SOME COMPARISONS OF SOLAR AND ROCK SALT FOR ICE MELTING

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Limited field trials in New Hampshire provided motivation for some laboratory comparisons of solar, rock, and a 1:1 mixture of solar and rock salt for ice melting. The solar salt as received contained much larger particles than the rock salt. In this preliminary study, unsized samples were applied to trays of ice at 10 F in a cold chamber, and the ice melted and salt dissolved were measured as a function of time. During the first 3.5 hours, the cumulative ice melted did not vary significantly for the 3 test materials, but the solar salt melted more ice per unit weight of salt dissolved than the other 2 materials. Failure of solar salt to melt more ice than rock salt during the first hour was contrary to prior road trials. To test the possibility that this difference was due to the absence of particle size reduction by traffic in the laboratory tests, 2 size ranges of solar salt were compared for melting effectiveness. Small crystals melted twice as much ice as large crystals during the first 15 minutes, but the large crystals melted more ice per unit of salt dissolved. Fine solar salt mixed with coarse rock salt might give rapid melting and long-lasting effectiveness on highways.

•THIS report represents a preliminary laboratory investigation of 3 specific materials. To further validate the results, extensive field trials under controlled conditions will be required and a comprehensive literature investigation must be performed. Nonetheless, it is felt that the data may be of interest to many who are concerned with this problem.

EXPERIMENTAL DESIGN

A rack was constructed to accommodate three 11 × 17 in. (280 × 430 mm) trays [one over the other with an approximately 4-in. (100-mm) separation] in a temperature-programmable cold chamber. The trays were arranged so there was an incline of approximately 8 degrees (0.14 rad). Holes were punched in the lower edge of the trays to allow salt solution to escape continuously. The solution dripped into a trough and thence into a weighed collection vessel.

The holes were temporarily sealed and water was frozen in the trays to a depth of ¾ in. (19 mm) and left in a freezer overnight. Before starting a series of trials, trays were placed in the cold chamber for 1 hour at 10 F (-12 C) to allow the chamber to come to an approximate moisture equilibrium. A trial was started by placing 100 grams of salt in a band about 2 in. (50 mm) wide along a 17-in. (430-mm) length of the tray at the upper edge of the incline. As the ice melted, water could run to the lower perforated edge and escape.

It was known that the temperature and air flow patterns varied somewhat within the chamber. To eliminate these variables from the data, 3 trials were run with 3 trays in place each time. In any given trial, 1 tray had solar salt, 1 had rock salt, and 1 had a 1:1 mixture. Positions were shifted so that each salt was tested 1 time in each

Publication of this paper sponsored by Committee on Snow and Ice Control.

of the 3 chamber locations, i.e., top, center, and bottom. No salt particle size selection was employed, but, for the material submitted, the rock salt was somewhat finer than the solar salt. The experimental plan can be represented by the following array:

Position	Trial 1	Trial 2	Trial 3
Top	Solar	Rock	Mixture
Center	Rock	Mixture	Solar
Bottom	Mixture	Solar	Rock

RESULTS

The data in Table 1 represent the total salt dissolved and the total ice melted in the 3 locations of the chamber. The data confirm the suspicion that the top of the chamber is warmer than the center and bottom because more ice melted in the top position than elsewhere. It is perhaps surprising that the least ice melted in the center rather than at the bottom of the chamber. This can be explained by examining the pattern of air circulation. Actually, it is probably colder and there is less evaporation in the center because the air in that area is more nearly static. This is reflected by the higher ratio of ice melted per gram of salt dissolved in the center compared to both top and bottom (Table 1). Evaporation losses during collection of salt solution would reduce the estimate of ice melted.

In Table 2 are given the total weights of ice melted and salt dissolved for several time intervals up to a total of 6 hours. Each datum is the sum of 3 measurements on 3 separate trays—1 from each of the 3 positions in the chamber. Since each trial had 1 sample of each type of salt, all differences must be due to salt differences and experimental error. The first measurements were taken after 60 minutes because some time is required for the first runoff to occur. Thereafter, measurements were made every 30 minutes. The data in Table 2 do not show differences clearly due to random variations for short time intervals.

