counteract existing or probable slippery conditions. New deicing methods and agents have been tested in different projects in the 5-year study of the Swedish MINSALT program. Projects were conducted during 1985–1990 to find ways of improving skid resistance that do not have the negative effects of salt. The results from the MINSALT projects have been reported in different papers and are summarized in a final report (*1*).

CHEMICAL DEICING WITH NaCl

As for chemical deicing—that is, salting—methods have progressed from spreading dry salt to spreading prewetted salt and saline solutions. Experiments aimed at using NaCl more efficiently included studies of optimum spreading rates under different weather and road-surface conditions. The importance of the road structure, the wearing course, and the salt (origins and gradations) were studied. Possibly the most negative effect of salt is its corrosiveness. Corrosion inhibitors—substances added to the salt to reduce its corrosiveness—were also studied in the laboratory.

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Several chemical alternatives to NaCl have been tested. In particular, calcium magnesium acetate (CMA) has been studied more closely in regard to its ice-melting capacity, corrosiveness, and effect on concrete. Studies of alternatives have also included chemicals suitable for runway purposes. Potassium acetate, a liquid deicer, has been tested and is being used at some Swedish airports.

As a rule, deicing by spreading sand on the roads also entails spreading salt, because the sand used for this normally contains about 3 percent salt by weight to permit its storage in cold weather, to facilitate spreading, and to make it more effective on an ice and snow cover. Several possible salt-free alternatives such as limestone products and chippings have therefore been tried out within the scope of the project. Finally, more efficient methods of ice scraping and snowplowing have also been tested. By reducing any remaining layer of ice and snow, the salt dosage needed to achieve an acceptable standard can be minimized.

Prewetted Salt, Saline Solution

Until the mid-1980s, spreading dry salt was the only chemical deicing method in Sweden. Under many conditions, dry salt had limited effect, particularly when spread on dry roads as an anti-icing measure. Studies have shown that much of the dry salt ends up at the side of the road during the actual spreading process and that even more is blown off the road by traffic. One way to make the salting more effective is to wet the salt before spreading. By prewetting the salt sufficiently, the time required for the salt to dissolve is reduced and the salt adheres better to the road surface.

The spreading of prewetted salt or a saline solution has been done for many years; it is now a well-known technique. The salt can be prewetted either when it is loaded onto the spreading vehicle or when it is spread.

Water, NaCl or $CaCl_2$ solutions, or other suitable solutions can be used for prewetting the salt. Water and NaCl solution have been used in Sweden. Water is used for the simpler method of prewetting the salt when loading it, and a saturated NaCl solution is used for prewetting with a salt spreader and when a saline solution is spread. $CaCl_2$ solution has been tested but not used in Sweden on account of its aggressive effect on cement concrete, higher cost, and the fact that no difference in its effect on ice and snow could be subjectively discerned in comparative tests with NaCl.

Special spreaders for prewetted salt were developed and put into service during the 1980s (Figure 1). In addition to the hopper for the dry salt, these spreaders have a solution tank [capacity approximately 2 m^3 (about 500 gal—conversions in this paper will be approximate)], pump, spray nozzle, and electrical equipment for regulating the amount of solution. As it is discharged onto the spreader disc or passes through the discharge pipe, the dry salt is sprayed with brine.

A saturated NaCl solution (approximately 23 percent by weight concentration) is used for prewetting the salt and for spreading saline solutions. Two types of saline solution plants are used to prepare the saturated saline solution. One fills a tank with salt and water that is pumped around until a saturated saline solution is obtained. Production volume is 8 m^3 (2,000 gal) of solution at a time. The same container is used for manufacture and storage. The other type of plant forces water under pressure through a bed of salt in a large tank. The saturated solution is then allowed to flow to a 10-m^3 (2,600-gal) storage receptacle. Manufacture of the saline solution is a continuous process, and the amount of salt and water is metered automatically.

