Comparative Evaluation of Calcium Magnesium Acetate and Rock Salt

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Described in this paper are laboratory tests conducted to determine the ice-melting and ice-penetration characteristics of rock salt, calcium magnesium acetate (CMA) manufactured by RAD Services, CMA manufactured by Chevron (Ice-B-Gon™), and a Chevron CMA/sand product. Ice penetration by the three CMA products was very inferior to ice penetration by rock salt, and diminished to essentially no penetration at temperatures at which rock salt continued to penetrate. RAD Services CMA melted ice in quantities, relative to rock salt, somewhat higher than estimated from theoretical differences at 15°F and 25°F, and exhibited an approximate lower temperature limit for melting of 10°F. Chevron Ice-B-Gon™ CMA melted ice in quantities, relative to rock salt, substantially less than estimated from theoretical differences, and exhibited an approximate lower temperature limit for melting of 15°F. Results of ice-melting capacity tests indicate that in the 20°F to 25°F range, 1 ton of rock salt is equivalent to 2.5 to 3 tons of Ice-B-Gon™ CMA. Given the need for high application rates and high costs of CMA relative to rock salt, simplified cost analyses do not indicate that benefits accruing from the use of CMA will counterbalance the high costs associated with general CMA use for snow and ice control.

Snow and ice control on highways is clearly essential to the nation's economy and for public safety. The use of chemical deicers has been and will continue to be a major part of snow and ice control methods.

Extensive use of rock salt (sodium chloride) is, however, the source of substantial cost penalties due to its corrosive action and its ability to degrade roadway surface materials. In some regions of this country, sodium chloride poses an environmental threat to groundwater quality.

The Federal Highway Administration's research programs (*1*) accordingly address both of the following: (a) alternatives to chemical deicers and (b) alternative chemical deicers which ideally will not exhibit the undesirable properties of rock salt and will compare reasonably favorably to rock salt in performance and in cost.

Research and development programs conducted in the last 10 to 15 years have identified calcium magnesium acetate (CMA) as a potentially viable chemical deicer. This material potentially can be manufactured in quantity from readily available raw materials (i.e., biomass and dolomitic limestone); in theoretical terms will require about 1.7 lb to melt the same quantity of ice as 1 lb of rock salt; and is not expected to be the source of adverse impacts on highways, highway structures, automobiles, and the associated environment. The latter advantages have been supported by laboratory-based studies but have yet to be adequately verified in the field. A major deterrent to extensive use in the field is cost, which is projected to be on the order of 15 times the cost of rock salt.

Important steps in the development of CMA were as follows:

1. The identification of CMA, by Bjorksten Research Laboratories under the support of FHWA (*2*), as the principal viable alternate to rock salt.
2. Research on fermentation processes by the University of Georgia.
3. The development of fermentation processes for production of acetic acid and subsequent production of CMA at costs less than costs for production with "synthetic acetic acid," by SRI International (*3*).
4. The manufacture of 200 tons of CMA (*4*), by the Bowling Green, Kentucky, plant of the R&D Chemicals Division of RAD Services, Inc., under subcontract to SRI International (FHWA Contract DTFH61-81-C-00122).
5. The distribution of tonnage quantities of the above CMA to the states of Michigan and Washington and 50-lb quantities to several states for testing and evaluation.
6. The conduct of field tests, principally in Michigan and Washington, with this material.
7. The development of a process in Iowa for manufacturing CMA-coated sand, accompanied by field tests in Iowa.
8. Implementation of research, by the New York State Energy, Research, and Development Authority, on methods to inexpensively produce acetic acid.
9. Process development and product manufacture by Chevron Chemical Company, activities focused on manufacture of CMA with improved physical and handling characteristics, and on production of CMA-coated sand.
10. Studies by the California Department of Transportation, the University of Oklahoma, Daedalian Associates, and others focused on defining impacts of environment and materials on corrosion properties of CMA.

These activities have yielded results that generally support the following:

- In highway uses, CMA must be applied at rates approximately twice those used for rock salt to get equivalent results.
- CMA effectiveness varies considerably with environmental conditions and traffic conditions, and CMA accordingly appears to be not as universally usable as rock salt.

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- Cost considerations tend to signify specialized use (i.e., on bridge structures as opposed to general highway ice control).
- The use of CMA in conjunction with abrasives (sand) may be a preferred mode of use.
- Elimination of adverse environmental impacts would appear to be justified.
- Reduction or elimination of corrosion is still to be demonstrated and quantified for production-quality CMA.

The tests of CMA reported in this paper were undertaken to provide a firmer basis for evaluating the performance capabilities of CMA compared to those of rock salt. The test program consisted of measurement of two deicer characteristics—ice melting and ice penetration—as a function of time and temperature. The authors want to emphasize the fact that the two types of tests used to compare deicers are laboratory tests rather than field tests. Conclusions relative to field use are thus subject to some uncertainties, particularly with regard to the probable influence of traffic and other field factors on deicer performance. A specific example consists of measurement of ice-melting and ice-penetration capabilities of CMA-coated sand in a manner that does not allow for factoring in the effect of traffic, and thus does not permit the assessment of whether or not CMA is effective in promoting the effect of an abrasive, or vice versa.