To facilitate detection of any meaningful differences, the data were recalculated in the form of cumulative results from initiation of the tests. These numbers are given in Table 3 and are shown in Figures 1 and 2. Figure 1 shows that considerably less solar salt dissolved than rock salt or the 1:1 solar-rock mixture over the 6-hour period. However, there was no meaningful difference in salt dissolved during the first hour. With respect to ice melted, differences during the first 3.5 hours were very small and probably not significant. After 3.5 hours, it is apparent that the mixture was more effective than either the solar or rock salt alone. This difference was probably caused by the large crystals of solar salt that were sitting on top of smaller crystals of rock and solar salt during the first half of the tests. The rock salt contained very few crystals with effective diameters (longest dimension) larger than 0.25 in. (6.3 mm), whereas some of the solar salt crystals were larger than 0.50 in. (12.7 mm). More will be offered on this point later.

It is also instructive to refer to Figure 2, where the ratio of ice melted to salt used is plotted. Here, it is apparent that solar salt melted more ice per unit weight of salt dissolved. As expected, the 1:1 mixture was intermediate in its efficiency, although it started out poorly.

In attempting to explain these results, it is important to recall that there was still at least 1 major difference between these tests and road conditions. In these laboratory tests there was no disturbance of the salt after it was applied (except runoff); that is, there was no traffic to cause crushing of crystals, etc. Somewhat faster initial melting was expected for solar than for rock salt, but this was not observed. One reasonable explanation for this anomaly was the larger mean particle size for the solar salt relative to the rock salt. A larger diameter would mean less surface area to contact ice and therefore slower melting. Although this particle size difference is not unusual, solar salt seems to work faster on the road, in the opinion of users. The most logical explanation for this difference is that solar salt, with a lower density than rock salt because it is not formed under high pressure, will crush to fine particles more quickly than rock salt under normal traffic conditions.

Table 1. Comparison of melting for 3 locations in cold box at 10 F.

Location in Cold Box	Sum of Three 6-Hour Tests: Total Salt Dissolved (g)	Total Ice Melted (g)	Ratio of Ice Melted to Salt Dissolved
Top	229.2	936.8	4.09
Center	193.4	804.8	4.16
Bottom	209.7	856.5	4.08

Table 2. Melting efficiency of solar, rock, and mixed salts at 10 F by time interval.

Time Interval Relative to Start (minutes)	Salt Dissolved During Time Interval Shown (g)			Ice Melted During Time Interval Shown (g)			Ratio of Ice Melted to Salt Dissolved During Time Shown		
	Solar	Rock	Mixed	Solar	Rock	Mixed	Solar	Rock	Mixed
0-60	25.2	27.7	26.6	109.0	94.5	80.6	4.33	3.41	3.03
60-90	26.8	28.5	25.6	99.6	109.5	104.3	3.72	3.84	4.07
90-120	25.6	27.1	26.7	109.9	117.1	113.7	4.29	4.32	4.26
120-150	21.5	32.7	29.8	93.8	97.9	110.1	4.36	2.99	3.69
150-180	20.3	24.3	23.1	101.8	96.9	103.2	5.01	3.99	4.48
180-210	17.4	16.8	22.6	87.0	70.0	92.5	5.00	4.17	4.09
210-240	17.6	14.8	19.1	69.1	77.2	87.3	3.93	5.22	4.57
240-270	13.4	14.6	17.0	53.9	54.5	72.3	4.02	3.73	4.25
270-300	13.2	13.5	15.5	62.5	48.7	73.7	4.73	3.61	4.75
300-330	4.5	8.9	10.6	28.2	30.6	45.0	6.27	3.44	4.25
330-360	5.3	6.4	9.6	27.7	33.3	42.7	5.23	5.20	4.45

Table 3. Melting efficiency of solar, rock, and mixed salts at 10 F by cumulative weight.

