Use of Chemicals and Abrasives in Snow and Ice Removal from Highways

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Ontario, like the other provinces of Canada and many of the northern states of the United States, faces each winter the tremendous task of removing snow and ice from highways and city streets. In recent years the demand for year-round bare pavements seems to have grown extensively and the maintenance groups who perform this work find their requirements increasing annually.

Assuming that the demand for bare pavement will continue to exist and there is no reason to assume otherwise—and also therefore that the cost of this work is not likely to decrease—it was decided to study carefully this entire question of snow and ice removal from the highways. It was thought that such a study might provide some clues concerning the melting effect of the various chemicals currently used and also an evaluation of the effect of mixtures of chemicals and abrasives.

Within the framework of this study no attempt was made to develop or investigate chemicals other than those currently in use, namely sodium chloride and calcium chloride. This does not mean that other chemicals have been ruled out rather it was thought that a better understanding of present practice might well lead to improved efficiency and economy.

It may be argued that investigations of this kind have been performed by others. Nevertheless, review of the literature indicated that several gaps in the knowledge of this subject still exist. In fact, many of the test methods which have been used by others (1), were stated to be open to question which, of course, leads to the obvious conclusion that the results would also be somewhat suspect.

●**UPON RECOGNIZING** the difficulty others had experienced, it was decided to attempt to develop a testing method which would produce reliable reproducible results. On completion of this step in the study it was then possible to determine the effect on the melting action of the various chemicals of such variables as the time of reaction, the temperature of the ice or snow and the concentration of the chemical. It was thought that by means of carefully designed experiments it would be possible to develop mathematical expressions which would relate these principal variables. Such expressions would then permit an estimate to be made of the most efficient chemical application for a given set of conditions.

Since the literature appeared to be somewhat incomplete regarding melting comparisons of calcium chloride and sodium chloride under a variety of conditions it was

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felt that such a comparison should be made. In addition, mixtures of the two chemicals were also treated in order to evaluate their melting action.

Finally, because mixtures of abrasives and chemicals are used by many agencies, a decision was made to test such mixtures in order to evaluate the melting action. Comparisons with melting results obtained when the chemical alone was used would be expected to give an indication of the effect of these treatments.

Certainly many other factors might very well be expected to affect the melting of ice and snow from pavement. However, it was decided to confine interests principally to a laboratory analysis of those factors previously outlined. Although field studies would have been desirable, and were in fact scheduled, the weather during the winter of 1957-58 did not cooperate and too little data were obtained to be of any real value.

TESTING PROCEDURES

In designing the experiment, advice was obtained regarding the number of tests required to provide an adequate sample for subsequent statistical analysis. This preliminary study confirmed the decision to limit the number of variables in the study.

The chemicals used in the study were coarse crushed (C.C.) rock salt, fine crushed (F.C.) rock salt, flake calcium chloride and pellet calcium chloride. All of the chemicals were used as supplied except that the rock salt was graded to meet the requirements of grading curves currently specified by the Ontario Department of Highways. The sand used in the experimental work was graded to satisfy a specified grading curve of the same agency. Grading requirements for rock salt and sand and the test gradings are given in Appendix F.

Each of the chemicals was tested separately and, in addition, mixtures consisting of C.C. rock salt with both types of calcium chloride and both C.C. and F.C. rock salt with various quantities of sand were tested. Details of the mixtures used and the raw data results are given in Tables 1 to 5 of Appendix A.

The testing program consisted of measuring the amount of ice melted by the various chemicals and mixtures under known conditions of chemical concentration, time of reaction and temperature. In order to evaluate the testing method which differed from methods used by others, two test runs were made on different dates using the same material and the results were analyzed for significant differences.

The details of the laboratory equipment and testing technique are not included in this paper in the interest of brevity. However, the interested reader will find all the details in a report (2) to be published by the Ontario Joint Highway Research Program.

ANALYSIS OF THE DATA

The first objective of the data analysis was to evaluate the effectiveness of the testing method. In order to make this evaluation, an analysis of variance was carried out on duplicate sets of data collected some eight months apart. These duplicate data consisted of complete sets of results using both C.C. and F.C. rock salt. In effect the results of this analysis had to be completed before additional testing could be undertaken.

The results obtained were most encouraging and indicated that the differences which occurred could largely be attributed to chance. Also this analysis indicated certain areas when the testing method could be refined in order to produce more reliable results.

Upon gaining reasonable assurance that the testing method was adequate, the remainder of the tests were performed and again the analysis of variance technique was used to evaluate the effects of the main variables, that is, time, temperature and concentration.

Similarly the same mathematical tool was used in determining the effect of adding various quantities of sand, the effect of mixing the chemicals and also for comparing the effectiveness of the various chemicals tested.

It should also be noted that an added advantage of this analysis technique is that by its use it was possible to determine the relative influence of the linear, quadratic and cubic components of the main variables under consideration, and in addition, the interaction of these main variables could also be established.

Because of the extent of the data, it is not reasonable to present all of the graphical plots, and, in fact, such presentation would probably be more confusing than helpful. Therefore, many of the plots contained in the following section of the paper are simply typical illustrations of the tests and should be so interpreted.

RESULTS

Effects of Principal Variables

The analysis of variance indicated that each of the principal variables had highly significant effects on the results and hence it can be inferred that real differences in melting can be associated with the three variables for all chemicals tested. Further it was found that the principal portion of the main effect in each case was contributed by the linear component. Although in some cases the quadratic and cubic components were also found to be significant, it was felt that the very large effect of the linear component in all cases indicated that a linear function could be expected to express reasonably the melting action of the various chemicals and mixtures.

It was also found that the various two factor interactions were highly significant. This indicated that the isolation of a single variable cannot be undertaken but rather the results are dependent on the combined effect of the variables. Thus, it should be understood that the figures shown later in this report indicating mean effects must be qualified according to the interaction effect. This does to some extent limit the scope of the data but at the same time it is believed the results should be of considerable interest.

Time Effect

The analysis of variance indicated that the effect of time was to contribute real differences to the results. This was to be expected since consideration of the raw data showed that the longer the chemical was permitted to act the greater the amount of melt.

Figure 1 is a representation of the effect of time for a single row of data in a cell. This plot tends to be typical of the results showing the time effect. It should be noted that in this plot the result is expressed in terms of what has been termed unit yield or unit melt which has been defined in this study as the weight of melted ice per unit weight of chemical applied.

Figure 2 shows the plot of an entire cell of data consisting of 16 points. These curves are essentially the same as the curve in Figure 1 except that the melt is given in terms of the total melt or pounds of ice melted per square yard of ice surface. Again the increase in total melt as time increases is quite evident.

To further illustrate this phenomenon Figure 3 has been prepared. The curves have been derived by plotting the mean melt results for each chemical for a given reaction time at all temperatures. This plot is of greater value in comparing the chemical types but it does tend to confirm what has been previously stated with regard to the relation between the amount of melt and time.

On the basis of these data it is apparent that where it is permissible to permit relatively long reaction times a saving of chemical is possible.

Concentration Effect

The analysis showed clearly that variations in the rate at which chemical was applied produced significantly different melts. Figures 4 and 5 correspond to Figures 1 and 2 except that these curves are plots of a section of the regression surface developed later in this paper. These plots are representative of the other test results pertaining to concentration.

Figure 4 indicates that the greatest melting efficiency occurs at the low concentration. This then tends to indicate that attempts to melt large quantities of ice will be most uneconomical.