MATERIALS AND TEST PROCEDURES

Ice-melting and ice-penetration tests were conducted in an insulated enclosure placed inside a cold room. The cold room was maintained at a temperature 5°F to 10°F colder than the test temperature. The temperature in the insulated enclosure was maintained by enclosure lighting augmented on demand by a thermostatically activated fan. The box was provided with two hand ports and a hinged Plexiglas™ window.

Temperatures used in the two tests were 25°F, 15°F, 10°F, and 5°F. With exceptions as noted later, deicer materials were applied at a rate of 3 oz/yd^2 in the ice-melting tests, and pellets weighing approximately 24 mg were used in the ice-penetration tests.

Materials

Deicer materials tested in this investigation were as follows:

- Rock salt—the two rock salt materials used in this study were supplied by the American Salt Company and by Morton-Thiokol under the commercial name of Safe-T-Salt™.
- RAD Services CMA (CMA-1)—supplied by the state of Michigan, the CMA-1 was relatively finely divided, with maximum particle weights of 12 to 15 mg. Production data (*4*) indicate that essentially all of this material passes a 6-mesh screen, about 55 percent passes a 12-mesh screen, 10 percent passes a 20-mesh screen, and 6 percent passes a 30-mesh screen.
- Chevron Ice-B-Gon™ CMA (CMA-2)—the CMA-2 consisted of white, essentially spherical particles with a size distribution approximately as follows, in weight percent passing: 5 mesh, 84 percent; 8 mesh, 39 percent; and 10 mesh, 28 percent.
- CMA-coated sand, manufactured by Chevron—the approximate size distribution (in percent passing) of the CMA-coated sand was 6 mesh, 69 percent; 8 mesh, 54 percent; 10 mesh, 47 percent; 12 mesh, 37 percent; and 14 mesh, 25 percent. The average CMA contents of size fractions and of a composite sample were determined by weighing dried sand and insolubles retained on filters, after washing with 4 percent acetic acid and water, with results as follows: +6 mesh, 3.95 percent CMA; −6+8 mesh, 7.85 percent CMA; −8+10 mesh, 10.5 percent CMA; −10+12 mesh, 12.2 percent CMA; −12+14 mesh, 14.3 percent CMA; −14 mesh, 27.65 percent CMA; calculated composite, 13 percent CMA; and measured composite, 14.6 percent CMA. Because of the difficulty of isolating a small representative sample, the calculated composite CMA percentage of 13 percent was used for specifying the application rate in ice-melting tests.

CMA-1 (RAD Services) was analyzed and subjected to solubility/freezing-point determination with results as follows: CMA content, 96.01; calcium acetate, 51.2 percent; magnesium acetate, 44.8 percent; mole ratio, Mg:Ca = 1:1.027; moisture, 3.0 percent; and insolubles, 1.0 percent.

The maximum solubility of filtered material at ambient temperatures was 28.22 percent CMA. Temperatures at which initial ice crystals formed from CMA solutions were 28.22 percent, 2.3°F; 26.0 percent, 6.3°F; 24.0 percent, 9.5°F; 20.0 percent, 15.5°F; and 15.0 percent, 19.7°F.

CMA-2 (Chevron Ice-B-Gon™) was similarly analyzed, with results as follows: CMA content, 90.22; calcium acetate, 33.71 percent; magnesium acetate, 56.51 percent; mole ratio, Mg:Ca = 1.865:1; moisture, 2.03 percent; and insolubles, 7.75 percent.

Maximum solubility of filtered material from CMA-2 at ambient temperatures was 29.6 percent. Temperatures at which initial ice crystals formed from CMA-2 solutions were 29.6 percent, −3.75°F; 28.4 percent, −1.3°F; 27.3 percent, 2.5°F; 26.3 percent, 3.6°F; 25.0 percent, 5.3°F; 20 percent, 14.5°F; 15 percent, 19.6°F; and 10 percent, 24.8°F.

Ice-Melting Test

The ice-melting test used a flat Plexiglas™ dish, 9 in. in diameter. A 1/8-in.-thick layer of ice was frozen in the dish and smoothed to remove surface irregularities. The dish containing the ice was then equilibrated to operating temperature in the enclosure for a minimum of 2 hours.

The deicer sample, usually in a quantity (4.17 g) sufficient to yield a loading rate of 3 oz/yd^2, was cooled to operating temperature and scattered uniformly over the ice surface. Melted brine was collected, measured, and reinjected to the ice system at intervals of 10, 15, 20, 25, 30, 45, and 60 min. This operation was effected in about 2 min by tilting the dish, syringing out the brine, and reinjecting brine into ice cavities.

The application rate of 3 oz/yd^2 is about three times the rates used for application of highway deicing salt. The rate was selected to ensure that measurable quantities of brine were generated in test equipment. Comparisons between deicers are considered to be valid because the deicers were tested under identical conditions. Extrapolations to field conditions and field application rates will be subject to some uncertainty.

CMA-coated sand containing 13 percent CMA was applied in the ice-melting test at the rate calculated for application of 3 oz CMA/yd^2 (i.e., 23 oz/yd^2 for CMA/sand combination).