Cumulative Time (minutes)	Cumulative Weight of Salt Dissolved (g)			Cumulative Weight of Ice Melted (g)			Ratio of Cumulative Weights of Ice Melted to Salt Dissolved		
	Solar	Rock	Mixed	Solar	Rock	Mixed	Solar	Rock	Mixed
60	25.2	27.7	26.6	109.0	94.5	80.6	4.33	3.41	3.03
90	52.0	56.2	52.2	208.6	204.0	184.9	4.01	3.63	3.54
120	77.6	83.3	78.9	318.5	321.1	298.6	4.10	3.85	3.78
150	99.1	116.0	108.7	412.3	419.0	408.7	4.16	3.61	3.76
180	119.4	140.3	131.8	514.1	515.9	511.9	4.31	3.68	3.88
210	136.8	157.1	154.4	601.1	585.9	604.4	4.39	3.73	3.91
240	154.4	171.9	173.5	670.2	663.1	691.7	4.34	3.86	3.99
270	167.8	186.5	190.5	724.1	717.6	764.0	4.32	3.85	4.01
300	181.0	200.0	206.0	786.6	766.3	837.7	4.35	3.83	4.07
330	185.5	208.9	216.6	814.8	796.9	882.7	4.39	3.81	4.08
360	190.8	215.3	226.2	842.5	830.2	925.4	4.42	3.86	4.09

Figure 1. Rate of melting in a 10 F chamber.

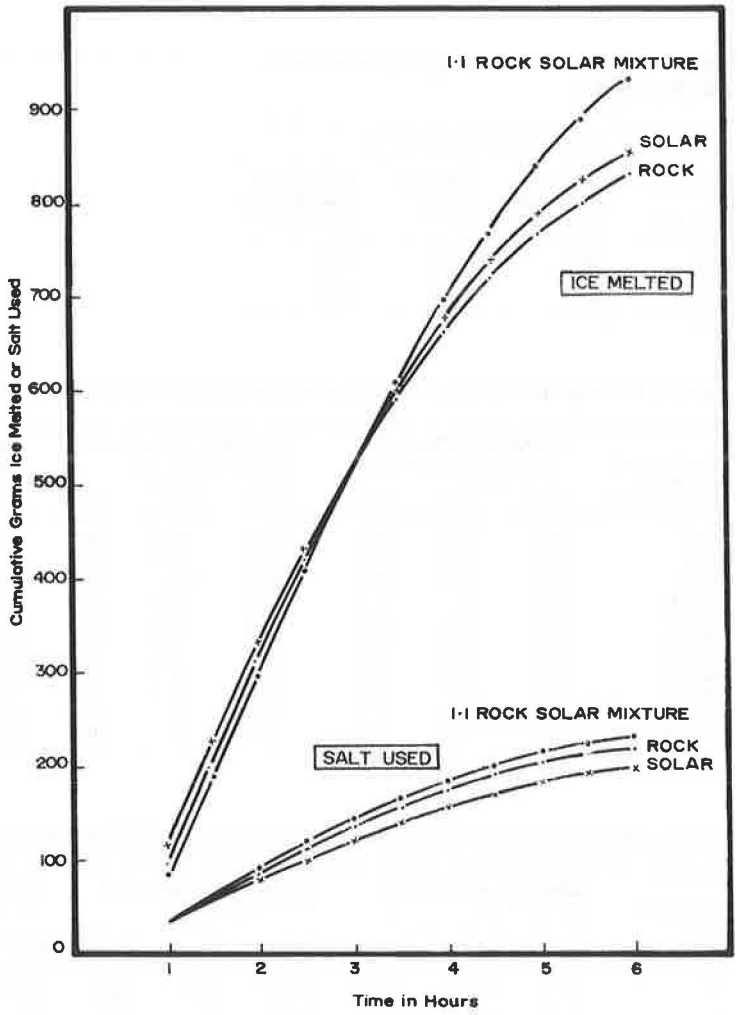
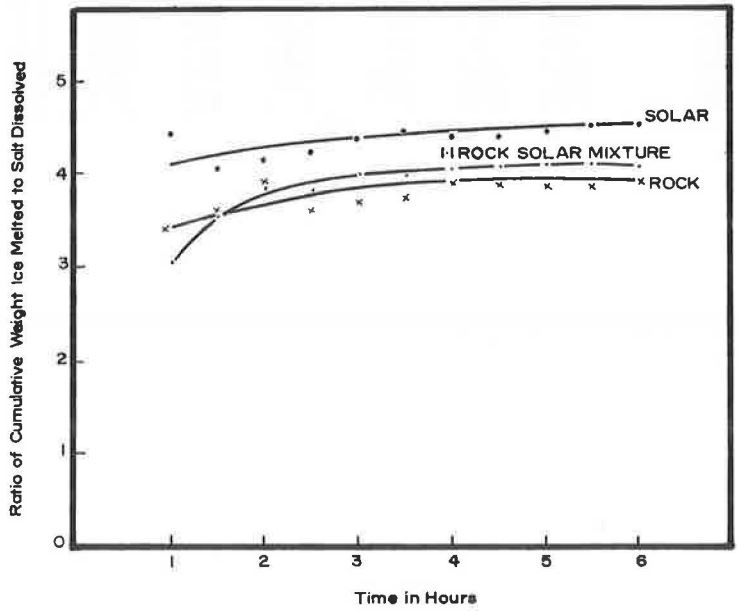