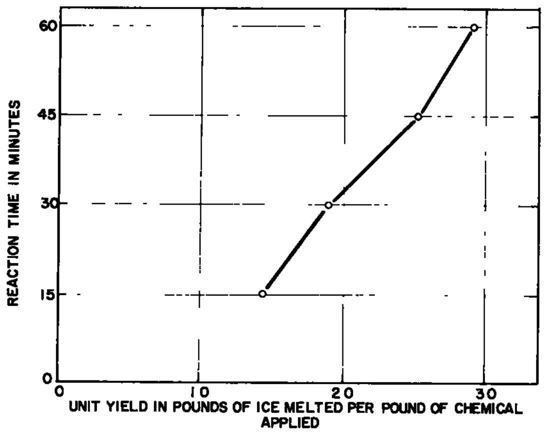

Figure 1. The time effect on unit yield (tests $S_cS_oT_2C_1$).

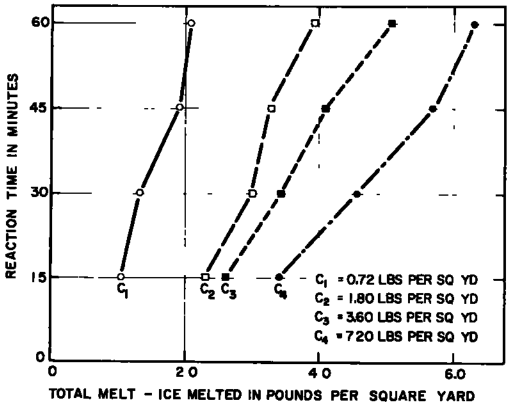

Figure 2. The time effect on total melt (cell data $S_cS_oT_2$).

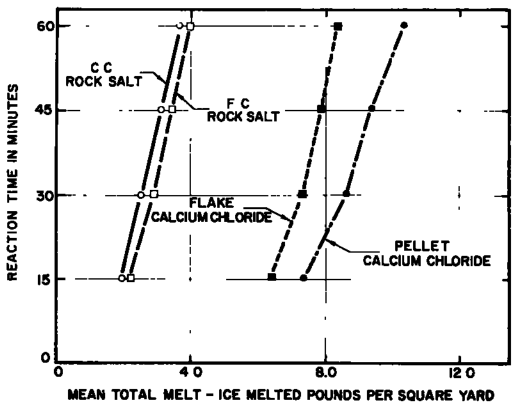

Figure 3. Mean time effects.

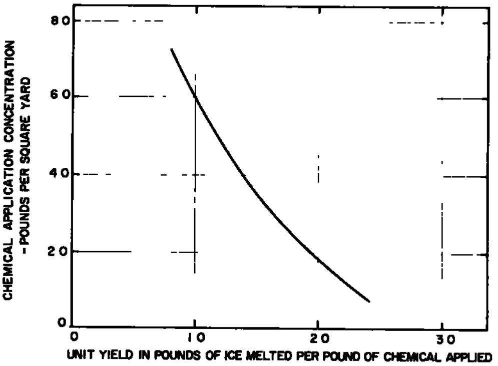

Figure 4. The concentration effect on unit yield (tests $S_cS_oT_2t_4$).

Figure 5 indicates that a maximum total melt occurred for each reaction time thus implying that concentrations in excess of this maximum would be truly wasteful.

Figure 6 gives a plot of the mean value of total melt for the various concentrations of the different chemicals. Each plotted point once again represents the mean of 16 test values. Since chemical types will be discussed separately it is sufficient to point out that pronounced variations in the effect of application rate do occur for the different chemicals tested.

Temperature Effects

In order to show the temperature effect on melting of the ice samples, Figures 7 and 8 have been prepared.

Figure 7 gives the estimated unit yield results for the various time periods on the regression analysis. It is interesting to note that the rate of melting increases rather rapidly with increasing temperature for each of the reaction times studied. In addition, as the reaction time increases the effect of increasing temperature also becomes more pronounced. Thus, on the basis of these data it would seem that C.C. rock salt is most effective in the range of 20 to 32 F.

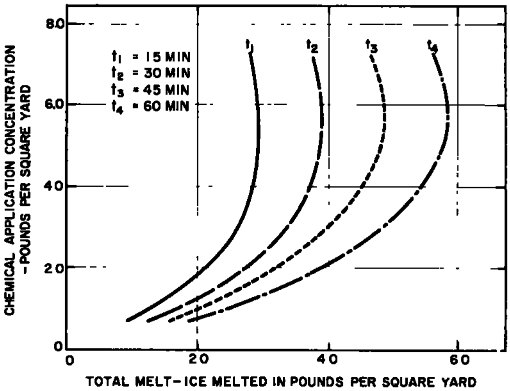

Figure 5. The concentration effect on total melt (cell data $S_cS_oT_2$).

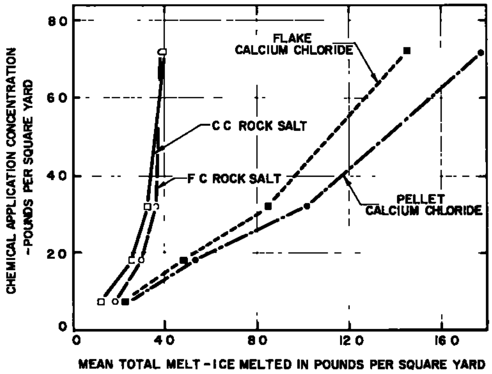

Figure 6. Mean concentration effects.

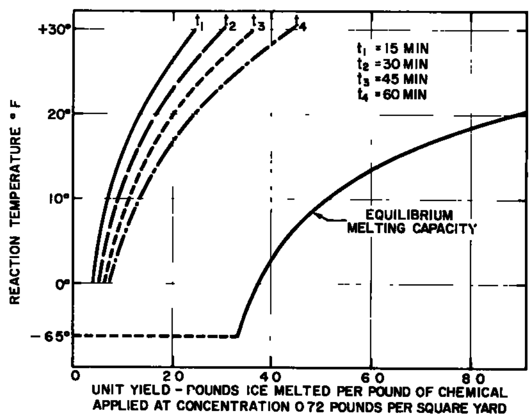

Figure 7. The temperature effect at equilibrium and at specified time (cell data $S_cS_oC_1$).

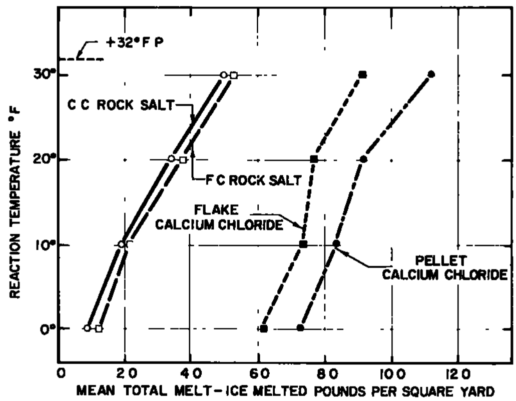

Figure 8. Mean temperature effects.

In addition to the four time-curves plotted in Figure 7, a fifth has been plotted. This curve, often referred to as the "equilibrium curve" for sodium chloride, shows the melting capacity of sodium chloride (3). There is some suggestion that this curve has been used to estimate the actual melting effect of rock salt. The danger of such action is, of course, obvious from the data plotted. No doubt if reaction times were extended the equilibrium curve would be attained but it seems difficult to say what that time would be. Also, in a practical sense, it is questionable to what extent reaction times in excess of one or two hours are significant in present day snow and ice removal.

Figure 8, giving a plot of the mean values, has been presented to indicate the similarity of the effect of temperature on the various chemicals tested.

It should be noted that the temperature referred to in these tests is the temperature of the snow or ice cover immediately prior to the application of the chemical. This temperature, in the field, is unlikely to be the same as that of the surrounding air.

Chemical Type Effect

In this discussion C.C. rock salt, F.C. rock salt, flake calcium chloride and pellet calcium chloride have been considered as separate chemical types for comparison purposes.

