Comparison of Liquid and Solid Chemicals for Anti-Icing Applications on Pavements

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Tests designed to assess the anti-icing properties of several chemicals that are potential candidates for winter highway maintenance were performed. Included in the test scenario were different application rates. Meteorological conditions were closely monitored to compare the efficacy of each chemical given a certain weather combination. The Saab friction tester was used to monitor friction levels on test sections to quantitatively monitor the effectiveness of each anti-icer. Statistical methods were used to correlate the collected data. The test also included observations of the handling properties of the chemicals, ease of application, and the effect of traffic on the sections, but these results are not provided. Overall anti-icing is effective, liquid chemicals were for the most part more effective than solids, and during this test, at low application rates, none of the chemicals appeared to be effective at temperatures below −6°C (21°F).

The use of chemicals to maintain safe operating conditions for vehicle operators and pedestrians is an important issue for winter maintenance crews worldwide. Cost and environmental concerns make it necessary to minimize the amount of chemical used and to look for alternatives to chemicals that may be harmful to the environment if used improperly.

In an attempt to optimize chemical usage a study was conducted at the Keweenaw Research Center in Houghton, Mich., under the Strategic Highway Research Program. The study was designed to assess the anti-icing properties of different liquid and solid chemicals in a field situation. To assess the efficacy of each chemical as an anti-icing agent, 12 chemicals were applied on 3.7-m (12-ft) by 30.5-m (100-ft) sections of asphalt prior to a forecast precipitation event. In several instances "different" chemicals implies that the same chemicals were applied at two application rates.

OBJECTIVES

The study was undertaken to determine the anti-icing properties of certain chemicals and to assess qualitatively some of the techniques used to successfully apply the different chemicals as anti-icers. This testing included observations of meteorological parameters before and during each test so that correlations to these variables could be made.

The concept behind anti-icing is that the chemical is applied to the pavement prior to the conditions for icing. This then inhibits the ice-to-pavement bond so that the overburden ice can be removed by mechanical means. Thus the chemical is not required to melt through the entire thickness of ice, as is the case for "deicing."

If anti-icing is successful a lesser quantity of a particular chemical can be applied to attain and sustain a safe operating condition. Since weather plays an important role in a successful anti-icing operation, significant weather parameters were monitored to correlate the parameters with chemical efficacy.

TEST SETUP

Thirteen scenarios were tested on a portion of asphalt airport runway located at the Houghton County Memorial Airport. Because of the heavy snowfall in the region this tarmac is not maintained for service during the winter months. All of the sections were asphalt. Twenty-seven successful tests were conducted during the winter of 1991 and 1992. The chemical applications are shown in Table 1.

Liquid chemicals were applied at a rate equivalent to 45 to 90 kg (100 or 200 lb) of dry (solid) chemical (calculated by using percent chemical per weight of solution) to 1.61 lane km (1 lane mi) (7.66 g/m^2 = 100 lb/lane mi).

The test sections were 3.6 m (12 ft) wide and 30.5 m (100 ft) long. Sections were separated by a 61-m (200-ft) buffer zone to help eliminate cross contamination between chemicals.

During a test the average friction value was used as the measure to indicate how well a treatment worked in achieving a safe level of tire-to-road surface friction. Friction measurements were taken every 15 min throughout the test with a Saab friction tester. This device consists of a fifth wheel on a car that measures friction by comparing torque and speed and recording it on an on-board computer. The data obtained give an average friction value over the

TABLE 1 Chemical Application Rates (100 #/l.m. = 100 lb/linear mi = 7.66 g/m^2)

Chemical	Rate
NaCl solid	100#/l.m. and 200#/l.m.
NaCl solid and $CaCl_2$ solid 5:1	100#/l.m.
NaCl solid and $CaCl_2$ liquid 10gal/ton	100#/l.m.
$MgCl_2$ liquid	100#/l.m.
CMA solid	100#/l.m. and 200#/l.m.
CMA liquid	100#/l.m. and 200#/l.m.
Potassium Acetate liquid	100#/l.m. and 200#/l.m.
Urea solid	100#/l.m.
Control	No chemicals

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30.5-m (100-ft) test section. Evaluations of whether a second application of chemicals or a snow removal operation was necessary were made at 2-hr intervals. This was accomplished by looking at the 15-min average Saab friction tester readings.

A statistical package was set up to analyze all of the measured data that were acquired during a test period. This package was developed to have each day's test results added to a large matrix as soon as a test was complete. For each day comparisons were made between treatments, taking into account the weather conditions for that day.

An even larger matrix was developed by adding the measured parameters from each test day to those from the previous day's tests. In this way a running comparison is made between the treatments for all previous tests, still taking into account the weather for each test day.