Figure 2. Melting efficiency of different salts in a 10 F chamber.



To test this hypothesis, 5 replicate samples of both solar and rock salt were prepared for compression tests. To eliminate particle size differences, all material was screened to smaller than No. 4, larger than No. 8 mesh. Samples (approximately 100 g) were loosely packed in a cup to a depth of 1 in. (25 mm), and the pressure required to compress it to $^3/_4$ in. (19 mm) during 1 minute was measured. The data are given in Table 4. In view of the empirical nature of this test and difficulty of uniformly packing the samples, it is not surprising that there is considerable variation. Still, a statistical test applied to the means indicates a difference in compressive strength at the 85 percent probability level. It seems reasonable to conclude that solar salt does crush more readily than rock salt.

It now remained to demonstrate that fine particles of solar salt will melt ice faster than larger particles of solar salt. For this test, duplicate 100-g samples were prepared in 2 different size ranges: 0.500 to 0.375 in. (12.7 to 9.5 mm) and 0.187 to 0.094 in. (4.7 to 2.4 mm) for the longest dimension. Two tests were run in the cold box using the 11 × 17 in. trays as before. In the first trial, the fine crystals were at the top of the chamber and coarse ones at the bottom. For the second trial, positions were reversed to compensate for temperature differences. To speed up the measurement process and to make it possible to get data shortly after the start of a trial, the average temperature in the cold box was raised to 27 F (-3 C).

The results are given in Tables 5 and 6 and are shown in Figures 3 and 4. The first point to note is that the small crystals melt more ice (on an absolute basis) than the large crystals throughout the trial. This is shown in Figure 3 and also in Figure 4 in the bottom curve where the ratio of ice melted by the 2 sizes of crystals is plotted. It is noteworthy that this higher melting efficiency for the small crystals is most strongly manifested at the start of the trial. During the first 15 minutes after application, the small crystals melted twice as much ice as the large crystals. This fact, coupled with the relative ease of crushing of solar salt, probably accounts for its very fast action in road tests.

Another fact shown by the data is that the small crystals dissolve much faster and therefore would not be as long-lasting in road use. Further, the fast rate of runoff associated with the use of small crystals produces a lower "total capacity for melting". This is shown in the 2 top curves of Figure 4, where the large crystals consistently melt more ice per gram of salt dissolved. In other words, large crystals melt more ice per unit of weight than small crystals, but they dissolve much slower and therefore actually melt much less ice during the first hour or so after application. The resistance of rock salt to crushing, with attendant reduction in particle size, probably partly explains why it is longer lasting than solar salt during normal road use.