From the analysis of variance it was found that in comparing C.C. rock salt with F.C. rock salt, the mean melt values obtained in the tests of these chemicals differed significantly with the F.C. rock salt producing the greater melt. Similarly the comparison of flake and pellet calcium chloride resulted in an observation of significant differences in the mean melt with the pellet variety developing the greater melt.

In order to visualize the influence of reaction time, concentration and temperature on the four chemical types, reference should be made to Figures 3, 6 and 8 respectively. It should be recalled that each point plotted on these curves represents the mean of 16 experimental results.

It is significant to note that in each of the plots the mean melt obtained from the calcium chloride tests is considerably greater than that of the rock salt. Also the pellet variety of calcium chloride consistently produced more melt than the flake calcium chloride. This latter situation might have been expected because of the difference in purity of the two products, but the purity alone does not explain the total difference since the curves are seen to diverge. It is probable that particle shape may influence the melting characteristics to some extent but no definite proof of this statement can be made at this time. Moreover it is apparent that in all cases the superiority of the pellet calcium chloride over the flake type increases as the time, concentration and temperature increases. This is particularly noticeable in Figure 8 where the two chemicals show essentially the same characteristic at low concentrations but at high concentrations are decidedly different.

Comparisons of the two types of rock salt shows that the F.C. rock salt is somewhat superior in practically all cases. However, at high concentrations the C.C. rock salt exhibited slightly higher melts than the F.C. type. Certain difficulties were encountered in obtaining an even spread due to "caking" of the F.C. rock salt and this factor may partially explain the latter differences. In addition, the variability of the F.C. rock salt results were always greater than for the other chemicals which provides further evidence of the difficulty in handling this material.

Of interest also, are the similarity of the curve plots in Figures 3 and 8. This similarity tends to indicate that the reaction time and the temperature variable influence the melting characteristics of the four chemical types in a similar manner. On the other hand variations in concentration affect the four chemicals in a decidedly different manner. With increasing concentration the melting of the calcium chloride samples increases at a relatively uniform rate whereas the rate of melting of the rock salt tends to decrease with increasing concentration. It should also be noted that at the low concentrations the mean melts of all of the chemicals tested do not differ appreciably. This fact should be of value in making decisions concerning the selection of a chemical for snow and ice melting purposes.

Sand Effect

Due to time limitations it was only possible to examine rock salt-sand mixtures in this study. In each of the tests, the amount of chemical was the same as in the previous tests and only the quantity of sand was varied. The results of this analysis are given in Figure 9.

It is quite evident from the plot and also from the analysis of variance that the principal effect of the sand was to retard the melting action of the chemicals tested. The effect of the sand on the F.C. rock salt was found to be more pronounced than on the C.C. rock salt within the range tested.

One would not expect the linear trends of the plotted curves to continue as the quantity of sand was increased but unfortunately the actual slope of the remainder of the curve cannot be established at this time because of lack of data.

On the basis of this part of the study it would appear that, where abrasives are necessary, mixtures with C.C. rock salt will produce better melting results than mixtures with F.C. rock salt but at the same time the effectiveness of the melting action of the salt is greatly reduced.

Calcium Chloride - C.C. Rock Salt Mixtures

Since some discussion has taken place in recent years regarding the possibility of combining rock salt and calcium chloride for application on the road, it was decided to attempt to evaluate the effects of some mixtures of these chemicals.

The results of these tests are shown in Figures 10 and 11 and indicate the main results in terms of unit yield or unit melt. It must be clearly understood that these plots in no way reflect the conditions for a single set of conditions but rather are mean values obtained from 64 measurements. The reason for this approach was to enable comparisons to be made using the analysis of variance technique.

Figures 10 and 11 each contain a curve which shows a calculated or expected yield for the mixture. The values used in plotting these curves were determined by proportioning the melt data obtained when the two chemicals were tested separately. It is interesting to note that the difference between the combined chemical tests and the estimated values is reasonably small. This suggests, then, that a knowledge of the melting characteristics of the separate chemicals will enable estimates to be made of the melt which might be expected if the chemicals are combined. The results of these tests might well have been expected but were performed since there has been, on occasion, some suggestion that this was not the case. To be sure slight differences have been found to exist between the experimental and estimated results however "t" tests failed to develop sufficient evidence to clearly indicate that these differences were truly significant.

A combination of "t" tests and analysis of variance results did indicate, however, that at all levels of the test of the mixtures significant differences in the melt did occur. In other words it is reasonable to suggest that the addition of increasing quantities of calcium chloride of either flake or pellet type to C.C. rock salt tends to improve the melting effect. This fact is clearly shown in Figures 10 and 11.

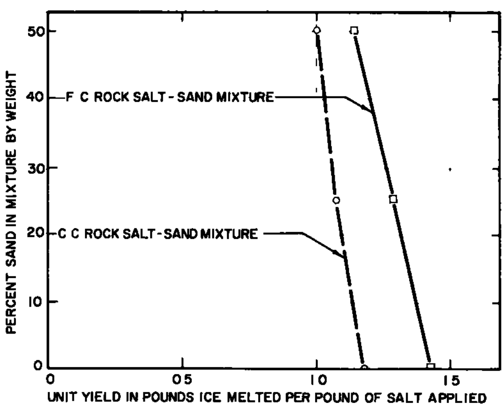

Figure 9. Mean sand effects.

Interactions

Comment must be made with regard to the two factor interactions evaluated in the

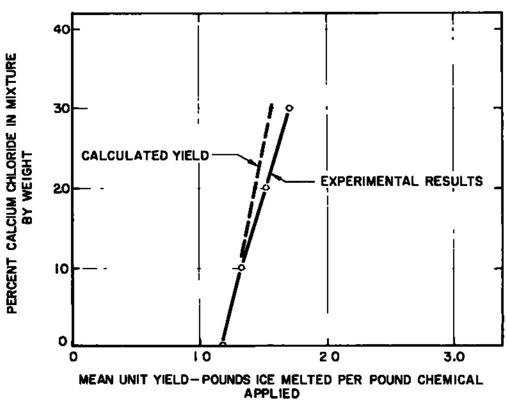

Figure 10. Mean flake calcium chloride admixture effect.

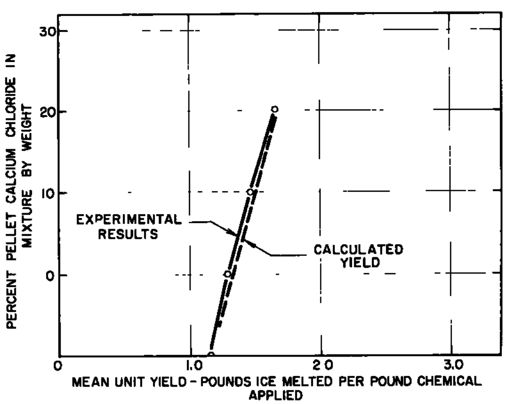

Figure 11. Mean pellet calcium chloride mixture effect.

analysis of variance. The interactions, for the most part, were found to be highly significant. In effect this means that the results depend on two interacting variables and therefore the effect of either variable should only be discussed at a fixed level of the other. Where significant interactions occur they are apparent by noting the tendency of curves to converge. The fact that interactions were found to be significant, indicates that generalized statements about the various variables cannot be made separately, and that care must be taken in drawing inferences from the data.

DEVELOPMENT OF THE PREDICTION EQUATIONS

One of the primary objectives of this study was to attempt to develop mathematical expressions which, for the various chemicals and mixtures tested, would relate the main variables—reaction time, temperature and concentration—according to the melting effect. In order to undertake this task it was necessary to utilize the statistical technique known as regression analysis.

At the outset, a series of preliminary plots of the raw data were made to see whether a noticeable curve shape was indicated. Also reference was made to the analysis of variance which indicated a significant linear effect. Earlier analysis showed that smaller variations occurred when unit yield data were used as opposed to total melt in formation. Finally it was found that the concentration-temperature interaction which was significant when arithmetic data were used was not significant when the logarithms of the unit yields were analyzed. Based on these preliminary tests it was decided that the expression relating the main variables with the unit yield should take a logarithmic form.