ANALYSIS

Perhaps the most important, quantifiable factor that can be used to determine how well each chemical performs is the friction value. If a test section (chemical) reaches some desired friction value during a test, the outcome of applying the chemical is at least partially successful. If the average friction over the test period remains above a given acceptable value, this is another indication that the chemical is performing with some success. In terms of maximum friction a chemical that brings the friction up to a value comparable to that for wet pavement is likely to be quite successful. Values of maximum friction less than that for wet pavement when compared with the average friction can also give some indication as to the performance of the chemical application.

To compare the relative efficacy of each of the chemicals, an analysis was performed by using the friction values obtained during each test and under varying environmental conditions. A Friedman analysis was used for each test by comparing the friction value at each 15-min time interval and ranking these values from 1 to 13. From these interval rankings a sum of ranks throughout a test period is made.

The Friedman test (*1*) is a nonparametric two-way analysis of variance test. It treats each test time within a given day as a block in which it ranks the friction coefficient values. The ranks of a treatment over that day are then summed and compared with those of the other treatments. The analysis is based on the hypothesis that there is no difference in the distributions, and it determines the probability that the hypothesis is correct. This test was repeated for each test day. All Friedman tests were performed to a level of significance of 0.05.

Once the sums have been obtained for each test individually, the ranking for the entire winter period can be obtained by simply ranking the results for each chemical for all of the tests performed.

During a single test many things can happen that designate how a chemical performed. The following are among the possible scenarios:

- Friction starts low and stays low.
- Friction starts low and increases throughout the test.
- Friction starts high and stays high.
- Friction starts high and decreases throughout the test.
- Friction starts low, increases, and then drops off toward the end of the test.
- Friction starts high, drops off, and then increases again.

Considering the many perturbations, the use of maximum or average friction may be deceiving. To examine the qualitative aspect of each test by some means beyond the average and maximum friction values, a method was devised to place a numerical value on the performance. This value, called *effect*, is designed to quantify subjectively the performance of a chemical throughout an entire test period. For instance a test section may have a friction value of 0.7 at the beginning of the test. Because the snow was falling or temperatures dropped considerably during the initial part of the test the friction may have dropped off rapidly. This section would have a high value for maximum and possibly average friction but may not have actually performed well overall. There is a possibility that any one section may rank either high or low with standards of friction, but the overall performance may not be reflected.

To give some quantitative basis to the perceived effectiveness, the performances of the chemicals as the combination of three independent contributions are considered. These are the time that it takes for the chemicals to start to work (A), the average friction obtained throughout a test (B), and how well each chemical sustained an acceptable value throughout the test period (C). All of the friction results were analyzed, and the final decision was made that 22 percent of the total ranking should be attributed to (A), 67 percent to (B) and 11 percent to (C). On the basis of that decision a set of equations was designed to determine an overall value for effectiveness. The range of minimum to maximum frictions that was used for the calculations was 0.1 to 0.8. The value of 0.1 is representative of what the Saab friction tester would produce on glare ice and 0.8 is representative of what it would produce on ice-free, wet pavement.

The chemicals were ranked for each test by the following equation:

$$\text{Effect} = A + B + C \quad (1)$$

whose coefficients are calculated as

$$A = \frac{30}{t_{0.5}} \quad (2)$$

$$B = (F_{\text{avg}} - 0.1) \cdot 8.57 \quad (3)$$

$$C = (F_{\text{max}} + F_{\text{end}}) \cdot 0.625 \quad (4)$$

where

$t_{0.5}$ = time at which Saab friction tester result becomes ≥ 0.5,
F_{avg} = average friction for test,
F_{max} = maximum friction attained during test, and
F_{end} = friction value at end of testing.

This method ranks the performance of the chemical over the duration of the test and results in a rating from 0 to 9, where 0 is very poor and 9 is excellent.

The coefficient A accounts for the time that it takes for the Saab friction tester to reach an acceptable value. A friction value in the range of 0.42 to 0.56 is considered "good" for verbal braking action when measured with the Saab friction tester (*2*). For the purposes of the tests described here the acceptable value was set at 0.5. All times are taken by assuming the elapsed time from the onset of precipitation if possible. Otherwise the test was started at the time that the chemicals were applied. The next Saab friction tester run after chemical application was at 15 min. If the friction value for a given test section has reached 0.5 at this point, then $t_{0.5}$ = 15 and A = 2. If the friction never reaches 0.5, then $t_{0.5}$ tends toward infinity and this value goes to 0. If the friction value does not reach 0.5 during a test, then A is set to 0.