The last point to be made concerns the much higher quantity of ice melted per gram of salt used in the last tests compared to the earlier ones. This is explained by the fact that the temperature in the last tests was 27 F (-3 C) and in the first tests it was 10 F (-12 C). Runoff occurs with a more dilute solution as the temperature is raised. However, it is clear that large applications of salt can produce melting and runoff at 10 F (-12 C). Further, it is likely that the use of small particles of solar salt would provide much-improved melting compared to unsized solar or rock salt when the temperature is below 15 F (-9 C).

SUMMARY

1. The compressive strength of solar salt is less than that of rock salt; that is, solar salt is crushed more easily. It is likely that traffic reduces solar salt to fine particles faster than rock salt.

2. Comparison of large solar salt particles (0.500 to 0.375 in. diameter) with smaller solar salt particles (0.187 to 0.094 in. diameter) showed that (a) small particles melt ice much faster than large particles immediately after salt application, but the difference decreases continuously over a 2-hour test period—for example, during the first 15 minutes, the small crystals melted twice as much ice as the large crystals, but between 105 and 120 minutes after the start, the small crystals only melted 1.1 times as much as the large crystals; (b) the small crystals also dissolved much faster and therefore

Table 4. Comparison of crush strength of solar and rock salt.

Trial	Load (lb) Required to Compress From 1 in. to ¾ in.	
	Solar	Rock
1	3,400	5,130
2	4,880	5,400
3	4,750	5,000
4	5,020	4,180
5	4,000	5,400
Means[a]	4,410	5,020

[a]A statistical comparison of the means shows that the average load required to compress the rock salt was higher than that for the solar salt at the 85 percent probability level.

Table 5. Melting efficiency of 2 sizes of solar salt crystals at 27 F by time interval.

Time Interval Relative to Start (minutes)	Salt Dissolved During Time Interval Shown (g)		Ice Melted During Time Interval Shown (g)		Ratio of Ice Melted to Salt Dissolved	
	Large Crystals	Small Crystals	Large Crystals	Small Crystals	Large Crystals	Small Crystals
0-15	5.6	15.5	43.9	87.2	7.84	5.63
15-30	12.6	20.0	88.4	118.9	7.02	5.95
30-45	13.4	23.3	86.4	115.4	6.45	4.96
45-60	12.9	26.7	86.6	111.2	6.71	4.16
60-75	13.1	21.1	77.9	108.2	5.95	5.13
75-90	12.9	18.0	86.9	99.4	6.74	5.52
90-105	12.8	14.2	79.4	77.3	6.20	5.44
105-120	9.5	12.0	61.2	68.8	6.44	5.73

Table 6. Melting efficiency of 2 sizes of solar salt crystals at 27 F by cumulative weight.

Time Interval Relative to Start (minutes)	Cumulative Weight of Salt Dissolved From Start (g)		Cumulative Weight of Ice Melted From Start (g)		Ratio of Cumulative Weights of Ice to Salt	
	Large Crystals	Small Crystals	Large Crystals	Small Crystals	Large Crystals	Small Crystals
0-15	5.6	15.5	43.9	87.2	7.84	5.63
15-30	18.2	35.5	132.3	206.1	7.27	5.81
30-45	31.6	58.8	218.7	321.5	6.92	5.47
45-60	44.5	85.5	305.3	432.7	6.86	5.06
60-75	57.6	106.6	383.2	540.9	6.65	5.08
75-90	70.5	124.6	470.1	640.3	6.66	5.14
90-105	83.3	138.8	549.5	717.6	6.60	5.17
105-120	92.8	150.8	610.7	786.4	6.58	5.21

Figure 3. Comparison of melting rates and salt use for large and small solar salt crystals in a 27 F chamber.