Visual observation of CMA-coated sand applied to the ice indicated a substantial variation in particle-size distribution from one test to the next. Accordingly, the quantity of CMA actually applied was determined on test termination by recovering and weighing the sand.

A series of tests was conducted with CMA-2 to determine the application rate required to yield approximately the same quantity of brine as rock salt. Application rates of 1.5, 3.0, 4.5, 6, 8, 11, and 15 oz/yd^2 were used in this series of tests.

Ice-Penetration Test

The ice-penetration test used an 11-in. × 2-in. × 3/8-in.-thick Plexiglas™ plate, placed on edge. Fifteen 1/8-in.-diameter, 1 1/2-in.-deep cavities were drilled in the Plexiglas™ at 5/8-in. spacings. The upper end of each cavity was enlarged with a conically shaped bit, yielding a cone 6 mm (0.24 in.) in diameter at the surface and 3.5 mm (0.14 in.) deep at the point of intersection of the cone with the 1/8-in. cavity.

Each cavity was filled with deionized and deaerated water. After freezing, the surface was melted with a metal piece and excess water removed. The apparatus was placed in the test enclosure and brought to temperature. A drop of dilute Bulls Eye™ (Milliken Chemical Company, Inman, South Carolina) dye was placed on the surface of the ice in each cavity approximately 30 minutes before test start. A weighed, pre-cooled deicer pellet was centered on the surface ice of each cavity, and depths of melting/penetration were recorded at selected intervals over a 1-hr period.

The penetration test with CMA-coated sand posed a special problem relative to selection of particles containing a quantity of CMA approximately equal to the quantity (24 mg) of deicer used with other materials. The several size fractions, which had been analyzed for CMA content, were further segregated into coated (as evidenced visually by a fairly uniform coat of CMA) and uncoated or poorly coated sand/CMA particles. The overall analyses showed the following:

- The large particles (+6 mesh) contain little CMA;
- Average CMA percentage of particle weight increases as particle size decreases;
- As particle size decreases, an increasing fraction of the pellets contain no sand; and
- A majority of the CMA is contained by the well-coated sand particles.

Thus, −6+8 mesh and −8+10 mesh coated particles contained about 40 percent CMA, while poorly coated sand grains in these size fractions contained 3 to 5 percent CMA. Well-coated −10 mesh material contained about 50 percent CMA, and a substantial fraction of the particles in this size range contained no sand. The coated −6+8 mesh particles weigh about 30 mg, and thus contain 10 to 12 mg of CMA on an average basis. Single CMA/sand pellets containing 24 mg CMA were not available, with the probable exception of fairly large pellets containing no sand core. Accordingly, penetration tests with CMA-coated sand used visually coated pellets isolated from the −6+8 mesh fraction. The average CMA content (10 to 12 mg) of these pellets was approximately 50 percent of the deicer weight used in penetration tests with CMA-1, CMA-2, and rock salt.

Single pellets of CMA-1 (RAD Services) having desired weights (23 to 26 mg) were not available in the supplied material. Accordingly, three 7 to 9 mg pellets were used for penetration tests with CMA-1.

DISCUSSION OF TEST RESULTS

On a theoretical basis, the normally cited comparative performance figure for CMA and rock salt is 1.7, that is, 1.7 lb of pure CMA with equimolar proportions of calcium acetate and magnesium acetate should have the melting capacity of 1 lb of sodium chloride, or 1 lb of CMA should melt 59 percent of the quantity of ice melted by 1 lb of sodium chloride. Factoring in the purities of the two CMA products tested in this investigation and the proportions of magnesium acetate and calcium acetate, CMA-1 (RAD Services) should melt 57 percent of the quantity of ice melted by the same quantity of rock salt; and CMA-2 (Chevron), 54 percent. The CMA/sand product should perform similarly to CMA-2 at rates adjusted for the CMA content of CMA/sand.

Comparative ice-penetrating capabilities for CMA and rock salt can be expected generally to reflect theoretical differences in ice-melting capacities, that is, it might be predicted that with pellets of equal weight, CMA will penetrate approximately 55 to 60 percent of that observed with rock salt. However, the penetration process is probably affected more by factors such as particle density, particle size, and thermochemistry than is the melting process. Ice melting may thus be more likely to parallel theoretical comparisons than will ice penetration.

Freezing-point data for the two products indicate that ice melting should occur down to a few degrees above 0°F for CMA-1 and to a few degrees below 0°F for CMA-2. Useful melting under field conditions usually does not occur at temperatures approaching eutectic temperatures, however. One of the objectives of this investigation consisted of defining a lower practical temperature limit for melting.

Ice-Melting Results

Data on volumes of brine generated at seven time intervals up to 1 hr are presented in Table 1 for 25°F and in Table 2 for 15, 10, and 5°F. The deicer application rate in these tests was 3 oz/yd^2 for rock salt, CMA-1, and CMA-2; and 23 oz/yd^2 for

TABLE 1 ICE-MELTING TEST RESULTS AT 25°F

	Average Brine Volume (ml)					
				CMA/Sand (23 oz/yd^2) by CMA Application Rate (oz/yd^2)		
Time (min)	Rock Salt	CMA-1	CMA-2	3.16	3.58	4.83
10	5.8	4.2	1.8	1.0	1.6	3.6
15	9.3	6.8	3.6	2.7	4.0	6.7
20	12.2	9.0	4.6	4.0	6.0	10.2
25	15.4	11.6	5.5	5.9	8.3	12.6
30	18.0	12.8	6.8	7.5	10.0	14.0
45	23.3	16.0	8.9	9.8	14.5	19.0
60	27.4	18.3	11.4	12.3	18.0	22.8

NOTE: Averaged data for tests with Morton-Thiokol Safe-T-Salt and American Salt. Deicer application rate, 3 oz/yd^2.