As a rule, 30 percent by weight of the saturated NaCl solution is added to the dry salt. The rate of dry salt is similarly reduced by 30 percent at the same time. This means that the amount of salt spread on the road is automatically reduced because the saline solution added to the salt contains a large proportion of water. The actual reduction in the salt dosage is slightly more than 20 percent. Besides this automatic reduction, the higher efficiency of the method as compared with conventional spreading means that the amount of salt spread on the road can be further reduced.

The advantages of using prewetted salt instead of dry salt, as shown by the tests carried out with wet salt spreaders and the results of subsequent practical winter road maintenance applications, include the following:

- The salt is spread more uniformly and less is wasted at the roadside.
- The salt adheres to the road surface better.
- Prewetted salt has a faster and more durable effect.
- Spreading speed can be increased.
- In some cases the road surface dries out quicker.

In summary, the advantages of prewetted salt mean that a smaller amount can be spread to maintain a certain standard and that preventive measures are possible.

Simple Prewetting with Water

Dry salt can also be prewetted in a simpler manner by spraying a saline solution or just water over it as it is loaded onto the spreading vehicle. The advantages of this prewetting method are that conventional spreaders can be used and that little capital needs to be invested in special new equipment.

In Sweden the simpler prewetting technique was tested in a road maintenance area during the winter of 1987–1988. Prewetting was accomplished by spraying water into the loaded salt hopper with a hose (Figure 2). Depending on the method of loading, the solution is added from above, by spraying it over the loaded salt as in the figure, or during the actual loading process, if it uses a conveyor belt.

In the winter of 1988–1989, tests with the simple prewetting method were carried out on a larger scale in about 70 local road maintenance areas. In addition to some special studies, practical experience of the method as used by road maintenance crews has been gathered in two questionnaires; the results are summarized as follows:

- The proportion of water should be 80 to 100 L/t (22 to 27 gal/2,200 lb), in the light of special tests.
- It must be possible to measure the amount of water because the equipment malfunctions if insufficient water is used.
- The method has been tested at temperatures down to about −12°C (10°F), but it is generally used down to −6°C (21°F).

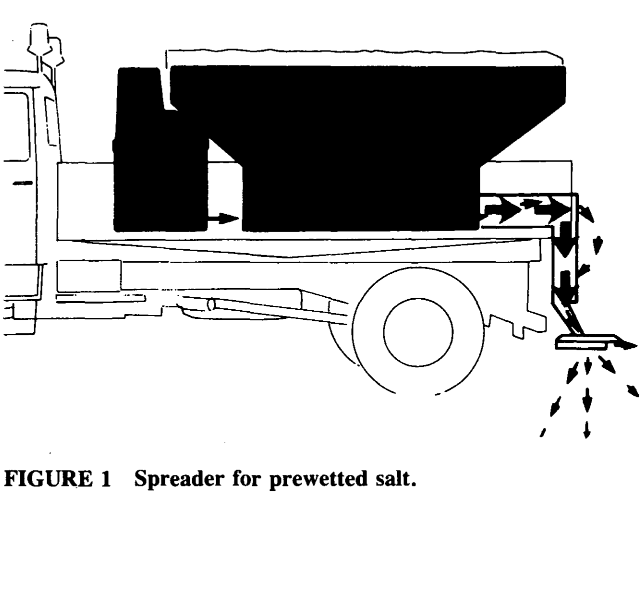

FIGURE 1 Spreader for prewetted salt.