The coefficient B accounts for the average friction throughout the test. Since maintaining the average friction over the period of the test at or above the desired value of 0.5 is considered to be the most important factor of chemical application, this portion of the ranking is given the most weight. For example if the average friction for the entire test was 0.8, which is an expected value for ice-free wet pavement, the value for this coefficient would be 6. If average friction is 0.1, which is representative of black ice, this portion goes to 0.

The coefficient C determines how well each chemical performed as far as attaining and maintaining higher friction throughout the test. In this case if the friction value increased to 0.8 and was still at 0.8 at the end of testing, the contribution to the effect would be 1. If both average and ending friction are 0.1, the contribution to the effect would be 0.1, nearly 0. All other combinations range between 0 and 1.

In summary the "effect" equation (Equation 1) is the sum of the three coefficients and has a maximum value of 9 and a minimum value of 0. These equations were developed by weighting the relative importance of each of the three friction considerations described and assigning a value to them. The effect was calculated for each chemical and each test and was then corroborated with the visual assessment of the friction plots to ensure that the outcome was reasonable in every case.

A simple example may clarify this ranking scheme. Consider the curves in Figure 1. These example curves are developed by the use of contrived datum points chosen to illustrate six possible combinations for friction plots. Table 2 gives the result of the effect calculation for each of these six curves by using Equation 1. The curves are designated C1, C2, C3, C4, C5, and C6 both in Figure 1 and in Table 2. From Table 2 it can be seen that effect can vary considerably depending on the changes in friction throughout a test.

TABLE 2 Effect Calculations

Data Set	$t_{0.5}$	F_{avg}	F_{max}	F_{end}	A	B	C	Effect
C1	30	0.50	0.80	0.10	1.0	3.4	0.6	5.0
C2	∞	0.30	0.30	0.30	0.0	1.7	0.4	2.1
C3	15	0.74	0.80	0.80	2.0	5.5	1.0	8.5
C4	15	0.31	0.80	0.10	2.0	1.8	0.6	4.4
C5	15	0.40	0.80	0.80	2.0	2.6	1.0	5.6
C6	75	0.40	0.80	0.80	0.4	2.6	1.0	4.0

To make use of the calculated effect, a value that was deemed acceptable was determined. To accomplish this a hypothetical test was chosen to estimate an outcome from chemical application that would be acceptable to highway users. In this test the friction starts out at a value of 0.1 and comes up to a value of 0.5 at a time of 45 min. The friction then remains at 0.5 throughout the rest of the test period. The calculated effect for this scenario is 4.0. This value has been chosen to depict the acceptable effect for a test.

RESULTS

The Friedman analysis was first performed on the average friction data for each test day. These rankings were then analyzed over the entire winter test period by use of a second Friedman analysis. Figure 2 is the result for this ranking for the 27 tests. The relative ranking of the 13 treatments is given on the top of Figure 2 along with the value for the sum of ranks. The larger the sum the better the overall performance of the chemical application. These values increase across the plots from left to right. The bars on the graph depict groups of chemicals that cannot be statistically distinguished from one another, that is, those chemicals whose performance does not appear to be significantly different from those of the others connected by the same bar.

Figure 3 contains the results for the effect calculations for all of the 27 test days.

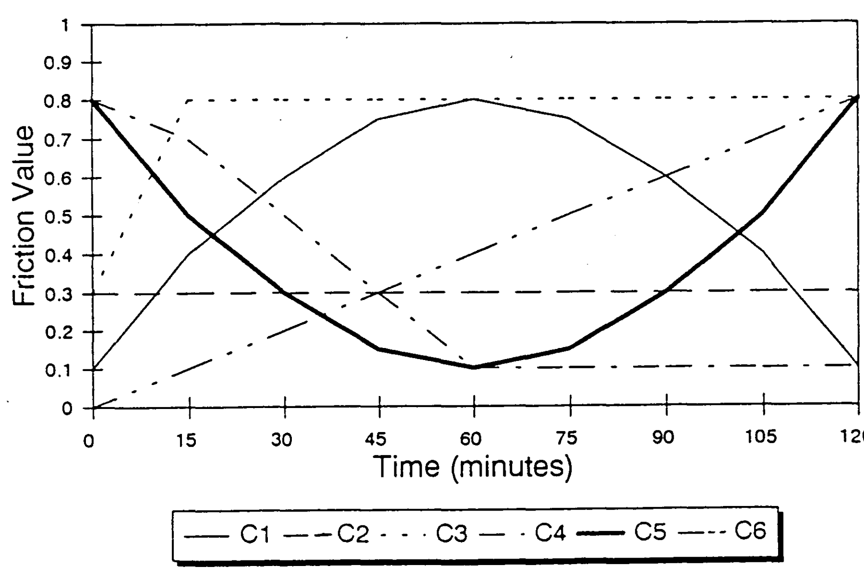

FIGURE 1 Example friction plots (time 0 = chemical application).