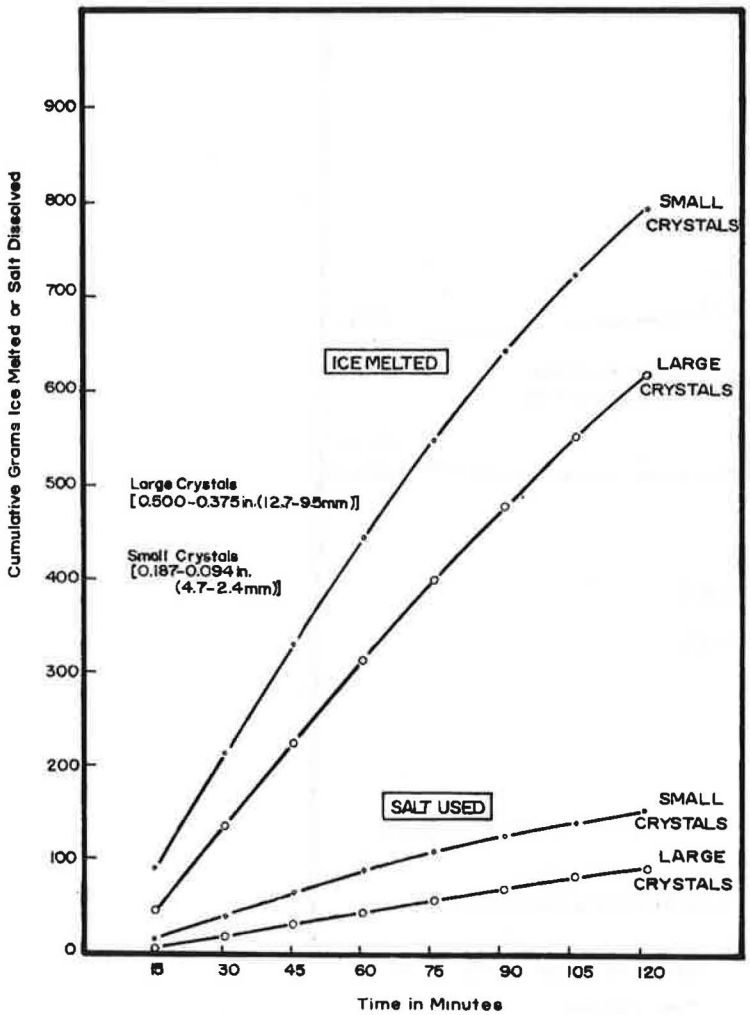
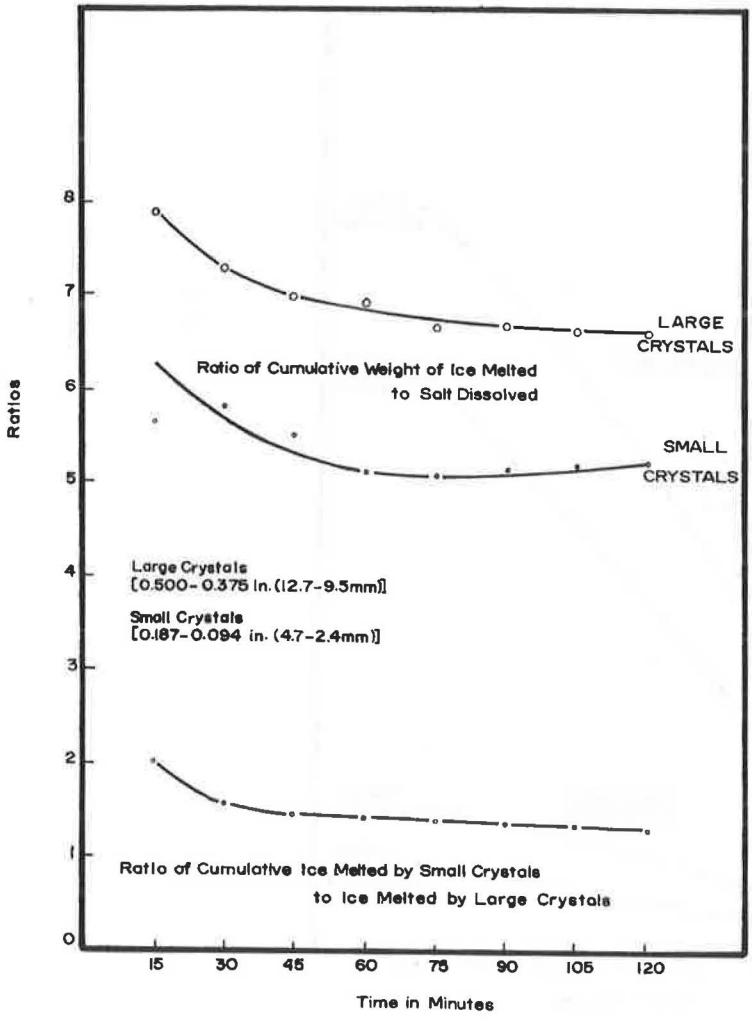