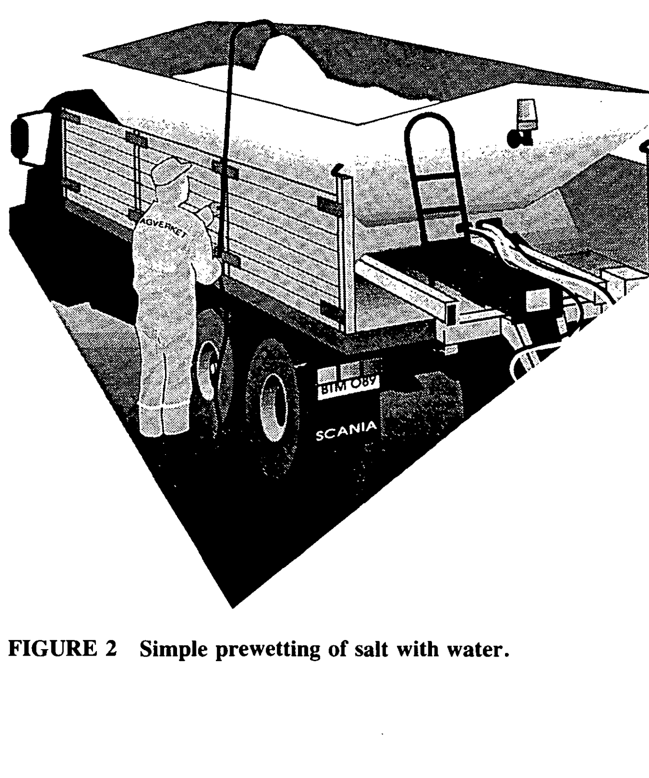

FIGURE 2 Simple prewetting of salt with water.

- Spreading speed has been 50 to 60 km/hr (30 to 38 mph).
- As a rule, 2 to 3 t (4,000 to 6,500 lb) of salt has been prewetted, although tests have been carried out with up to 8 t (18,000 lb). The amount of salt that can be prewetted depends to some extent on the size of the spreader.
- About 90 percent of the road maintenance areas have reported that the method produces good results and that they intend to continue using it.

Simple prewetting with water makes it possible to gain the advantages of prewetted salt with conventional spreaders at an extremely low investment cost, improve the adhesion of the salt so that it stays longer on the road, and increase spreading speed. One limitation of the method is that the spreader should not be loaded with more than 2 to 3 m^3 (70 to 105 ft^3) of salt to ensure that it is thoroughly wet before spreading. However, this is enough for 60 to 90 km (40 to 60 mi) of preventive salting. The limitations of the method make it better suited to road maintenance areas with lower traffic densities on their salted roads. In areas with more trafficked roads, prewetted-salt or saline-solution spreaders are more suitable for chemical deicing and anti-icing measures.

Spreading of Saline Solution

Deicing with a saline solution entails spreading a saturated salt solution containing 20 to 25 percent NaCl by weight. Spreading this solution on the roads therefore corresponds to only about a quarter of the amount of dry salt.

Swedish studies of spreading brine were begun in the winter of 1987–1988 when tests were carried out on a small scale in two local road maintenance areas. This smaller preliminary study consisted of a visual examination to assess spreading efficiency, spreading pattern, effect on the road surface, and refreezing, if any. Brine was tested on a larger scale in the following winters: 1988–1989 in 7 areas and 1989–1990 in another 20 areas.

Two types of spreading equipment for saline solution were tested; both were speed-independent, which means that the amount of solution spread is not dependent on the speed of the vehicle. The normal capacity of the tank of brine is 8 m^3. The brine is spread on the road either by means of nozzles on a spreader arm or by means of two rotating discs (Figure 3). Depending on the spreader, the width can be set between 2 and 10 m (6 and 30 ft) and the application rate between 3 and 18 g/m^2 (40 and 225 lb/lane-mi) of dry salt. The dosage corresponds to 10 to 80 g/m^2 (2 to 16 gal/1,000 ft^2), corresponding to about 5 g/m^2 (60 lb/lane-mi) of dry salt. The road administration bought more spreaders for the 1989–1990 season, so that about 80 spreaders were in use. As in the previous winter, the spreading of saline solution was followed with a questionnaire concerning the methods and spreading equipment used. The 26 local road maintenance areas and 2 municipalities covered by the study gave their views and reported on the results they had obtained.