It was realized, however, that the quadratic and cubic components were significant in some cases and therefore, the mathematical model selected might not be absolutely perfect. Nevertheless, it was apparent that, within the range of variables tested, the contributions of the quadratic and cubic components were numerically quite small. Moreover, it was believed that the loss in degrees of freedom, if these latter components were included, would offset any improvements to the model which might occur by their inclusion in the model. There is some suggestion that if the testing ranges were extended, consideration of a quadratic or possibly a cubic model should be given; however, for this study there seemed to be logical arguments for selecting a linear logarithmic model.

In performing the analysis it was decided that there would be considerable merit in developing a series of expressions relating unit yield to chemical concentration and temperature for each of the levels of reaction time tested. With this kind of information it would then be possible to determine, for a specified reaction time, the melting effect of the various chemicals and mixtures for any concentration-temperature combination.

It was also decided that to make the equation more useful in a practical sense, it would be desirable to express the yield in terms of inches of snow melted. Since total melt was a direct function of unit melt no difficulty was encountered in this transformation. However, in order to express the melt in terms of inches of snow melted, data reported by Nichols and Price (4) were used. These reports suggest that the specific gravity of newly fallen snow can be taken as 0.06 and this value was used in determining the equivalent depth of snow in this study. The concentration of the chemical was transformed into units of pounds per square yard.

The mathematical expression which was finally derived was of the following form:

$$\text{Log } X = \log D + QD + RT + Z$$

where

X = the depth of fresh fallen snow in inches
D = the concentration of the chemical or mixture applied to the ice or snow surface in pounds per square yard
T = the temperature of the snow in ^{0}F
Q and P = parameters based on the analysis of the experimental data

Z = a constant developed in the regression analysis

Values of Q, R and Z for a wide variety of conditions are given in Tables 6 and 7 of Appendix C.

In order to illustrate some of the results obtained from using the prediction equations Tables 8 and 9 have been included in Appendix D. These tables by no means represent all possible comparisons, but rather are included simply to give some indication of predicted melting capacities of the various chemicals and mixtures tested (2, 6).

PRACTICAL APPLICATION OF THE PREDICTION EQUATIONS

The prediction equations developed and the values of melting capacity previously discussed are certainly of interest. However, it was thought that these data would be of much greater value to the maintenance engineer if they could be presented in a slightly different form.

In an attempt to satisfy this requirement, Tables 10 through 17 are given in Appendix E. Tables 10 to 13 refer to a 15-min melting time and Tables 14 to 17 to a 60-min melting time. It was thought that the linearity of the time effect previously referred to was sufficiently well established so that information for melting times lying between these limits could be interpolated by using a direct proportion.

The tables of Appendix E were prepared using the prediction equations and expressing the results in terms of pounds of chemical per mile necessary to melt various thicknesses of fresh fallen snow at the temperatures studied. In keeping with present practices in the province of Ontario, it was assumed that the chemical would be applied over a 3-ft wide strip of pavement along the center line. It was further assumed that 50 percent melt would be sufficient to produce a slush which would be removed by traffic action. This latter concept has been based on the results of studies reported by Price (5).

In the development of these tabulations, care has been taken not to include any values outside of the range of the test data. Although the possibility of extrapolating the equations was considered, it was believed that such action would be misleading. The principal area of deficiency of data was found to occur with the lower concentrations. In keeping with this criterion it was therefore impossible to extend the data to include applications of less than 500 lb per mile. For this reason in all of the tables of Appendix E, a solid black line has been drawn to indicate the lower limit of the test information.

Similarly, studies of present practice with rock salt, indicated that application rates in excess of 1,000 lb per mile were rarely reported. Therefore, the maximum application rate contained in Appendix E was taken to be 1,000 lb per mile. No similar information was apparent regarding present practice in the use of calcium chloride with the result that the same upper limit was chosen for this material. This in no way suggests that the limit is feasible for calcium chloride application—it undoubtedly is not—but selection of this value permits comparisons to be made.

In reviewing the data, it was apparent that a broader range of reaction times might well have been selected. Unfortunately at the start of the work, very little guiding information was available with the result that the time factor appears to need additional study in order to extend the range. This in no way invalidates the study but merely places a restriction on its application.

Consideration of the tables of Appendix E indicates quite clearly that attempts to remove large depths of snow by melting with chemicals would be an extremely expensive proposition. Thus, it seems reasonable to suggest that chemicals can be expected to be most useful in removing relatively small depths of snow. In the case of heavy snow fall it would seem that mechanical removal will be necessary with the added consideration that chemicals might be of some assistance in reducing the possibility of ice forming on the road surface. No data are available from this study concerning this latter situation but there appears to be reason to suggest that research regarding quantities of chemical required and the time of application would be most useful.

It is also apparent from these tables that the chemicals lose much of their effectiveness at low temperatures. Rock salt is most effective in the 20 to 32 F range while calcium chloride does function somewhat more satisfactorily at lower temperatures. In the final analysis, however, the decision must be made on the basis of cost. By using these tables, it is possible to compare costs. In addition, the tables provide a simple means for determining the amount of chemical necessary for a variety of conditions. This too, should be of value in selecting the best application rate and consequently in obtaining the greatest effectiveness for the chemical available.

CONCLUSIONS

The primary objective of this study was an attempt to evaluate, in the laboratory, the ice and snow melting properties of chemicals and chemical mixtures which are commonly used by street and highway authorities.

At the outset, it was necessary to develop a testing procedure which would provide reasonably reliable and reproducible data, since other investigators suggested that certain erroneous results were due to deficiencies in the testing method. Statistical analyses of the data reported in this paper indicated reasonable assurance that the test method used would meet the specification of reproducible results. A warning should be issued at this point that the results reported in this study may be expected to differ considerably from those obtained by other researchers since different testing methods have been employed.

The three main variables, reaction time, temperature and concentration, considered in this study to be measures of the melting properties of the chemical, were found to produce results which would have been expected. However, the statistical analysis of the data indicated significant interaction effects which implied that no single variable could be considered separately. This simply means that each variable contributed significantly to the ice and snow melting characteristics of the chemical or mixture and in some way each variable influences the effect of the others.

Comparisons of the mean melting results indicated a greater melting action by calcium chloride when compared with rock salt. This was particularly noticeable at low temperatures and for short time intervals. This implies that, on the basis of melting comparison, some benefit can be derived from the use of calcium chloride particularly where rock salt is evidently ineffective. Nevertheless economic considerations must also be taken into account and tabular values of the necessary rates of application have been provided for this purpose.

Consideration of the data indicates that F.C. rock salt has superior melting characteristics to C.C. rock salt. This conclusion however is based entirely on melting tests and it is reasonable to suggest that other factors such as storage and spreading difficulties will have to be assessed before a final decision can be made regarding the relative merits of the two differently graded rock salts.

Rather interesting results were obtained by mixing rock salt and calcium chloride. Certainly there seems to be some advantage in these mixtures in that the effect of the of the calcium chloride would appear to be one of extending the useful temperature range of rock salt so that it becomes effective at lower temperatures. The data for these tests were somewhat limited but there is reason to suggest that some value might derive from additional studies of rock salt-calcium chloride mixtures.

The effect of mixing sand with rock salt was generally one of inhibiting the melting action. The melt retarding effect of the sand was found to be almost directly proportional to the percentage of sand used in the mixture. It is possible that traffic might counteract this retardation effect to some extent by bringing more salt into contact with the ice. This theory was not tested, and therefore, no definite statement concerning the traffic variable can be made at this time. However, on the basis of the tests performed it appears that attempts to obtain combined abrasive and melting action by mixing rock salt and sand will certainly result in a reduction in melting effect because of the dispersion of the salt in the sand.