TABLE 2 ICE-MELTING TEST RESULTS AT 15°F, 10°F, AND 5°F

Temperature (°F)	Time (min)	Average Brine Volume (ml) Rock Salt	CMA-1	CMA-2	CMA/Sand (23 oz/yd^2)
15[a]	10	2.2	0.2	0.0	0.0[b]
	15	3.7	1.2	0.0	0.0
	20	5.2	2.7	0.3	0.0
	25	6.7	3.2	0.7	0.0
	30	8.1	4.2	1.1	0.3
	45	10.4	6.9	1.8	1.2
	60	12.4	8.1	2.3	2.7
10[c]	10	1.2	0.0	Not tested	
	15	1.7	0.0		
	20	2.2	0.0		
	25	2.9	0.2		
	30	4.0	0.5		
	45	5.4	1.1		
	60	7.2	2.3		
5[a]	10	1.0	0.0	0.0	0.0[b]
	15	1.3	0.0	0.0	0.0
	20	1.5	0.0	0.0	0.0
	25	1.9	0.0	0.0	0.0
	30	2.6	0.0	0.0	0.0
	45	3.8	0.0	0.0	0.0
	60	5.2	0.0	0.0	0.0

[a]Averaged data for tests with Morton-Thiokol Safe-T-Salt and American Salt.
[b]Values in this column correspond to a nominal CMA application rate of 3 oz/yd^2.
[c]Averaged data for tests with Morton-Thiokol Safe-T-Salt.

CMA/sand. The rate of 23 oz/yd^2 for CMA/sand nominally provides 3 oz/yd^2 of CMA.

Inspection of results with CMA-1 at 25°F and 15°F indicates that this CMA product melts ice in about the quantities expected relative to rock salt. At 10°F, CMA-1 appears to be on the verge of becoming inactive as an ice melter; at 5°F, no ice was melted over the 1-hr test period.

Inspection of results with CMA-2 indicates a considerably lower melting capacity than CMA-1 at 25°F; CMA-2 at 15°F performs similarly to CMA-1 at 10°F, and yielded no melted ice at 5°F. At the end of the 1-hr test period, the larger pellets of CMA-2 were only slightly dissolved at 15°F and 25°F; large pellets in fact failed to dissolve in an additional 2-hr period with the test apparatus at ambient (72°F to 75°F) temperatures.

The intent was to apply CMA/sand at a rate that would apply 3 oz/yd^2 of CMA. In the 25°F tests, insufficient care was taken to isolate representative samples. The wide variability of results in these tests prompted recovery, drying, and weighing of sand after each test. The variability is in part explained by the differences in actual application rates of CMA (3.16, 3.58, and 4.83 oz/yd^2). CMA/sand at 3.16 oz CMA/yd^2 performed moderately better than CMA-2 at 3 oz/yd^2. The performance of CMA/sand at 3.58 and 4.83 oz CMA/yd^2 is considerably better relative to CMA-2 than can be explained by the higher CMA application rates.

One general observation is applicable to CMA-1, CMA-2, and CMA/sand. With rock salt as well as with other deicers tested in related studies, ice melting occurs with extensive penetration through the 1/8-in. layer of ice, even at the lower range (5°F to 10°F) of temperatures tested. This penetration is accompanied by undercutting and creation of an expanding network of under-the-ice channels through which brine flows to the brine collection area of the test apparatus. The CMA materials largely fail to penetrate through the ice layer, except in the final 20 to 30 min of a 25°F test; brines remain principally on the surface of the sheet of ice and tend strongly to float undissolved deicer particles to the brine collection area. (The latter behavior is much less noticeable with CMA/sand—the sand particles have little tendency to float in the brine.)

The ice-melting capacity of CMA-1 and CMA-2 is compared to that of rock salt in Table 3. The column labeled "I"

TABLE 3 CMA ICE-MELTING CAPACITY RELATIVE TO ROCK SALT

Deicer	Temperature (°F)	Time (min)	Theoretical CMA:Rock Salt (I)	Observed CMA:Rock Salt (II)	CMA Obs.:Theor. (II:I)
CMA-1	25	60	0.57	0.64	1.12
	45			0.69	1.21
	30			0.71	1.25
	20			0.75	1.28
	15			0.73	1.28
	10			0.73	1.28
CMA-1	15	60	0.57	0.66	1.16
		45		0.67	1.17
		30		0.52	0.91
		20		0.52	0.91
		15		0.33	0.58
		10		0.09	0.16
CMA-1	10	60	0.57	0.31	0.54
		45		0.21	0.37
		30		0.12	0.21
		20		0	0
		15		0	0
		10		0	0
CMA-1	5			No ice melting	
CMA-2	25	60	0.54	0.40	0.74
		45		0.38	0.70
		30		0.38	0.70
		20		0.33	0.61
		15		0.32	0.59
		10		0.32	0.59
CMA-2	15	60	0.54	0.18	0.33
		45		0.18	0.33
		30		0.14	0.26
		20		0.07	0.13
		15		0	0
		10		0	0
CMA-2	5			No ice melting	