Summarizing, experience gained during the three winters shows that

- The method is considered to be extremely effective as a preventive measure and for dealing with hoar frost on the roads.

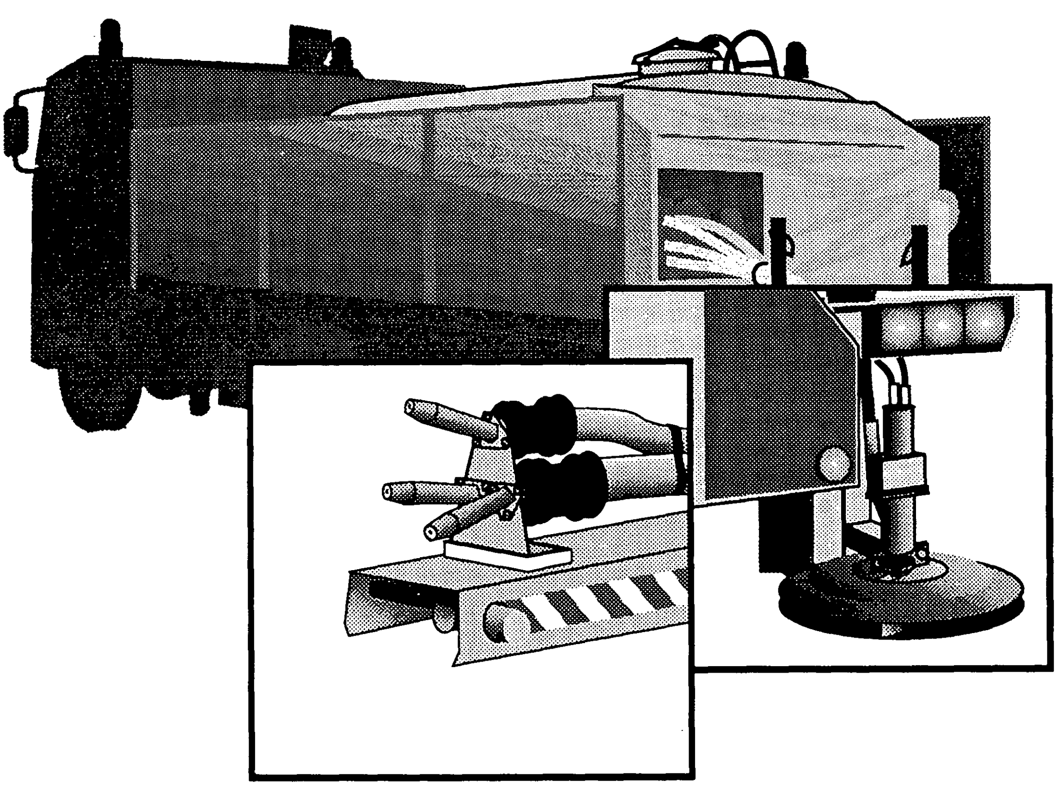

FIGURE 3 Spreaders for saline solution: *left insert*, nozzles; *right insert*, spinners.

- During a snowfall, the method is of doubtful merit. On wetter roads and where ice has already formed, the method is similarly of doubtful merit, or downright unsuitable. Correct dosage is a critical factor. Dilution of the brine resulting in refreezing can be a problem.
- A saline solution of 20 g/m² (4 gal/1,000 ft²) [corresponding to about 5 g/m² (about 60 lb/lane-mi) of dry salt] is sufficient in most cases as anti-icing and less severe deicing measures.
- The method has been tested on roads and highways with average daily traffic ranging from 1,500 to 12,000.
- Spreading has been possible at speeds of up to 60 km/hr (40 mph).