By means of a regression analysis it has been possible to develop mathematical expressions relating the melting characteristics of the chemicals with the main variables tested. These mathematical expressions have been used to develop the tabulations showing the amount of chemical required to melt various quantities of snow under a variety of conditions of temperature and melting time. By means of these tables it is also possible to make cost comparisons of the various chemicals tested when used under a given set of conditions.

The test data indicate rather conclusively that the melting of snow by means of chemicals should be considered only when the fall of snow is relatively light. It is apparent that heavy falls of snow will necessitate the use of mechanical methods for snow removal.

Although considerable confidence can be placed in the mathematical expressions developed in this study, there is a possibility that improvements in the mathematical model are possible. Extension of the testing program to include low concentrations and longer melting periods might very well produce results which would indicate modification to the model developed in this study. However, until additional information becomes available, it is believed that the proposed equations, if used within the range of the variables tested, will provide reasonable estimates of the ice and snow melting capacities of the chemicals listed.

FURTHER RESEARCH

This study by no means provides a solution to all of the problems of snow and ice removal from highways. Consideration has only been given to those factors relating to the problem which could be measured in the laboratory. Although it would have been desirable to introduce into the study other factors which are more closely related to field conditions it was felt that an intense study of limited scope would be preferable to a broader but less intense analysis.

Many factors were derived from the study, perhaps the most important of these were related to gaps in the knowledge rather than additions to it. It was felt that a statement about possible future research might be of value to those interested in the problems of winter maintenance. The following paragraphs contain some thoughts regarding problems which are as yet unsolved or only partially solved.

Based on this study it would seem that studies at low concentrations and longer time periods would be useful and informative. In addition, much more data are required concerning the relative effectiveness of mixing calcium chloride and rock salt. Since only two rock salt gradings were investigated and were found to produce different results, this aspect of the work should receive further attention in order to determine whether an ideal grading can be found.

It was observed qualtitatively in this study, that the rate of penetration of the chemicals differed considerably. The effect of this phenomenon in the field certainly warrants additional study. Similarly the brine solutions formed were found to be somewhat more viscous than water and the nature of the effect of these solutions on the various pavement surfaces with regard to possible skidding would seem to be of interest.

The effect of the chemicals in preventing bonding of ice or packed snow to the pavement also appears to be worthy of study since this use of chemicals would seem to be important in the case of heavy snow fall.

Probably the most important subject for study is the effect of traffic on a chemically treated or untreated snow or ice covered road surface. Many statements have been made regarding this matter, but quantitative data on the subject are rather meager.

Many other factors, too numerous to mention, also require investigation. It is hoped that the present study will shed a little more light on the subject and will encourage others to undertake additional studies in this very complex field of snow and ice removal from highways.

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Appendix A

TABLE 1

OBSERVED MELT FOR SALT AND SALT-SAND MIXTURES (C.C. ROCK SALT)

		C.C. Rock Salt Without Additives				75% C.C. Rock Salt 25% Sand				50% C.C. Rock Salt 50% Sand			
		t_1[1]	t_2	t_3	t_4	t_1	t_2	t_3	t_4	t_1	t_2	t_3	t_4
T_0	C1	0.34[2]	0.56	0.63	0.68	0.18	0.42	0.54	0.37	0.19	0.19	0.26	0.41
	C2	0.33	0.41	0.46	0.60	0.04	0.08	0.10	0.18	0.14	0.23	0.28	0.19
	C3	0.20	0.23	0.31	0.33	0.02	0.02	0.09	0.13	0.04	0.05	0.05	0.07
	C4	0.10	0.17	0.20	0.28	0.04	0.09	0.08	0.11	0.02	0.02	0.03	0.02
T_1	C1	0.82	1.01	1.34	1.50	0.74	0.99	1.21	1.41	0.66	0.98	0.96	1.44
	C2	0.65	0.90	0.99	1.26	0.50	0.70	0.99	1.11	0.62	0.93	1.04	1.28
	C3	0.42	0.52	0.65	0.76	0.25	0.47	0.53	0.73	0.18	0.20	0.24	0.59
	C4	0.26	0.35	0.41	0.51	0.15	0.24	0.37	0.34	0.06	0.07	0.11	0.14
T_2	C1	1.44	1.89	2.51	2.91	1.41	1.70	2.30	2.65	1.40	1.86	2.24	2.48
	C2	1.27	1.66	1.80	2.14	1.02	1.30	1.73	2.00	0.93	1.36	1.65	1.94
	C3	0.72	0.96	1.14	1.40	0.72	0.90	1.10	1.30	0.65	0.90	1.17	1.35
	C4	0.47	0.63	0.79	0.87	0.50	0.46	0.60	0.83	0.20	0.20	0.45	0.46
T_3	C1	2.50	2.98	3.56	4.77	2.33	2.99	3.94	4.36	2.23	2.97	3.51	4.40
	C2	1.81	2.28	2.62	3.26	1.68	2.26	2.78	3.48	1.81	2.52	2.87	3.41
	C3	1.17	1.55	1.79	2.12	1.15	1.59	1.94	2.24	1.08	1.38	1.81	2.06
	C4	0.62	0.82	1.12	1.27	0.64	0.78	1.10	1.24	0.48	0.68	0.81	0.85

[1] For coding system see Appendix B.

[2] All melt quantities are expressed in terms of unit melt (unit yield). This quantity has been defined as the number of grams of ice melted per gram of chemical applied.

TABLE 2

OBSERVED MELT FOR SALT AND SALT-SAND MIXTURES (F.C. ROCK SALT)

		F.C. Rock Salt Without Additives				75% F.C. Rock Salt 25% Sand				50% F.C. Rock Salt 50% Sand			
		t_1[1]	t_2	t_3	t_4	t_1	t_2	t_3	t_4	t_1	t_2	t_3	t_4
T_0	C1	1.06[2]	1.34	1.42	1.59	0.70	0.81	1.03	0.97	0.57	0.77	0.79	1.07
	C2	0.68	0.77	0.96	1.01	0.37	0.44	0.61	0.61	0.28	0.35	0.37	0.41
	C3	0.29	0.42	0.53	0.51	0.18	0.21	0.24	0.24	0.14	0.20	0.22	0.19
	C4	0.11	0.13	0.13	0.15	0.12	0.15	0.13	0.13	0.10	0.10	0.15	0.13
T_1	C1	1.33	1.71	1.99	2.29	1.04	1.70	1.54	1.91	0.75	1.21	1.58	1.95
	C2	0.84	1.16	1.25	1.57	0.83	1.12	1.20	1.33	0.72	1.03	1.21	1.47
	C3	0.52	0.66	0.78	1.00	0.32	0.36	0.34	0.44	0.33	0.30	0.36	0.35
	C4	0.22	0.31	0.28	0.27	0.16	0.15	0.18	0.17	0.17	0.16	0.18	0.16
T_2	C1	1.67	2.52	2.81	3.33	2.28	2.63	3.05	3.44	1.91	2.23	2.88	3.20
	C2	1.43	2.00	2.40	2.52	1.62	1.91	2.46	2.79	0.92	1.67	1.76	1.78
	C3	0.91	1.12	1.38	1.57	0.77	0.76	1.20	1.52	0.53	0.50	0.60	0.45
	C4	0.42	0.56	0.75	0.93	0.24	0.28	0.28	0.27	0.22	0.24	0.21	0.25
T_3	C1	3.22	2.98	4.43	4.73	3.43	3.71	4.31	4.48	3.18	3.64	4.31	4.59
	C2	1.60	2.25	2.76	3.34	2.09	2.66	3.82	3.50	2.44	2.92	3.38	4.06
	C3	1.12	1.52	1.83	2.06	1.26	1.64	1.95	2.27	1.08	1.26	1.52	1.55
	C4	0.72	0.94	1.31	1.47	0.44	0.44	0.86	0.61	0.38	0.40	0.42	0.40

[1] For coding system see Appendix B.
[2] All melt quantities are expressed in terms of unit melt (unit yield). This quantity has been defined as the number of grams of ice melted per gram of chemical applied.