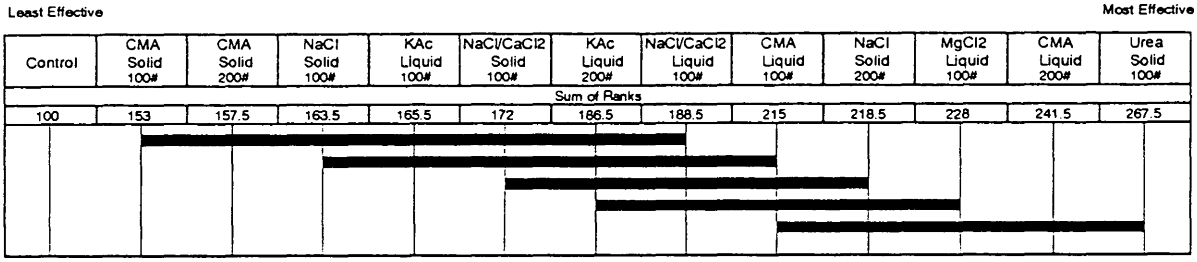

FIGURE 2 Friedman analysis, sum of ranks, All tests (27 cases) (# = lb = 0.45 kg).

After calculating the effect values for each chemical for all of the tests run during the winter period, the Friedman analysis was performed on these results. Figure 4 gives the results of these calculations for the 27 tests.

The data were further analyzed to identify any correlations between the weather parameters and the performance of the chemicals. The statistical significance of any correlations present was tested by using the Pearson and Bonferroni methods (*1*). From these tests it can be determined if the outcome of a test is statistically dependent on a given meteorological parameter.

Examination of all of these sets of data revealed that in no instance did the effect achieve an acceptable value of 4 (discussed earlier) when the pavement temperature was below −6°C (21°F). Realizing this the Friedman analysis was performed for the tests when the pavement temperature was above −6°C (21°F). This was done for both friction and effect, and the results are given in Figures 5 and 6. During 21 tests the pavement temperature was above −6°C (21°F).

Pavement temperature was the only meteorological parameter that showed a relationship to the outcome of the anti-icing procedure. Wind and ambient air temperature are two other parameters that have been shown to affect chemical efficacy (*3*). These two parameters were eliminated by the nature of testing, since no tests were conducted during periods of high wind and extremely cold temperatures.

The effect values were also analyzed in terms of the three components *A*, *B*, and *C* in an attempt to assess the chemicals in the three separate categories.

Figure 7 shows the result of the Friedman analysis for the *A* values, which should give a good indication of how fast each chemical begins to work. This result is for all of the 27 tests performed.

The same analysis was performed for cases in which the pavement temperature was at or above −6°C (21°F). The graph is not given to avoid redundancy. In both cases the order that each chemical performed in comparison with the others was identical. For the most part the liquids were faster than the solids when the *A* value was used as the indicator.

Figure 8 shows the result for the 27 cases for the *B* values.

The *B* value should give a good indication of how effective each chemical is at attaining an acceptable value of average friction. The analysis was also performed on the 21 cases. There were some subtle differences between the 27- and 21-test analyses. For the most part the liquids were again superior to the solids. The most important difference between the two results was that urea fell behind liquid CMA at 7.66 g/m^2 (100 lb/linear mi) and potassium acetate (KAc) at 15.32 g/m^2 (200 lb/linear mi) when the temperature was brought up to −6°C (21°F). This indicates that the urea may perform better than some of the other chemicals at the colder temperatures.