CHEMICAL ALTERNATIVES TO NaCl

Calcium Magnesium Acetate

The negative effects of chemical deicing with NaCl have for many years prompted researchers to develop alternative chemical compounds that are neither corrosive nor environmentally harmful and whose efficiency and cost make them suitable for winter road maintenance. The most recent and comprehensive study aimed at finding alternatives to NaCl was carried out in the United States toward the end of the 1970s. Following an evaluation of the tests embracing freezing-point reduction, corrosion, toxicity, cost, environmental aspects, and so forth, CMA was identified as a promising alternative to road salt (*2*).

Studies of CMA were carried out in Sweden before the MINSALT project was initiated. These studies were included in the project once it was under way. To begin with, a small quantity of CMA was manufactured on a laboratory scale, but when it was marketed commercially during the latter part of the project, tests were conducted with the proprietary product. The studies carried out at the Swedish Road and Traffic Research Institute, as well as studies conducted by other research institutes, were chiefly concerned with CMA's melting properties, corrosiveness, and effect on cement concrete.

CMA's freezing-point reduction—the lowest temperature at which melting can occur—varies according to the Ca/Mg ratio between about −10°C (−14°F) and −28°C (−18°F); for NaCl it is about −21°C (−6°F). The lowest and optimum freezing point is obtained with a Ca/Mg ratio of about 3/7 to 2/8 (in mol). The CMA products ICE-B-GON and Clearway CMA have a ratio of 3/7.

The melting effect of CMA does not vary so widely, however, because of the Ca/Mg ratio; it depends more on the shape, size, and density of the particles. Melting ability has been tested on blocks of ice at different temperatures. In Figure 4 the result from one melting test at −2°C (28°F) is shown. The CMA pellets were 2 to 3 mm (0.08 to 0.12 in.) in size. The solubility of CMA is lower than $CaCl_2$ and NaCl but better than urea. It should be noted that CMA has a very slow initial melting reaction, whereas NaCl and especially $CaCl_2$ have a very rapid melting effect. The same relations have been determined at lower temperatures, tests at −6°C (21°F) and −10°C (14°F), but the slower melting effect compared with $CaCl_2$ and NaCl is even more prominent.

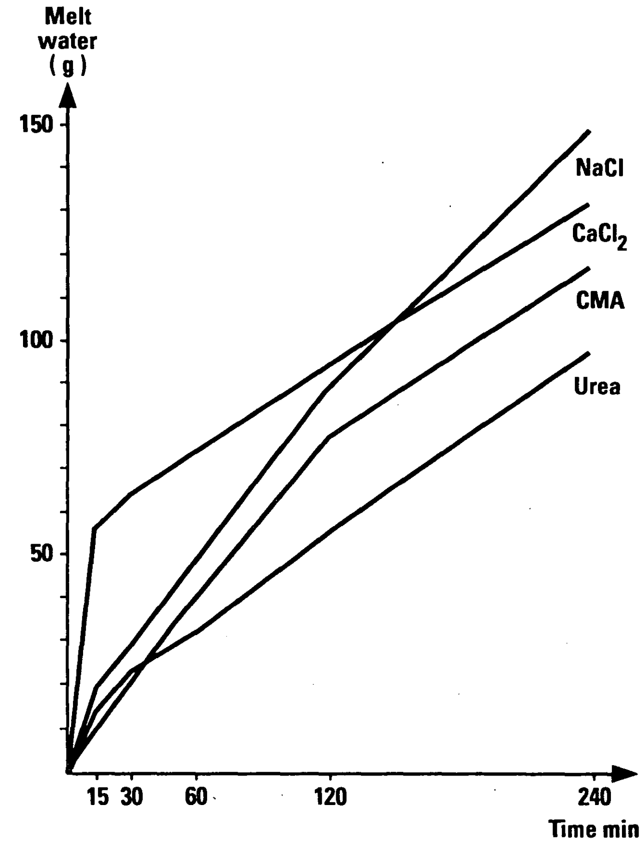

FIGURE 4 Ice melting effect of some deicers in laboratory testing at −2°C (28°F); application rate = 20 g on 114 cm² (0.7 oz on 18 in.²).