TABLE 3

OBSERVED MELT FOR FLAKE AND PELLET CALCIUM CHLORIDE

		Flake Calcium Chloride				Pellet Calcium Chloride			
		t_1[1]	t_2	t_3	t_4	t_1	t_2	t_3	t_4
T_0	C1	2.09[2]	2.19	2.23	2.40	1.55	2.02	2.29	2.53
	C2	1.95	2.08	2.20	2.29	1.97	2.34	2.49	2.54
	C3	1.68	1.97	2.17	2.23	1.94	2.39	2.58	2.74
	C4	1.23	1.61	1.76	1.80	1.47	1.92	2.21	2.49
T_1	C1	2.74	2.74	2.91	3.26	2.66	2.70	2.93	3.06
	C2	2.34	2.50	2.66	2.88	2.19	2.51	2.64	3.04
	C3	2.05	2.24	2.40	2.50	2.34	2.74	2.89	3.01
	C4	1.51	1.91	2.16	2.24	1.83	2.21	2.41	2.75
T_2	C1	3.02	3.19	3.35	3.79	2.54	2.95	3.18	3.24
	C2	2.49	2.66	2.70	2.83	2.43	2.85	3.01	3.23
	C3	2.17	2.31	2.42	2.53	2.46	2.85	2.97	3.37
	C4	1.77	1.94	2.19	2.35	2.10	2.47	2.71	2.89
T_3	C1	3.88	4.25	4.73	5.36	4.17	5.21	5.38	5.90
	C2	2.93	3.17	3.32	3.58	3.41	3.81	4.21	4.57
	C3	2.33	2.77	2.93	2.93	2.83	3.11	3.38	3.94
	C4	2.06	2.29	2.57	2.80	2.63	2.89	3.04	3.33

[1] For coding system see Appendix B.
[2] All melt quantities are expressed in terms of unit melt (unit yield). This quantity has been defined as the number of grams of ice melted per gram of chemical applied.

TABLE 4

OBSERVED MELT FOR FLAKE CALCIUM CHLORIDE—C.C. ROCK SALT MIXTURES

		10% Calcium Chloride 90% Rock Salt				20% Calcium Chloride 80% Rock Salt				30% Calcium Chloride 70% Rock Salt			
		t_1[1]	t_2	t_3	t_4	t_1	t_2	t_3	t_4	t_1	t_2	t_3	t_4
T_0	C1	0.52[2]	0.70	0.96	1.00	0.97	1.21	1.28	1.34	1.08	1.17	1.41	1.41
	C2	0.51	0.63	0.71	0.75	0.70	0.81	0.90	0.94	0.94	1.08	1.27	1.31
	C3	0.45	0.53	0.63	0.67	0.57	0.64	0.77	0.82	0.73	0.84	0.92	1.02
	C4	0.26	0.34	0.49	0.48	0.39	0.45	0.55	0.61	0.62	0.64	0.80	0.83
T_1	C1	1.05	1.32	1.64	1.78	1.43	1.74	2.01	1.99	1.53	1.69	1.83	2.15
	C2	0.96	1.18	1.23	1.43	1.37	1.41	1.73	1.87	1.24	1.45	1.61	1.88
	C3	0.65	0.75	0.91	1.03	0.80	0.98	1.08	1.33	1.03	1.31	1.48	1.62
	C4	0.46	0.49	0.59	0.68	0.61	0.68	0.82	0.89	0.81	0.89	1.05	1.16
T_2	C1	1.48	1.72	2.09	2.51	2.01	2.30	2.73	3.42	1.83	2.38	2.77	2.99
	C2	1.23	1.48	1.76	2.04	1.57	1.75	2.06	2.23	1.66	1.81	2.18	2.29
	C3	0.91	1.12	1.32	1.62	1.07	1.30	1.47	1.65	1.19	1.49	1.77	1.85
	C4	0.61	0.64	0.79	1.00	0.76	0.92	1.05	1.24	0.96	1.06	1.27	1.46
T_3	C1	2.63	3.54	4.50	5.29	2.69	2.91	3.81	4.59	2.98	3.37	3.80	4.87
	C2	1.61	2.19	2.54	2.76	1.95	2.34	2.84	3.32	1.97	2.59	2.86	3.70
	C3	1.34	1.58	1.96	2.46	1.42	1.68	1.85	2.25	1.67	2.02	2.22	2.51
	C4	0.87	1.00	1.29	1.38	0.99	1.18	1.31	1.45	1.14	1.40	1.59	1.74

[1] For coding system see Appendix B.
[2] All melt quantities are expressed in terms of unit melt (unit yield). This quantity has been defined as the number of grams of ice melted per gram of chemical applied.

TABLE 5

OBSERVED MELT FOR PELLET CALCIUM CHLORIDE—C.C. ROCK SALT MIXTURES

		10% Calcium Chloride 90% Rock Salt				20% Calcium Chloride 80% Rock Salt				30% Calcium Chloride 70% Rock Salt			
		t_1[1]	t_2	t_3	t_4	t_1	t_2	t_3	t_4	t_1	t_2	t_3	t_4
T_0	C1	0.64[2]	0.73	0.89	0.75	0.79	0.96	1.17	1.10	1.09	1.32	1.27	1.38
	C2	0.46	0.54	0.62	0.78	0.59	0.76	0.80	0.97	0.86	0.91	1.09	1.02
	C3	0.37	0.44	0.52	0.54	0.57	0.65	0.71	0.80	0.74	0.92	1.04	1.12
	C4	0.24	0.37	0.43	0.44	0.37	0.47	0.50	0.53	0.52	0.69	0.79	0.88
T_1	C1	1.04	1.28	1.48	1.61	1.17	1.54	1.59	1.99	1.41	1.52	1.64	1.79
	C2	0.88	1.05	1.18	1.33	0.95	1.08	1.20	1.35	1.27	1.43	1.60	1.71
	C3	0.65	0.71	0.88	1.08	0.80	0.96	1.03	1.25	1.00	1.14	1.39	1.51
	C4	0.41	0.49	0.57	0.67	0.54	0.63	0.72	0.90	0.68	0.86	1.06	1.21
T_2	C1	1.80	2.07	2.47	3.23	1.82	2.32	3.32	3.41	2.08	2.44	2.76	3.41
	C2	1.29	1.58	2.00	2.23	1.39	1.65	1.95	2.19	1.60	1.87	2.46	2.66
	C3	0.91	1.22	1.42	1.52	1.09	1.36	1.64	1.77	1.22	1.43	1.83	2.02
	C4	0.58	0.71	0.90	1.06	0.74	0.89	1.17	1.25	0.98	1.89	1.39	1.56
T_3	C1	2.32	2.90	3.66	4.24	2.28	3.52	4.14	4.52	2.49	3.29	4.02	4.41
	C2	1.76	2.27	2.64	3.28	1.56	2.13	2.39	2.75	2.00	2.47	2.87	3.20
	C3	1.18	1.65	1.80	2.10	1.39	1.73	2.01	2.35	1.65	1.80	2.10	2.32
	C4	0.84	1.01	1.24	1.43	1.10	1.30	1.50	1.74	1.22	1.47	1.61	1.89

[1] For coding system see Appendix B.
[2] All melt quantities are expressed in terms of unit melt (unit yield). This quantity has been defined as the number of grams of ice melted per gram of chemical applied.

Appendix B

CODING SYSTEM

The following is a list indicating the symbols used in coding the various test data as well as the significance of the symbols.