Figure 4. Comparison of melting efficiency for large and small crystals of solar salt in a 27 F chamber.



would not last as long in normal road use; and (c) the fast rate of runoff associated with the small crystals produces a lower "total capacity for melting"—i.e., small crystals melt less ice per unit weight of salt than large crystals.

3. Because large crystals melt more total ice than small crystals but small crystals produce faster initial melting, it appears probable that a mixture of normal-sized solar and rock salt should, under road conditions, produce both fast initial action and long-lasting action. This conclusion is justified by the fact that traffic should break the solar salt into rather fine particles quite quickly but will not reduce the rock salt size as quickly.

4. A 6-hour test at 10 F (-12 C) was conducted to compare rock salt, solar salt, and mixed (1:1) rock and solar salt under static conditions; that is, the salt was not disturbed after application and therefore there was no crushing action as in normal road use, and we would not expect fast melting action. As expected, there was little difference in the amount of ice melted during the first 3.5 hours; but between 3.5 and 6 hours, the rock and solar salt mixture melted 50 percent more ice than either rock or solar salt alone.

5. For these same conditions, solar salt melted more ice per unit weight of salt dissolved, the 1:1 mixture was intermediate, and the rock salt melted the least ice per gram of salt used. This was probably because the mean particle size of the solar salt was larger than that of the rock salt.

6. Because solar salt crushes readily, its use would be advantageous for severe temperature conditions, such as 10 to 15 F (-12 to -9 C).

ACKNOWLEDGMENT

The work described in this paper was supported by Granite State Minerals, Inc., Portsmouth, New Hampshire, and is published with its permission.

DISCUSSION

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In work of this type performed for us, we have found that the location of the trays in a ventilated cold room is most important, and we are pleased to see that researchers at the University of New Hampshire considered this variable in their investigation.

The purpose of the tests performed for us was to determine the effect of particle size on melting rates, and therefore each of the components of the screened fractions was weighed out for each test in order to control this parameter. However, 5-g samples were used. Therefore, a slight error in sampling could have made a considerable difference in the results, whereas the University of New Hampshire was using 100-g samples. We would recommend that salt meeting the latest ASTM D-632 specification be used.

We believe that a better case could have been made for the solar salt and rock and solar salt mixtures under the influence of traffic if the degradation in terms of screen size had been determined for these salts crushed between a hard surface and original-equipment rubber tires with 1,085-lb loading and assuming a reasonable vehicle count for a reasonable melting period. These screen fractions could then have been weighed out and used to make a direct measurement of the melting rate.

We considered cumulative ice melted as the most important measurement in tests run for us. Actually, readings in our tests were taken on the runoff solution after 15, 30, 60, 90, and 120 minutes. Readings taken after 90 minutes were not considered significant. Significant differences in ranking were found when running these tests at 9, 18, and 28 F (-13, -8, and -2 C).

We fully realize that research of this type at this stage of development is subject to opinion. We trust that the work done by the University of New Hampshire, plus our comments, will increase the body of knowledge with regard to these techniques.