DATE	CONTROL	CMA 100	CMA 200	KAc 100	KAc 200	MgCl2 100	NaCl 200	NaCl/CaCl2 100 Liq	NaCl/CaCl2 100 Liq	Solid CMA 100	Solid CMA 200	Urea 100
12/12/91	3.8	9.2	9.0	9.1	9.0	9.1	8.7	8.5	9.1	8.7	8.9	8.9
12/13/91	4.9	5.2	5.0	5.0	5.3	5.1	5.0	4.4	4.9	4.9	4.5	4.8
12/20/91	2.3	2.4	2.7	2.2	2.3	2.9	2.0	2.0	1.9	2.3	2.3	2.0
01/02/92	3.3	8.7	8.8	8.6	8.7	8.8	6.0	6.7	5.6	6.2	5.7	6.2
01/06/92	6.8	8.0	6.6	6.2	5.6	5.9	5.9	5.4	5.0	4.9	4.9	4.1
01/08/92	4.2	4.7	5.7	4.6	5.6	5.4	4.6	4.7	4.5	4.7	4.6	4.5
01/09/92	4.5	2.6	2.6	2.7	2.8	3.4	2.6	2.6	2.7	2.6	2.6	2.1
01/10/92	5.5	4.7	4.9	2.1	1.8	4.6	2.3	2.2	2.2	2.5	2.1	2.4
01/11/92	3.2	6.9	8.7	8.3	6.2	8.7	5.1	6.7	5.4	5.9	4.9	6.0
01/22/92	2.2	4.6	4.7	2.6	3.0	3.4	2.6	3.6	2.4	2.7	2.5	2.6
01/23/92	1.6	2.6	4.2	3.1	4.5	4.6	2.5	2.6	2.6	2.8	2.7	2.6
01/27/92	2.1	3.4	3.7	3.4	3.2	3.5	3.1	3.9	2.9	2.4	1.9	2.8
01/28/92	1.5	2.7	2.5	2.1	2.4	2.5	2.1	2.3	2.1	2.2	2.3	2.4
01/30/92	1.7	5.1	5.3	4.1	4.8	4.9	4.4	6.7	5.6	6.4	6.1	6.4
01/31/92	1.7	2.4	3.1	2.4	3.2	3.7	2.6	3.2	2.6	2.9	2.8	3.2
02/06/92	2.0	2.4	2.4	2.7	2.7	2.4	2.7	2.9	2.2	2.2	2.1	2.2
02/10/92	1.8	2.0	2.8	2.3	2.4	2.5	2.4	2.5	2.5	2.1	1.7	1.7
02/11/92	2.1	1.8	2.0	2.2	2.1	2.1	2.4	2.2	2.2	2.1	2.1	1.9
02/12/92	1.9	2.1	2.4	2.1	2.0	2.3	2.0	2.3	2.2	2.3	2.3	2.5
02/13/92	1.5	2.6	4.3	1.9	3.0	4.4	2.3	2.3	2.2	2.0	2.1	2.2
02/14/92	1.7	7.5	8.7	4.2	8.3	8.8	8.6	8.8	7.1	5.2	6.4	8.6
02/20/92	1.7	4.7	4.4	4.4	4.0	3.6	1.8	4.3	4.3	1.6	1.7	3.7
02/24/92	2.1	6.2	7.1	5.4	6.5	7.4	5.1	5.6	4.8	5.2	4.7	5.0
02/25/92	3.4	7.5	8.5	6.5	7.5	8.5	5.6	6.2	6.2	6.2	5.8	6.7
02/27/92	6.6	6.6	7.6	6.6	7.5	8.9	7.9	8.0	8.8	8.0	8.8	8.7
03/09/92	1.8	2.4	1.9	2.4	2.1	2.7	2.5	2.2	2.6	2.6	2.7	2.3
04/01/92	4.2	2.5	4.0	2.5	5.6	5.7	2.4	5.0	2.6	2.8	2.7	2.6

FIGURE 3 Effect values for all tests (27 cases).

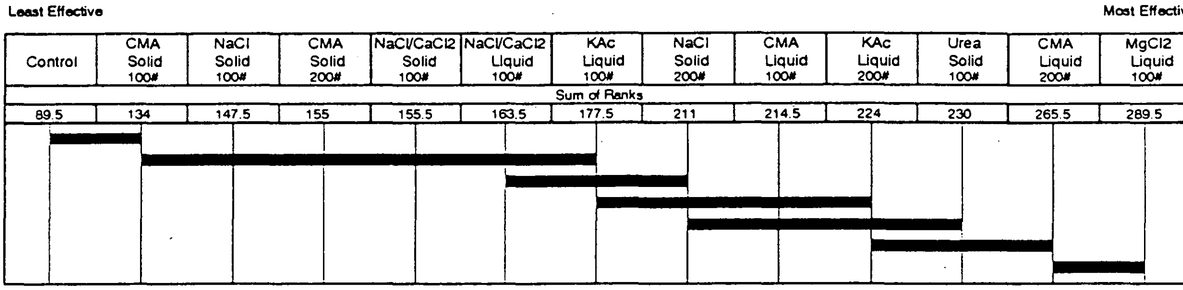

FIGURE 4 Friedman analysis, effect values, all tests (27 cases).