Chemical

S_c = Coarse crushed rock salt (C.C. rock salt)

S_f = Fine crushed rock salt (F.C. rock salt)

Temperature

T_0 = Test Temperature 0 F

T_1 = Test Temperature + 10 F

T_2 = Test Temperature + 20 F

T_3 = Test Temperature + 30 F

Time

t_1 = Test melting time of 15 minutes
t_2 = Test melting time of 30 minutes
t_3 = Test melting time of 45 minutes
t_4 = Test melting time of 60 minutes

Concentration (Rate of Application of Chemical to Ice Surface)

C_1 = 0.72 lb of chemical per square yard of ice

C_2 = 1.80 lb of chemical per square yard of ice

C_3 = 3.60 lb of chemical per square yard of ice

C_4 = 7.20 lb of chemical per square yard of ice

Sand Additive

S_0 = 100% salt - 0% sand

S_1 = 75% salt - 25% sand

S_2 = 50% salt - 50% sand

Appendix C

TABLE 6

PREDICTION EQUATION PARAMETERS

	Q	R	Z
15-min Reaction Time			
C.C. rock salt without additives	-0.0831	+0.0263	-0.7905
F.C. rock salt without additives	-0.1133	+0.0191	-0.4804
Pellet calcium chloride with C.C. Rock salt			
100% calcium chloride	-0.0278	+0.0084	-0.1496
90% salt - 10% calcium chloride	-0.0658	+0.0182	-0.5966
80% salt - 20% calcium chloride	-0.0492	+0.0146	-0.5229
70% salt - 30% calcium chloride	-0.0483	+0.0121	-0.3930
Flake calcium chloride with C.C. rock salt			
100% calcium chloride	-0.0367	+0.0065	-0.0860
90% salt - 10% calcium chloride	-0.0578	+0.0178	-0.6076
80% salt - 20% calcium chloride	-0.0601	+0.0137	-0.4238
70% salt - 30% calcium chloride	-0.0447	+0.0112	-0.3787
60-min Reaction Time			
C.C. rock salt without additives	-0.0750	+0.0254	-0.5218
F.C. rock salt without additives	-0.1150	+0.0222	-0.2843
Pellet calcium chloride with C.C. Rock Salt			
100% calcium chloride	-0.0125	+0.0071	-0.0092
90% salt - 10% calcium chloride	-0.0600	+0.0208	-0.4367
80% salt - 20% calcium chloride	-0.0531	+0.0172	-0.3397
70% salt - 30% calcium chloride	-0.0386	+0.0141	-0.2743
Flake calcium chloride with C.C. rock salt			
100% calcium chloride	-0.0267	+0.0066	-0.0182
90% salt - 10% calcium chloride	-0.0619	+0.0190	-0.3879
80% salt - 20% calcium chloride	-0.0603	+0.0156	-0.2745
70% salt - 30% calcium chloride	-0.0472	+0.0137	-0.2332

TABLE 7

PREDICTION EQUATION PARAMETERS
(Various Reaction Times for C.C. and F.C. Rock Salt Without Additives)

Reaction Time in Minutes	Q	R	Z
C.C. rock salt			
15	-0.0831	+0.0263	-0.7905
30	-0.0784	+0.0250	-0.6645
45	-0.0755	+0.0253	-0.5967
60	-0.0749	+0.0254	-0.5218
F.C. rock salt			
15	-0.1133	+0.0191	-0.4804
30	-0.1141	+0.0199	-0.3701
45	-0.1137	+0.0215	-0.3292
60	-0.1149	+0.0222	-0.2843

Appendix D

TABLE 8

PREDICTED[1] 60-MIN MELTING CAPACITIES OF VARIOUS MELTING MIXTURES
(Temperature 0 F)

Chemical	Application Rate, lb per sq yd				
	0.72	1.50	3.00	5.00	7.20
C.C. rock salt without additives	0.19[2]	0.35	0.54	0.63	0.62
F.C. rock salt without additives	0.31	0.52	0.71	0.69	0.56
Flake calcium chloride	0.66	1.31	2.39	3.53	4.44
Pellet calcium chloride	0.69	1.41	2.70	4.24	5.73
Flake calcium chloride - C.C. Rock salt mixtures					
90% rock salt - 10% calcium chloride	0.27	0.50	0.80	1.00	1.06
80% rock salt - 20% calcium chloride	0.35	0.65	1.05	1.33	1.41
70% rock salt - 30% calcium chloride	0.39	0.75	1.27	1.70	1.92
Pellet calcium chloride - C.C. rock salt mixtures					
90% rock salt - 10% calcium chloride	0.24	0.45	0.73	0.92	0.97
80% rock salt - 20% calcium chloride	0.30	0.57	0.95	1.24	1.37
70% rock salt - 30% calcium chloride	0.36	0.70	1.22	1.70	2.02

[1] Calculated from the prediction equation.
[2] Melting capacities are expressed in inches of fresh snow having a specific gravity of 0.06.

TABLE 9

PREDICTED[1] 60-MIN MELTING CAPACITIES OF VARIOUS CHEMICAL MIXTURES
(Temperature +30 F)

Chemical	Application Rate, lb per sq yd				
	0.72	1.50	3.00	5.00	7.20
C.C. rock salt without additives	1.10[2]	2.01	3.10	3.66	3.61
F.C. rock salt without additives	1.43	2.43	3.26	3.20	2.57
Flake calcium chloride	1.04	2.07	3.78	5.57	7.00
Pellet calcium chloride	1.13	2.30	4.41	6.92	9.36
Flake calcium chloride - C.C. rock salt mixtures					
90% rock salt - 10% calcium chloride	0.99	1.84	2.98	3.73	3.93
80% rock salt - 20% calcium chloride	1.02	1.90	3.09	3.89	4.13
70% rock salt - 30% calcium chloride	1.00	1.92	3.27	4.38	4.97
Pellet calcium chloride - C.C. rock salt mixtures					
90% rock salt - 10% calcium chloride	1.01	1.88	3.08	3.87	4.02
80% rock salt - 20% calcium chloride	0.99	1.88	3.13	4.08	4.49
70% rock salt - 30% calcium chloride	0.95	1.85	3.25	4.52	5.36

[1] Calculated from the prediction equation.
[2] Melting capacities are expressed in inches of fresh snow having a specific gravity of 0.06.

Appendix E

TABLE 10

APPLICATION RATES[1,2] OF CHEMICALS FOR SNOW REMOVAL
(C.C. Rock Salt Reaction Time = 15 min)

Snow[3] Depth in Inches	Temperature F 0	+10	+15	+20	+22	+24	+26	+28	+30
0.10	624[4]								
0.20		685	500						
0.30			589	545					
0.40				764	659	580	500		
0.50				1000	861	747	650	562	
0.60						932	800	677	607
0.70							966	852	720
0.80								983	870
0.90									983

[1] The prediction equation has been used to determine the rate of chemical application.
[2] Application rates are expressed in pounds per mile assuming 50 percent melt on a 3-ft strip of pavement center line.
[3] The specific gravity of fresh fallen snow has been assumed to be 0.06.
[4] Application rates above the solid line are below the minimum concentration tested in the laboratory. Application rates greater than 1,000 lb per mile have not been included but may be obtained from the prediction equations.

TABLE 11

APPLICATION RATES [1,2] OF CHEMICALS FOR SNOW REMOVAL
(F.C. Rock Salt Reaction Time = 15 min)

Snow[3] Depth in Inches	Temperature F 0	+10	+15	+20	+22	+24	+26	+28	+30
0.10									
0.20	641[4]								
0.30		615							
0.40		896	668	500					
0.50			896	668	606	545			
0.60				852	756	659	606	545	
0.70					931	826	739	659	571
0.80						1,000	879	782	694
0.90								913	809
1.00									931

[1] The prediction equation has been used to determine the rate of chemical application.
[2] Application rates are expressed in pounds per mile assuming 50 percent melt on a 3-ft strip of pavement center line.
[3] The specific gravity of fresh fallen snow has been assumed to be 0.06.
[4] Application rates above the solid line are below the minimum concentration tested in the laboratory. Application rates greater than 1,000 lb per mile have not been included but may be obtained from the prediction equations.