NOTE: Rock salt equals 1.0.

indicates that CMA-1 theoretically should melt 57 percent of the ice melted by the same quantity of rock salt; and CMA-2, 54%. The column labeled "II" presents the observed percentages as a fraction. The column labeled "II:I" basically presents numbers that indicate whether CMA has performed better (numbers > 1.0) or worse (numbers < 1.0) than expected from the simple theoretical differences (0.54 and 0.57 versus 1.0 for rock salt).

The data in Table 3 indicate the following:

- At 25°F CMA-1 performs better than theory, relative to rock salt, from beginning to end of the test period.
- At 15°F CMA-1 is a slower starter (10- to 30-min data), but over the 1-hr period performs better than theory, relative to rock salt.

- At 10°F CMA-1 generates measurable brine only after about 25 minutes. Over the 1-hr period, CMA-1 at 10°F yields about 55 percent of the melting expected, relative to rock salt.
- At 25°F CMA-2 melts ice at 60 to 75 percent of its theoretical capability, relative to rock salt.
- At 15°F CMA-2 is on the verge of becoming inactive or inert, in this respect resembling CMA-1 at 10°F.

Results of a series of tests undertaken to determine CMA-2 application rates required to yield a melting capacity equal to that of rock salt at 3 oz/yd^2 are presented in Tables 4 and 5.

TABLE 4 CMA-2 ICE-MELTING TESTS AT VARIOUS APPLICATION RATES: 25°F

Time (min)	Average Brine Volume (ml) CMA-2 by Application Rate (oz/yd^2) 1.5	3	4.5	6	8	Rock Salt (3 oz/yd^2)
10	0.7	1.8	2.6	3.9	4.1	5.8
15	1.4	3.0	4.3	6.2	7.3	9.3
20	2.2	4.0	6.3	8.8	10.2	12.2
25	2.7	5.5	8.3	10.8	12.5	15.4
30	3.5	6.9	10.4	13.1	15.6	18.0
45	4.8	8.9	13.5	17.4	21.3	23.3
60	6.4	11.4	16.3	21.3	26.4	27.4

TABLE 5 CMA-2 ICE-MELTING TESTS AT VARIOUS APPLICATION RATES: 15°F

Time (min)	Average Brine Volume (ml) CMA-2 by Application Rate (oz/yd^2) 1.5	3	4.5	6	11	15	Rock Salt (3 oz/yd^2)
10	0.0	0.0	0.1	0.0	0.0	0.0	2.2
15	0.0	0.0	0.4	0.5	0.5	0.4	3.7
20	0.2	0.3	1.0	1.1	1.2	1.3	5.2
25	0.3	0.7	1.3	1.8	2.3	2.2	6.7
30	0.5	1.1	2.0	2.5	3.6	3.7	8.1
45	0.6	1.8	3.3	4.5	6.1	6.9	10.4
60	0.8	2.3	4.6	6.0	9.0	10.3	12.4

From the data, it is apparent that at 25°F an application rate of 8 oz CMA-2/yd^2 yields brine in approximately the quantities given by 3 oz rock salt/yd^2. At 15°F, an equivalence point having any real significance could not be established. As higher and higher rates of CMA-2 were applied, it became evident that melted ice was increasingly absorbed in the masses of CMA present on the ice surface.

Ice-Penetration Results

Ice-penetration data are presented in Table 6. At 25°F the rock salt pellets penetrated through about 21 mm (0.8 in.) of ice in 60 min, compared to 4 to 5 mm (0.16 to 0.2 in.) of ice by CMA-1 and CMA-2, and 2.9 mm (0.11 in.) of ice by CMA/sand. The CMA/sand pellets, however, contained about 10 to 12 mg CMA compared to 23 to 26 mg CMA in CMA-1 and CMA-2 pellets. The times required for penetration of 3.2 mm (1/8 in.) of ice at 25°F are about 5 min for rock salt and 40 to 45 min for CMA-1 and CMA-2.

The rock salt exhibits significant ice-penetrating capabilities at 5°F, that is, 3.2 mm (1/8 in.) in about 40 min, and 4.4 mm (0.18 in.) in 60 min.