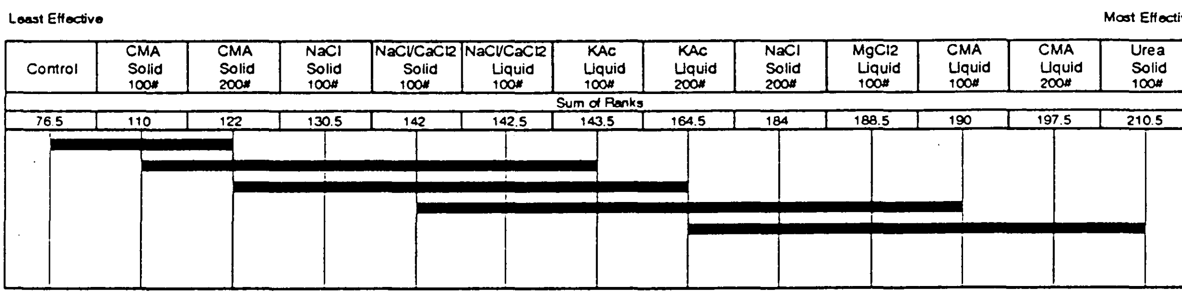

FIGURE 5 Friedman analysis, sum of ranks, pavement temperature above −6°C (27 cases).

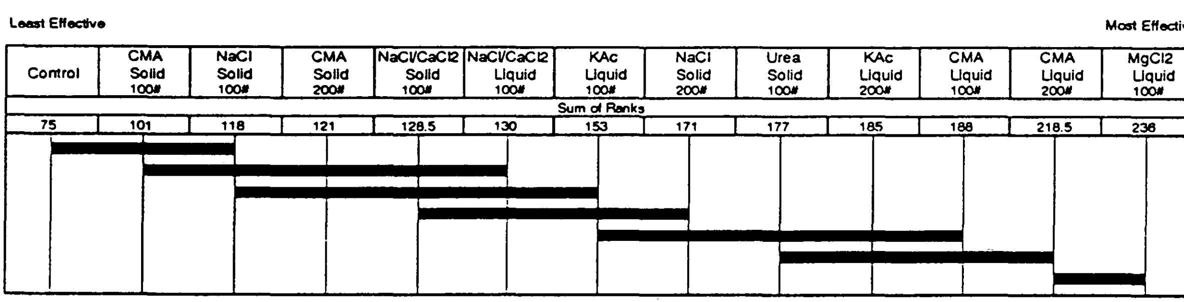

FIGURE 6 Friedman analysis, effect values, pavement temperature above −6°C (21 cases).

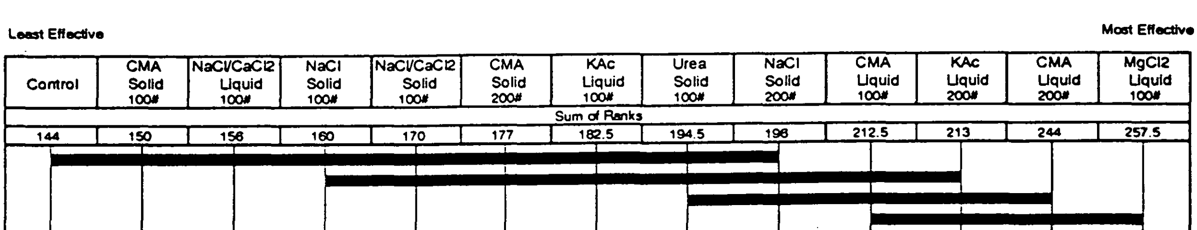

FIGURE 7 Friedman results, *A* values, all tests (27 cases).

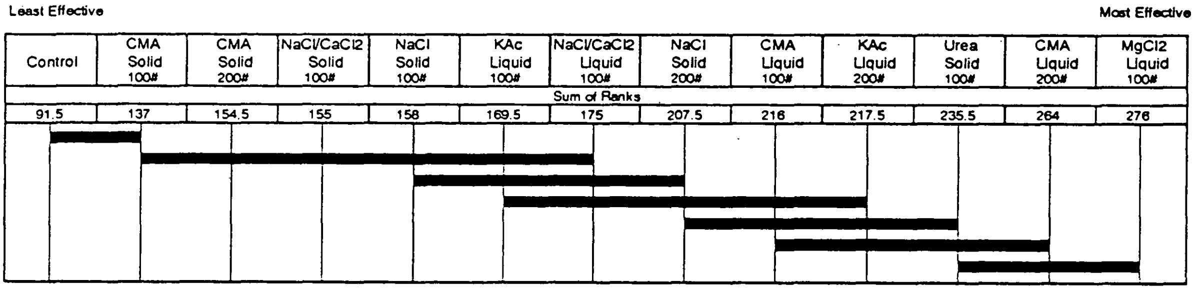

FIGURE 8 Friedman results, *B* values, all tests (27 cases).

Finally the result of examination of the *C* values by use of the Friedman analysis is shown in Figure 9 for the 27 cases. The *C* value should give an indication as to how well the chemicals can maintain a higher friction value with time.

The liquids, with the exception of the 15.32-g/m^2 (200 lb/linear mi) application of NaCl, were once again grouped as the better performers. This indicates, as is probably already well known, that salt tends to maintain quality on the pavement at least at the higher dosage.

