Measuring salt and freezing temperature on roadways

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1. Introduction

The ability to monitor the amount of salt spread on the roadway is a very sought-after feature required of modern road weather stations. Even though several different theoretical approaches exist to realise this ability, it leads to challenging technological problems.

The freezing temperature of a salt-treated roadway is naturally dependent on the salt content, and should be known, once the salt concentration is measured. If the question of the freezing temperature is considered more closely, however, it turns out that there are theoretical and practical difficulties in defining what it is or what it should be.

2. Physics

Everyone knows that water freezes at 0 degrees centigrade, and also that salty water freezes at a lower temperature. It is natural to expect that the freezing temperature of the layer of salt solution on a roadway tells us how safe the road is against freezing. Closer examination reveals, however, that the situation is not that simple.

2.1. Freezing

Mixtures, such as salt solutions, do not generally have a freezing point. Usually there is a range of temperatures at which the solution gradually freezes, or melts. The water solution of the most common road salt, sodium chloride, exhibits eutectic behavior, and part of its equilibrium diagram is shown in fig. 1.

If we take a solution with salt concentration c_0, and cool it, we will sooner or later arrive at the liquidus line in the equilibrium diagram, as seen in fig.1. At that point, ice crystals may start to form. Usually there is some undercooling and we will have to go a few degrees below the liquidus for the first ice. In the case of sodium chloride and other common road salts the ice that gets formed is pure ice containing almost no salt. If we decrease the temperature further, the salt stays in the unfrozen solution and its concentration increases in such a way that we are moving along the liquidus line in the equilibrium diagram. The lower the temperature, the more ice gets formed. This continues until we arrive at the eutectic point. There all what is left of the solution freezes into salty ice before the temperature can decrease further.

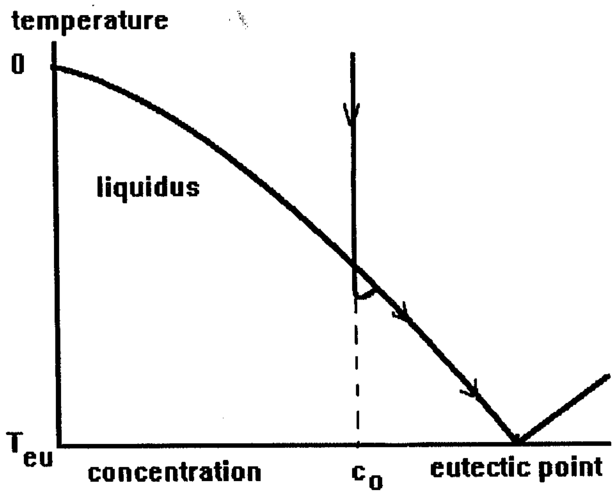

Figure 1. Part of water-salt equilibrium diagram illustrating freezing and melting.

The roadway becomes slippery, when there are enough ice crystals in the partially frozen solution to make it so. Therefore, in this sense, the feezing temperature is somewhere a little below the liquidus, but it is hard to define exactly. In addition, the amount of undercooling depends on the rate decrease in the temperature and other variable factors, and the thin layer of solution on the roadway does not obey exactly the equilibrium diagram for bulk solutions.

The freezing temperature that is usually given for solutions in the literature is the liquidus temperature.

2.2. Road surface layers

Most of the time the salt solution on the road surface forms a thin layer, perhaps typically of 0.1 ... 0.5 mm mean thickness. Small amounts of evaporating and condensing moisture are enough to drastically alter the thickness of this layer. Indeed, large relative changes in it have been observed in the timescale of minutes. It is only the amount water that varies, however, as the total salt content stays relatively unchanged. This results in the changes getting directly reflected into the salt concentration and into the momentary freezing temperature.

Consequently, the freezing temperature of the solution is often not a very stable quantity and this seriously limits its usefulness as an indicator of how safe the roadway is against freezing. Furthermore, quite often events resulting dangerously slippery roads involve precipitation, snow or freezing rain, which will alter the salt concentration even more.

3. Measuring salt

Measuring the salt concentration of a solution is not difficult in a laboratory and can be made in numerous ways very accurately. Unfortunately none of those ways can be easily applied to a sensor for continuous monitoring of the salt content on the road surface. And the fact that the sensor should not be too costly makes the task even more difficult.

A significant source of error in salt measurements is the local variation in the salt content on the road surface. Usually there is only one or two sensors embedded into the road surface, and those can only measure the salt content at those points, where they are located. The value obtained from them certainly only approximates the average salt concentration on the whole road surface. This inaccuracy is made worse by the fact that the place, where the sensor is mounted, is always bound to differ, at least slightly, from the rest of the pavement, because the sensor is there. It is important to note that it serves no purpose to attempt to reach much higher nominal accuracy in the sensors, than the uncertainty caused by this factor.

3.1. Possible methods

A sensor monitoring the salt concentration has to measure some physical property that depends on the salt content. The property could be optical, such as the coefficient of refraction, or thermodynamical, such as freezing temperature, or electrical, such as electrical conductivity, or something else, such as the density of the solution. Also the sensor could attempt to analyze the solution with some sprectroscopical method. Most of these possibilities get rejected because of the need of instruments that are either too delicate to last on the road surface or too expensive.

Measuring the freezing temperature directly is an attractive possibility. But closer examination reveals its serious practical difficulties. The simplest implementation of this involves cooling the road surface and then detecting when the solution on it will freeze. The cooling seriously disturbs the state of the road surface and the heat produced by any practical cooling method disturbs it even more. Therefore, this cannot be used in continuous monitoring of the freezing point. Furthermore, detecting the freezing becomes difficult, when the liquid layer on the road surface is very thin, as it often is in practice.