TABLE 6 ICE-PENETRATION TEST RESULTS

Temperature (°F)	Time (min)	Average Penetration Depth (mm) Rock Salt	CMA-1	CAM-2	CMA/Sand[a]
25	3	1.8	0.0	0.0	0.0
	5	3.0	0.0	0.0	0.0
	10	4.7	0.5	0.2	0.3
	15	7.6	0.9	0.6	0.6
	20	9.5	1.5	1.3	1.0
	30	13.9	2.1	2.1	1.8
	45	18.1	3.3	3.4	2.3
	60	20.7	4.1	4.7	2.9
15	3	0.6	0.0	0.0	0.0
	5	1.1	0.0	0.0	0.0
	10	2.4	0.0	0.0	0.0
	15	3.3	0.05	0.0	0.0
	20	3.9	0.07	0.0	0.0
	30	5.4	0.2	0.0	0.0
	45	8.6	0.7	0.0	0.0
	60	10.6	1.1	0.0	0.0
5	3	0.3	0.0		
	5	0.5	0.0		
	10	1.3	0.0		
	15	1.6	0.0		
	20	1.9	0.0		
	30	2.7	0.0		
	45	3.5	0.0		
	60	4.4	0.0		

NOTE: Mesh-size-8 pellets: 23–26 mg.

[a]Mesh-size-8 pellets of visually coated CMA/sand, average CMA per pellet: 10 to 12 mg.

Comparative ice-penetration data relative to rock salt are presented in Table 7. At 25°F, the three CMA products penetrate ice to about 20 percent of the depth penetrated by rock salt in 60 min. Rock salt penetrates significantly within 3 min while it takes about 10 min for the CMA products to produce even slight depths of penetration.

At 15°F CMA-1 penetrates about 10 percent of the distance in ice penetrated by rock salt in 60 min, while CMA-2 and CMA/sand exhibit no observable penetration of ice.

In summary, the three CMA products are markedly less effective than rock salt from the standpoint of ice penetration; and they have essentially no ability to penetrate ice at 15°F and lower. The differences in ability to penetrate ice perhaps are best illustrated by the fact that CMA at 25°F is about equivalent to rock salt at 5°F.

SUMMARY OF LABORATORY TEST RESULTS

Theoretical comparisons of CMA and rock salt indicate a 1.7 to 1.8:1 difference in ice-melting capacities, and lower temperature limits of potential utility which are slightly in favor of rock salt (i.e., –6°F for NaCl, –3.75°F for CMA-2, and +2.3°F for CMA-1).

Results of the tests performed in this investigation generally indicate that one CMA product, CMA-1, melts ice at rates and quantities somewhat better than predicted from theoretical comparisons, at 25°F and 15°F; that the second CMA product (CMA-2) performs substantially less well than predicted at 25°F and 15°F; and that the lower temperature limits for melting are about 15°F for CMA-2, 10°F with CMA-1, and 5°F and lower with rock salt. The results of the tests thus indicate

TABLE 7 COMPARATIVE ICE PENETRATION

Temperature (°F)	Time (min)	CMA-1 ÷ Rock Salt	CMA-2 ÷ Rock Salt	CMA/Sand ÷ Rock Salt[a]
25	3	0.0	0.0	0.0
	5	0.0	0.0	0.0
	10	0.11	0.04	0.07
	15	0.13	0.09	0.09
	20	0.16	0.14	0.10
	30	0.15	0.15	0.16
	45	0.18	0.19	0.17
	60	0.20	0.23	0.20
15	3	0.0	0.0	0.0
	5	0.0	0.0	0.0
	10	0.0	0.0	0.0
	15	0.015	0.0	0.0
	20	0.018	0.0	0.0
	30	0.037	0.0	0.0
	45	0.08	0.0	0.0
	0	0.10	0.0	0.0

NOTE: CMA relative to rock salt = 1.

[a]CMA/sand compared to 10- to 12-mg pellets of halite.

that the CMA products are seriously limited relative to rock salt for use at lower temperatures.

The relative inferiority of the CMA products is considerably more pronounced with regard to ice-penetrating capabilities. Rock salt has some penetrating ability at temperatures as low as 5°F; the CMA products penetrate reasonably well only at 25°F.

The following marked differences between CMA-2 and rock salt are probably caused by the inferior ice-penetrating ability of CMA. First, CMA products tend strongly to yield surface films of brine, in which smaller particles float; rock salt particles generate melt cavities into which the pellets sink, and the rock salt brine increasingly undercuts the ice with time. Second, the larger pellets of CMA-2 are only partially dissolved at the end of 60-min tests, while the larger rock salt pellets are fairly completely dissolved, even at the lower temperature tested. It can be concluded from these observations that the inherent rate of interaction between ice/brine and CMA is lower than the corresponding rate with rock salt; and that as a consequence, conditions conducive to rapid and efficient melting (i.e., immersion of pellets in brine) are precluded from developing.

The principal cause of the marked difference in the ice-melting capacities of CMA-2 and CMA-1 is attributed to the above effect. CMA-1 is a much more finely divided material; initially it has the benefit of substantially greater ice surface to deicer particle contact, and, as a consequence of higher surface area/smaller particle size, is enabled to interact more readily with ice and the surface film of brine.

EXTENSION OF ICE-MELTING RESULTS TO HIGHWAY USE

Extension of the ice-melting data to highway use permits the estimation of application rates needed to obtain comparable ice melting, excluding the effects of traffic and other possible effects. An application rate of 300 lb rock salt per lane mile should yield ice melting equal to that of about 460 lb of CMA-1 at 15°F to 25°F; approximately 790 lb of CMA-2 at 25°F; and approximately 1,800 to 1,900 lb of CMA-2 at 15°F.