The final analysis of the test data was performed on test days when two applications of chemical were deemed necessary to attempt to reach the desired level of service. The use of freezing point depressants for anti-icing is effective; however, in the present study the situation in which the snow that had fallen on the chemically treated asphalt pavement was simply peeled off to clear the pavement was not always observed. What did occur is that in many instances, when the chemicals were placed on the bare pavement, the majority of the snow was easily removed, but a thin film or layer of slush-like snow that could not be removed with a plow blade remained. The influence of the chemicals was visually apparent in these instances, in that the snow was much thinner than that on the untreated sections or the buffer zones and the treated sections were translucent and sometimes appeared to be bare. However in those instances when a low friction was recorded, close inspection revealed that a very thin ice layer was present. In those cases even power sweeping did not in general provide dramatic improvement, but depending on the pavement temperature another application of chemical was effective in removing the snow, particularly for the case of the liquids. Of the 27 tests run during the winter, 7 had a second application after 2 hr.

Since only seven test periods of data were analyzed care should be taken when drawing conclusions from these results.

Figure 10 shows the result of the Friedman analysis for the first 2 hr of the seven tests, or generally the anti-icing portion. From Figure 10, it can be seen that the relative order of effectiveness of the chemicals changed somewhat, but most importantly that it is difficult to separate the chemicals from each other, as indicated by the fact that only three bars exist and the overlap between them is substantial. This result should be obvious since the reason for applying chemicals a second time is that the first application was for the most part unsuccessful.

Figure 11 is the Friedman graph for the second application of chemicals. This result is not as expected because all of the liquids, with the exception of potassium acetate at 7.66 g/m^2 (100 lb/linear mi) performed better than the solids. This does not agree with the conception that liquids do not perform as well as solids as deicers. It is possible that the anti-icing effect of the liquids was adequate to get favorable results from a second application. Keep in mind, however, that only seven sets of data were available for this analysis.

OVERVIEW

As a general conclusion the use of liquids in an anti-icing program is superior to the use of dry chemicals (solids). This is certainly the case for the CMA liquid versus CMA solid, the only one of the chemicals for which there was a direct comparison. The one exception to this was the dry urea. This ranking of the urea is somewhat surprising since visually it did not appear to perform as well as the liquids.

Visually the liquids produced a more even pattern of anti-icing. This is likely due, at least in part, to the fact that they were not as easily displaced as the solids once they were applied to the bare pavement. When the liquids were placed on the thin film of

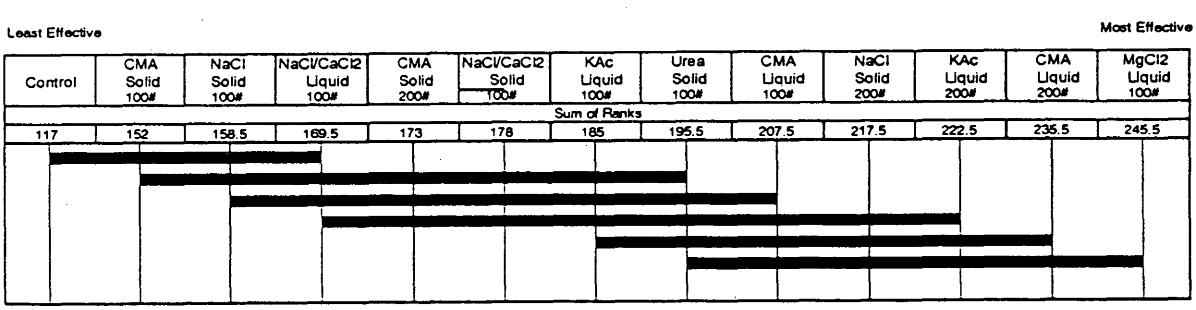

FIGURE 9 Friedman results, *C* values, all tests (27 cases).

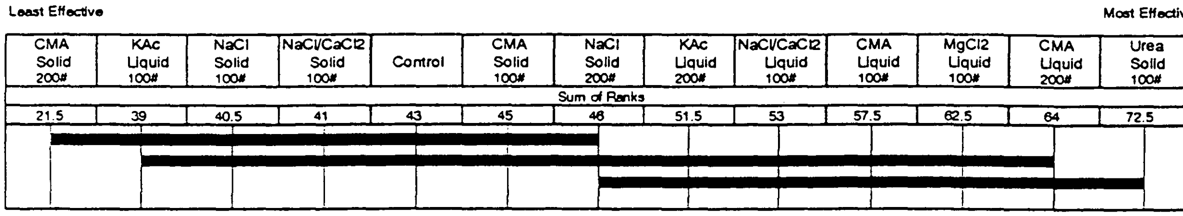

FIGURE 10 Friedman results, double application, first 2 hr (seven cases).