TABLE 12

APPLICATION RATES[1,2] OF CHEMICALS FOR SNOW REMOVAL
(Flake Calcium Chloride Reaction Time = 15 min)

Snow[3] Depth in Inches	Temperature F						
	0	+5	+10	+15	+20	+25	+30
0.10							
0.20							
0.30							
0.40							
0.50	562[4]	519					
0.60	686	633	589	636	500		
0.70	809	747	686	633	589	536	500
0.80	931	861	791	730	677	624	571
0.90		984	905	835	765	712	659
1.00			1,000	931	861	791	730
1.10					967	879	809
1.20						967	887
1.30							976

[1] The prediction equation has been used to determine the rate of chemical application.
[2] Application rates are expressed in pounds per mile assuming 50 percent melt on a 3-ft strip of pavement center line.
[3] The specific gravity of fresh fallen snow has been assumed to be 0.06.
[4] Application rates above the solid line are below the minimum concentration tested in the laboratory. Application rates greater than 1,000 lb per mile have not been included but may be obtained from the prediction equations.

TABLE 13

APPLICATION RATES[1,2] OF CHEMICALS FOR SNOW REMOVAL
(Pellet Calcium Chloride Reaction Time = 15 min)

Snow[3] Depth in Inches	Temperature F						
	0	+5	+10	+15	+20	+25	+30
0.10							
0.20							
0.30							
0.40	518[4]						
0.50	650	589	536				
0.60	790	712	641	580	519		
0.70	931	835	756	659	615	554	500
0.80		966	870	782	712	641	580
0.90			984	887	800	720	650
1.00				1,000	896	809	730
1.10					1,000	896	809
1.20						984	879
1.30							967

[1] The prediction equation has been used to determine the rate of chemical application.
[2] Application rates are expressed in pounds per mile assuming 50 percent melt on a 3-ft strip of pavement center line.
[3] The specific gravity of fresh fallen snow has been assumed to be 0.06.
[4] Application rates above the solid line are below the minimum concentration tested in the laboratory. Application rates greater than 1,000 lb per mile have not been included but may be obtained from the prediction equations.

TABLE 14

APPLICATION RATES[1,2] OF CHEMICALS FOR SNOW REMOVAL
(C.C. Rock Salt Reaction Time = 60 min)

Snow[3] Depth in Inches	Temperature F								
	0	+10	+15	+20	+22	+24	+26	+28	+30
0.10									
0.20	668[4]								
0.30		545							
0.40		774	536						
0.50		983	694	500					
0.60			861	615	536				
0.70				730	642	562	500		
0.80				861	747	650	571	500	
0.90				1,000	862	747	650	571	500
1.00					975	844	738	642	562
1.10						949	826	720	632
1.20							922	800	694
1.30							1,000	879	765
1.40								959	835
1.50									905
1.60									975

[1] The prediction equation has been used to determine the rate of chemical application.
[2] Application rates are expressed in pounds per mile assuming 50 percent melt on a 3-ft strip of pavement center line.
[3] The specific gravity of fresh fallen snow has been assumed to be 0.06.
[4] Application rates above the solid line are below the minimum concentration tested in the laboratory. Application rates greater than 1,000 lb per mile have not been included but may be obtained from the prediction equations.

TABLE 15

APPLICATION RATES[1,2] OF CHEMICALS FOR SNOW REMOVAL
(F.C. Rock Salt Reaction Time = 60 min)

Snow[3] Depth in Inches	Temperature F								
	0	+10	+15	+20	+22	+24	+26	+28	+30
0.10									
0.20									
0.30	607[4]								
0.40	880								
0.50		607							
0.60		747	554						
0.70		941	668	500					
0.80			800	581	518				
0.90			941	668	589	518			
1.00				765	668	589	518		
1.10				871	756	668	589	518	
1.20				985	853	747	651	572	518
1.30					950	827	721	633	563
1.40						914	800	695	615
1.50						1,000	880	756	668
1.60							959	827	721
1.70								897	782
1.80								967	844
1.90									914
2.00									976

[1] The prediction equation has been used to determine the rate of chemical application.
[2] Application rates are expressed in pounds per mile assuming 50 percent melt on a 3-ft strip of pavement center line.
[3] The specific gravity of fresh fallen snow has been assumed to be 0.06.
[4] Application rates above the solid line are below the minimum concentration tested in the laboratory. Application rates greater than 1,000 lb per mile have not been included but may be obtained from the prediction equations.

TABLE 16

APPLICATION RATES[1,2] OF CHEMICALS FOR SNOW REMOVAL
(Flake Calcium Chloride Reaction Time = 60 min)

Snow[3] Depth in Inches	Temperature F 0	+5	+10	+15	+20	+25	+30
0.10							
0.20							
0.30							
0.40							
0.50							
0.60	572[4]	527					
0.70	677	624	562	527			
0.80	774	712	651	598	554	510	
0.90	880	809	739	677	624	580	536
1.00	985	905	826	765	703	651	598
1.10		1,000	914	844	774	712	660
1.20				932	853	783	721
1.30				1,000	949	853	791
1.40					1,000	923	853
1.50						1,000	923
1.60							985

[1] The prediction equation has been used to determine the rate of chemical application.
[2] Application rates are expressed in pounds per mile assuming 50 percent melt on a 3-ft strip of pavement center line.
[3] The specific gravity of fresh fallen snow has been assumed to be 0.06.
[4] Application rates above the solid line are below the minimum concentration tested in the laboratory. Application rates greater than 1,000 lb per mile have not been included but may be obtained from the prediction equations.

TABLE 17

APPLICATION RATES[1,2] OF CHEMICALS FOR SNOW REMOVAL
(Pellet Calcium Chloride Reaction Time = 60 min)

Snow[3] Depth in Inches	Temperature F 0	+5	+10	+15	+20	+25	+30
0.10							
0.20							
0.30							
0.40							
0.50							
0.60	545[4]	500					
0.70	642	589	536	500			
0.80	739	677	624	571	528		
0.90	826	765	704	642	589	545	500
1.00	923	870	773	712	660	607	554
1.10		940	861	792	730	669	615
1.20			940	871	792	730	659
1.30				940	871	800	730
1.40				1,000	931	861	791
1.50					1,000	923	844
1.60						985	905
1.70							959

[1] The prediction equation has been used to determine the rate of chemical application.
[2] Application rates are expressed in pounds per mile assuming 50 percent melt on a 3-ft strip of pavement center line.
[3] The specific gravity of fresh fallen snow has been assumed to be 0.06.
[4] Application rates above the solid line are below the minimum concentration tested in the laboratory. Application rates greater than 1,000 lb per mile have not been included but may be obtained from the prediction equations.

Appendix F

TABLE 18

GRADING DATA

Sieve Size	% Passing D.H.O.[1] Spec.	% Passing Test Grading
C.C. Rock Salt		
3/8 in.	100	100
1/4 in.	90-100	95
No. 4	30-100	80
No. 8	5-65	45
No. 14	0-30	15
No. 28	0-10	0
F.C. Rock Salt[2]		
No. 8		100
No. 10		100
No. 14		80
No. 28		44
No. 48		14
No. 80		4
No. 100		0
Sand for Winter Use as an Abrasive		
1/4 in.	100	100
No. 8	65-95	80
No. 14	40-90	57
No. 28	20-70	35
No. 48	5-35	18
No. 100	0-15	2.5
No. 200	0-5	0

[1] Ontario Department of Highways.
[2] No Ontario specification available.