One ton of rock salt is accordingly equivalent to about 1.5 tons of CMA-1 at 15°F to 25°F, 2.6 tons of CMA-2 at 25°F, and 6 tons of CMA-2 at 15°F. However, due to its marked dusting tendency, CMA-1 cannot be considered to be a practical deicer with existing highway equipment. Evaluations of CMA as a highway deicer must accordingly be based on the CMA-2 product applied at the high rates indicated for CMA-2.

The CMA/sand product can be less clearly evaluated and compared with rock salt. The somewhat limited data and accompanying observations indicate that the CMA content of CMA/sand is more useful than an equivalent quantity of CMA in CMA-2, consistent with the fact that the CMA in CMA/sand is concentrated in finer particles and on the surfaces of medium size particles (particles retained by 8- and 10-mesh screens). At 25°F the two CMA/sand samples containing a higher-than-average percentage of CMA yielded significantly higher quantities of brine per unit weight of CMA than did CMA-2.

COST ANALYSIS

Comparative costs for field use can be developed only with considerable uncertainty because snow and ice removal or control is a complicated function of weather and temperature; traffic; rate, frequency, and timing of deicer application; and other control measures. The point in question concerning relative costs is whether substitution of CMA for rock salt at the application rates presented above will result in the same or acceptable levels of snow and ice control.

Since the RAD Services product (CMA-1) is not a practical material with current highway equipment, cost comparisons at present should be based on the Chevron Ice-B-Gon™ product (CMA-2). For this product, a minimum application rate is about two and one-half times the application rate of rock salt, with rates five to six times that being required at temperatures of the order of 15°F. If the following are accepted: a factor of 3 (3 tons of CMA equivalent to 1 ton rock salt), $16.00 FOB plant as the cost per ton of rock salt, and $500.00 FOB plant as the cost of CMA, the relative deicing materials costs, excluding transportation, storage, and handling costs, are 1 ton rock salt: $16.00 and equivalent CMA (3 tons): $1,500.

The reported annual consumption of highway deicing salt in the United States is about 10 million tons (*5*), for a total FOB plant cost of $160 million. Substitution of CMA for rock salt would result in a total FOB plant cost of $15 billion, or $14.84 billion greater than the cost of rock salt. The FOB plant cost differential of $14.84 billion will be increased by added costs for transporting, storing, and handling the larger quantity of CMA. Annual costs of corrosion attributed to highway salt usage (*6, 7*) have been estimated as $1.2 billion for automobile corrosion, and $1.6 billion for bridge maintenance and replacement, for a total cost of $2.8 billion.

It is apparent that the added costs of across-the-board substitution of CMA for rock salt will be five to six times the benefit which might accrue from elimination of the corrosion attributed to highway salt use. Given the uncertainties about the extent of reduction of corrosion attending the use of production grade CMA, it is probable that the cost benefit from corrosion reduction will be less than the reported cost of $2.8 billion.

CONCLUSIONS

The CMA product (CMA-2) currently commercially available in a form suitable for highway snow and ice control can be thought of as being technically equivalent to rock salt in one of two important control characteristics—ice melting—when approximately three times as much material is used at the upper end of the ambient temperature range of interest (i.e., 20°F to 25°F). It is unacceptably inferior to rock salt with respect to ice melting at lower temperatures with no utility at temperatures of 15°F and lower. From the standpoint of ice penetration and undercutting/disbondment, CMA-2 is indicated to be much less effective than rock salt at all temperatures.

Costs for general use of CMA-2 as an alternate to rock salt are much higher than costs of rock salt. The additional cost for CMA-2 is not adequately counterbalanced by cost benefits that might result from corrosion control.

It can be concluded that the current CMA will be limited to special uses, exemplified by its incorporation in sand and its use on bridge structures and in areas where continued use of rock salt is environmentally objectionable.

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DISCUSSION

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The conclusions drawn from the research discussed in this paper are in direct conflict with independent findings from the field demonstrations of CMA by federal, state, local, and provincial transportation organizations. As such, the laboratory study discussed demonstrates that current methods are inadequate for the reliable evaluation of a deicer's efficacy in the field.

It has been widely known that CMA melts less ice than sodium chloride. However, highway snow and ice control is not accomplished through the mere melting of ice from the nation's roads—not even when sodium chloride is the deicer employed. Rather, chemical deicers work by breaking the bond of snow or ice with the highway surface, allowing traffic and plows to move the pack off the roadway and restore safe conditions. CMA has been shown to be effective in maintaining and restoring safe driving conditions at field demonstration sites across the United States and Canada.

McElroy et al. conclude that Chevron CMA (Ice-B-Gon™ deicer) must be applied at roughly 3 times the rate for sodium chloride to be effective. This is in direct conflict with the findings in field use. Indeed, a recent report of field experience on the Queen Elizabeth Way by the Ontario Ministry of Transportation (*1*) showed year-long Chevron CMA usage ratios to be 1.19 on high-speed highways and 0.95 on low-volume service roads. These data also reflect at least one instance in which salt application was deemed to be ineffective and was suspended during a severe storm whereas Chevron Ice-B-Gon deicer continued to keep the roadway track bare or better. A similar report by the Massachusetts Department of Public Works showed a year-long ratio of only 0.73 in use on urban streets.