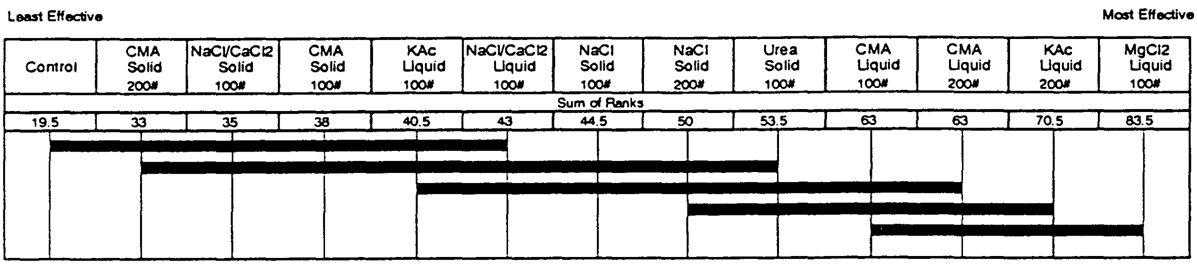

FIGURE 11 Friedman results, double application, second 2 hr (seven cases).

slush or ice as described above they were much more effective in removing this thin layer. When considering deicing such as this the liquids were much faster; however, if there is a substantial mat of snow the liquids were not necessarily as effective as the solid chemicals. The solid chemicals then appeared to have the advantage of burrowing and not becoming dilute as quickly, thus providing a better chance of exposure to the pavement, although at the rates at which they were applied, deicing under such conditions was generally ineffective.

In a review of all of the analyses performed on the data collected during 1991 and 1992 some interesting trends have evolved. Figure 12 is a tabulation of the Friedman results for several different scenarios. The shaded boxes around the chemical names are included to signify the liquid chemicals and to make it easier to differentiate them from the solids.

In summary:

- Liquids are generally more effective than solid chemicals for anti-icing.
- A thin layer often remains after snow that has accumulated on top of the treated pavement but that is effectively treated with

All Effects (27 Cases)	T1	T11	T7	T12	T9	T10	T4	T8	T2	T5	T13	T3	T6
Effects for 21 Cases, Pave. Temp.>+ -6C	T1	T11	T7	T12	T9	T10	T4	T8	T13	T5	T2	T3	T6
"A" Effect Values, 27 Cases	T1	T11	T10	T7	T9	T12	T4	T13	T8	T2	T5	T3	T6
"A" Effect Values, 21 Cases	T1	T11	T10	T7	T9	T12	T4	T13	T8	T2	T5	T3	T6
"B" Effect Values, 27 Cases	T1	T11	T12	T9	T7	T4	T10	T8	T2	T5	T13	T3	T6
"B" Effect Values, 21 Cases	T1	T11	T12	T9	T7	T10	T4	T8	T13	T5	T2	T3	T6
"C" Effect Values, 27 Cases	T1	T11	T7	T10	T12	T9	T4	T13	T2	T8	T5	T3	T6
"C" Effect Values, 21 Cases	T1	T11	T7	T12	T10	T9	T13	T4	T2	T5	T8	T6	T3
2-Test Days (7 Cases), Both Tests Included	T12	T1	T9	T4	T11	T7	T8	T10	T2	T5	T13	T3	T6
2-Test Days (7 Cases), 1st Test	T12	T4	T7	T9	T1	T11	T8	T5	T10	T2	T6	T3	T13
2-Test Days (7 Cases), 2nd Test	T1	T12	T9	T11	T4	T10	T7	T8	T13	T2	T3	T5	T6

[shaded box] Denotes Liquid Chemicals

T1 = CONTROL
T2 = CMA, LIQUID, 100#
T3 = CMA, LIQUID, 200#
T4 = KAc, LIQUID, 100#
T5 = KAc, LIQUID, 200#
T6 = MgCl2, LIQUID, 100#
T7 = NaCl, SOLID, 100#
T8 = NaCl, SOLID, 200#
T9 = NaCl/CaCl2, SOLID, 100#
T10 = NaCl/CaCl2, LIQUID, 100#
T11 = CMA, SOLID, 100#
T12 = CMA, SOLID, 200#
T13 = UREA, SOLID, 100#

FIGURE 12 Overall friedman results in increasing order of effectiveness for each set of tests.

another light application of chemicals has been plowed off. In this instance the liquids were superior.

- Solid chemicals are probably better for use in attempting to remove a thick mat but would require a larger amount of chemical.
- None of the chemicals tested was effective at a pavement temperature below −6°C (21°F).

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