Perhaps the greatest positive effect of CMA over NaCl is reduced corrosion. Several corrosion studies have been carried out with CMA. Corrosion tests with CMA on car body steel showed that CMA is much less corrosive than NaCl and $CaCl_2$. The weight loss on steel plates, which were covered with a mix of mud and the deicer for 100 days, was considerably less for CMA than for the other deicing chemicals in the test. Immersion tests with aluminum plates also showed promising results for CMA, which was less corrosive than NaCl, $CaCl_2$, and urea. The difference in speed of corrosion was not so marked as with steel, however.

The corroding effect of CMA on magnesium alloy plates has also been tested, since magnesium alloy can be used in aircraft. The immersion test compared CMA with urea and showed that CMA was the more corrosive of the two deicers. The result indicates that to avoid the corrosive effect some kind of surface treatment of the magnesium metal must be accomplished or a corrosion inhibitor be mixed with the CMA.

Several studies concerning the freeze-thaw and chemical effect of CMA on cement concrete have been carried out. As shown by freeze-thaw tests, the chloride salts clearly peak at a concentration of 3 to 4 percent. After declining with slightly rising concentration, the degree of damage increases dramatically for high concentrations of $CaCl_2$ and $MgCl_2$. Here, the chemical effect manifests itself. For NaCl, on the other hand, the degree of damage clearly diminishes with a rising concentration and is extremely small for a saturated solution. According to freeze-thaw tests, CMA's incidence of damage rises in direct proportion to its concentration up to the same level as NaCl's maximum (which occurs at about 3 percent) (Figure 5).

Tests at the Lund Institute of Technology during 1985–1986 were aimed at studying the chemical effect of CMA and other substances on concrete. The specimens in a NaCl solution were little damaged, but the effect on the cement concrete in CMA was considerable. Samples in $CaCl_2$ solution were also heavily damaged, perhaps even faster than with CMA. The tests were carried out with CMA of dubious composition, so the relevance of the results is open to question, especially as current (1992) CMA for road maintenance purposes is a different product altogether and comprises a stable compound without an excess of acid. These tests were therefore duplicated during 1991–1992, but the results have not yet been reported.

To study the effect of deicing agents, and CMA in particular, on concrete under more realistic and varying conditions, field experiments were carried out during 1986–1990. After the period of exposure, the concrete specimens were tested and analyzed with respect to compressive strength, tensile splitting strength, carbonation depth, frost resistance, chloride content, and acetate content. A thin grinding analysis was also carried out.

The results of the tests show that all exposure damage with respect to CMA was less than for NaCl and other chloride salts. In summary, nothing in the analyses performed indicates that deicing with CMA would cause more damage to cement concrete than that caused by NaCl. The spraying of the agents on the specimens during the tests is certainly more intensive than what occurs in ordinary road maintenance work, but it would be unwise to draw too far-reaching conclusions from the results at hand. The periods of exposure were extremely short in relation to the expected lifetime of the structures.