The authors also conclude that the use of Chevron CMA as an alternative to rock salt is not cost-effective. Another recent report, issued by the New York State Energy Research and Development Authority (*2*) in the interest of reducing fuel use by motorists and contractors in the repair of highway damage, concluded that the total cost of salt-related damage in New York is between $920 and $2,080 per ton of salt now used. With the bulk price of Chevron CMA currently $600/ton, Ice-B-Gon deicer is indeed a cost-effective alternative to conventional deicing chemicals.

In addition, we would like to point out that the material described as Chevron CMA in the research does not meet Ice-B-Gon deicer specifications. Chevron was not asked to supply a sample for this research (which we do frequently) and does not know its origin or the sampling method used to obtain it.

Highway snow and ice control is an extremely complex subject. The effective maintenance of our infrastructure requires more than the simple melting of ice. It requires the use of responsible methods for keeping roads safe while minimizing the impact of these programs on the environment and on the roads themselves. It is toward this goal that the transportation community, and Chevron, continues to strive in the development of alternative deicers such as calcium magnesium acetate and Chevron Ice-B-Gon deicer.

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DISCUSSION

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In this paper, ice-melting data for a calcium magnesium acetate (CMA) deicer are presented and compared to corresponding information on rock salt. On the basis of information compiled, it was concluded that (a) rock salt is a much better ice-melting material than CMA and (b) CMA is unacceptably inferior to rock salt with respect to ice melting at low temperatures.

This paper does not point out that there are other methods by which deicing can occur and by which CMA works in deicing highways. Recent field studies have shown that although rock salt does melt ice much faster and to a larger extent than CMA, CMA deices by penetrating to the road surface, debonding and dislodging the snow or ice pack from the surface, and converting the pack to a loose, mealy mixture for easy removal by traffic or snowplows. These field observations showed that CMA, in quantities 1.2–1.6 times that of rock salt, worked as well as salt in its overall deicing ability by this method.

Thus there is more than one mechanism that a deicer can use to deice highways. CMA should not be judged solely by its melting capabilities for deicing ice and snow.

AUTHORS' CLOSURE

We appreciate Walters' comments but do not believe that our findings are in direct conflict with independent findings from field demonstrations, as he states. Review of CMA research by the states of Michigan, Iowa, and Washington as well as by the Province of Ontario suggests that a higher application rate of CMA is required to achieve a degree of effectiveness comparable with that of rock salt. Unfortunately, field research to date has compared winter storms that are usually above 25°F. CMA ice-melting and ice-penetrating abilities outlined in our paper are at 25°F and lower; thus the results do not rigorously apply to current field studies. Moreover, the laboratory tests do not represent the effects of traffic, wind or air currents, or the abrasive action of the deicer.

The study by Manning mathematically averages the CMA:rock salt used and arrives at a ratio of 1.19, as Walters correctly points out. However, according to Manning, the initial ratio of 1.7 for the application rate of CMA to salt was used, and after 2 months it was reduced to 1.5 to 1. Manning states: "The relatively small number of storms (15) prevented the investigation of other application rates," and "the optimum application ratio was not determined."

In 2 of 15 storms, rock salt/sand was compared directly with CMA/sand. One storm ratio was 0.76 to 1 and the second was 2.34 to 1. In the remaining storm events, rock salt, rock salt/sand, CMA, and CMA/sand were employed in varying combinations with varying numbers and rates of application. Sand was the major ice and snow control agent directed at snow control and did not include provisions for determining optimum comparative application rates.

Given the relative randomness of spread timings, rates per application, and intermingling of deicer with deicer/sand, in our opinion the 1.19 to 1 ratio of CMA to salt averaged in the field testing by Manning is low.

The current cost of CMA is approximately 25 to 27 times higher than rock salt based upon FOB average cost. Societal cost per ton of rock salt has been set at $101.50 in 1976 by The Institute for Safety Analysis (TISA), $300 in 1976 by EPA, and, as Walters notes, $920 to $2,080 in 1987 by the New York State Energy Research and Development Authority. Vehicle corrosion accounts for 67 percent (EPA study) and 63 percent (TISA study) of the overall societal cost. In our opinion, vehicle corrosion can be better approached economically by rustproofing.

In response to the question of the quality of the Ice-B-Gon CMA employed in our research, we elected to secure material made available for purchase by a state highway department rather than material supplied in response to a request for a research project. The material used in the tests appears to meet all product specifications with the exception of water insolubles (7.75 percent versus ≤ 3.0 percent).

In summary, we submit the following comments:

1. Research results indicate that the CMA product tested was sluggish, as related to rock salt, in its ice-melting and ice-penetrating capabilities and in this respect was substantially limited at temperatures below 20°F within the tested time frame (1 hr).
2. Field experience to date does not adequately indicate how much CMA relative to rock salt is required for acceptable snow control, and therefore an adequate basis for establishing a ratio does not now exist. The theoretical ratio is 1.7 CMA to 1.0 rock salt.
3. The cost benefits of using either rock salt or CMA for ice and snow control are subject to debate and questions. Corrosion reduction is also subject to the same questions.
4. We suggest that the reader or potential deicer user should evaluate costs and cost benefits in terms of factors and considerations unique to his use situation.