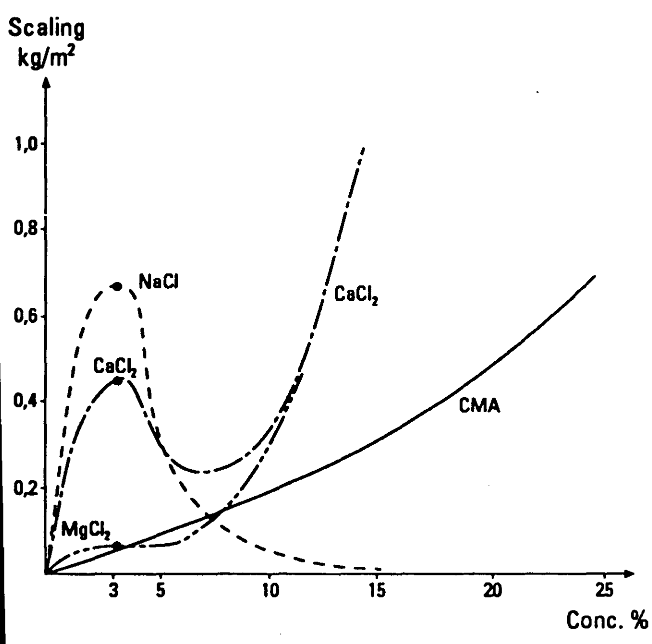

FIGURE 5 Concrete-frost testing according to Swedish Standard 137236: tests with 3 percent solutions of NaCl, $CaCl_2$, $MgCl_2$, and 3 to 26 percent solutions of CMA; weight loss after 56 cycles (*3*).

CMA's biggest drawback as an alternative deicing agent is its price, which is about 15 to 20 times higher than the price of NaCl, and there is nothing to indicate that this can be reduced to any great extent, not even for large-scale production. The dominating expense connected with the use of CMA is the direct cost of production. The principal advantages to be gained from switching to CMA are reductions in corrosion of the vehicle fleet, in chemical aggression on bridges and other cement concrete structures, and in environmental damage (groundwater and vegetation).

Against this background, the likelihood that CMA will replace NaCl must be considered small. Furthermore, the cost/benefit sides of the balance sheet are somewhat complicated in a changeover to CMA. The use of CMA could result in major savings for the individual motorist in the form of reduced corrosion, whereas the major costs associated with CMA would be borne by the road maintenance authority.

Sodium Formate and Potassium Acetate

Besides CMA, other alternatives have been considered, although in less detail. In some cases, small-scale studies have been conducted. The substances that have been tested are, among others, calcium chloride ($CaCl_2$), urea, sodium formate, and potassium acetate (proprietary name Clearway-1).

Limited laboratory tests concerning melting effect and freezing-point depression were made with sodium formate as small pellets (less than 1 mm). The result showed that sodium formate is comparable to NaCl as a deicer. The same result was shown in a minor field test. Sodium formate as a saturated brine was spread on hoar frost and as an anti-icing measure. In both cases comparison was made to NaCl brine, and no difference between the two deicers could be seen.

Another chemical investigated was a noncorrosive potassium acetate solution (proprietary name Clearway-1) primarily for airfield use. This is a 50 percent by weight aqueous solution with a small amount of corrosion inhibitor added to fulfill the rigorous demands for use on airfields.

Potassium acetate has been tested in the laboratory and on airfields during some winters. It has a very low freezing point, −40°C (−40°F), with a 50 percent by weight solution. Because the acetate is a liquid, it has a very rapid melting effect. The field tests showed that compared with urea the acetate had a more rapid and better melting effect, but there was a question about its long-term effect. Potassium acetate is hygroscopic (draws moisture out of the air), which can lead to longer wet periods, dilution, and perhaps refreezing.

The positive effects of potassium acetate compared with NaCl and urea are reduced corrosion and environmental damage. The major drawback is the price, which is even higher than for CMA. Potassium acetate is not an alternative to NaCl but could be an interesting and effective alternative to urea for airfields.

CONCLUSIONS

The search for a chemical to replace NaCl has shown that there is no economical alternative that can be used any time soon. There are possible compounds such as CMA and sodium formate, but there are also much higher material costs and still questions about some effects connected with these alternatives. NaCl will therefore still be the most used deicer for road purposes.

Salt-spreading methods have progressed from dry salt to prewetted salt and brine. The results from the MINSALT project have led to a proposed strategy that will reduce salt consumption and increase the effectiveness of the salting. This can be accomplished by working more with anti-icing measures, before the icy conditions occur, and less with deicing. Prewetted salt or brine should be used.

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