3.2. ROSA system

Vaisala's ROSA system uses electrical measurements for salt detection. It does not compare with laboratory methods in accuracy, but it serves its purpose well in practice and is not expensive.

The specific electrical conductivity of a salt solution is directly dependent on its concentration. Measuring the specific conductivity of the liquid layer on the road surface has the problem, however, that the thickness of the layer is not known. Therefore, it is not enough just to measure the conductivity between electrodes placed on the road surface, but in addition to that there has to be some other measurement that gives information on the layer thickness. In the ROSA system, besides conductivity, also electrochemical polarizability is measured.

Electrochemical polarisation is observed in ionic conductors, such as electrolyte solutions. It manifests itself as a voltage opposing the current flowing between electrodes placed into the solution and is caused by electrically charged microscopic layers getting formed on the electrode surfaces. The rate of polarisation depends on salt content of the liquid and also on the thickness of the layer on the road surface, but in a slightly different way than the electrical conductivity. This makes it possible to solve the salt concentration and also the thickness of the layer.

3.3. Experimental results

Figures 2 and 3 show measurement results obtained in experiments in November 1995 with a ROSA system operating near Helsinki in Finland. Two road surface sensors are installed about 1 m from each other on a secondary road. There was slight traffic on the road during the experiments. The air and road temperature were a few degrees above 0 C during all experiments, the road surface wet, and there was no rain, but it was cloudy. Some residual salt was left on the road in one of the experiments.

Four experiments were carried out on different days each using sodium chloride solutions with the concentrations of 20 g/l, 50 g/l, 100 g/l and 200 g/l. One liter of the solution was slowly poured on each sensor and the output of the system registered by 5 minute intervals. Initially the solution formed a puddle around the sensor covering maybe about half a square meter, but it soon spread out helped by the traffic. The results shown here contain some smoothing and delay that is inherit to the ROSA system.

Figure 3. contains graphs for two different freezing temperature values. In the lower graphs are the actual freezing temperatures, i. e. with the estimated thickness of the liquid layer taken into account, while in the upper graphs the thickness is always taken to be the same, in this case 0.5 mm.

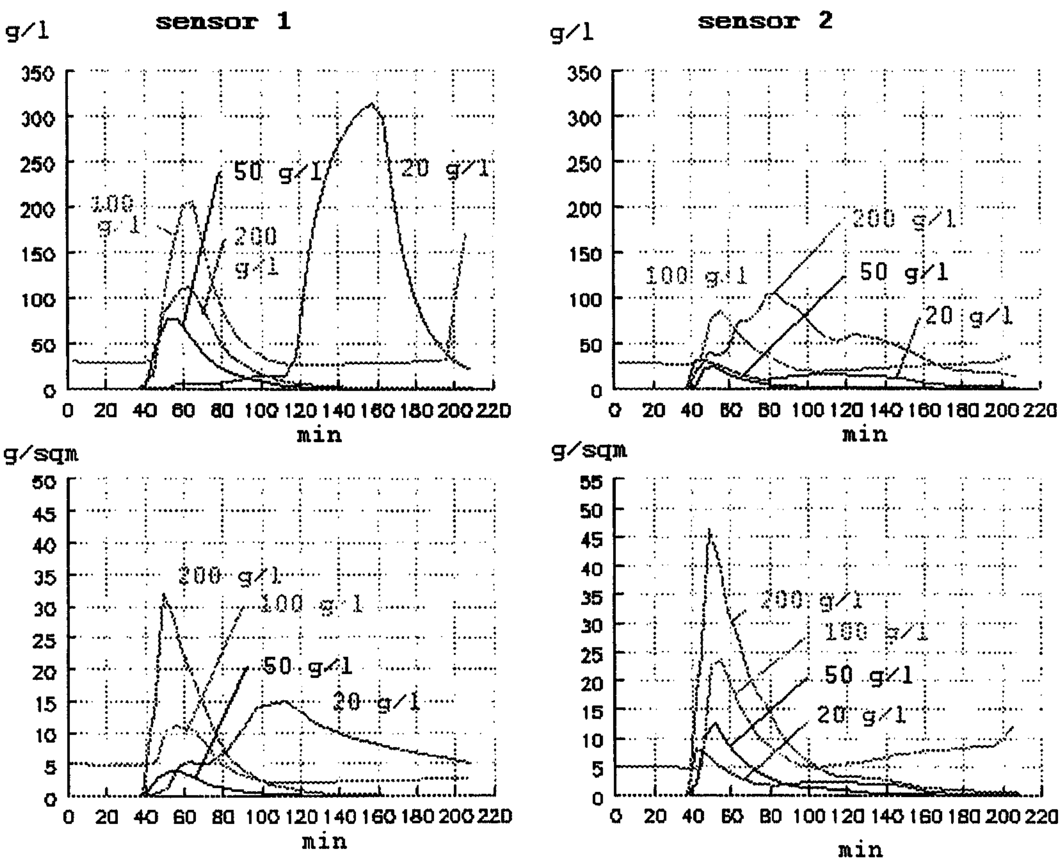

Figure 2. Salt amount measurement results. The upper graphs show the concentration of salt as estimated by ROSA at each of the two road surface sensors. The lower graphs show the amount of salt per unit area.

It can be seem in the graphs that the absolute values are not very exact, but that measurements are well suitable for estimating the amount of salt present on the road surface. The values for the total amount of salt are clearly more accurate then those of the salt concentration. It is to be expected that the actual freezing temperature values are less stable than those computed with the constant thickness.

The measurement at sensor 1 with the weakest solution (20 g/l) gives a result that seems to be clearly wrong after about 60 minutes from the start of the experiment. The probable reason for this anomaly is drying salt getting accumulated on the sensor.

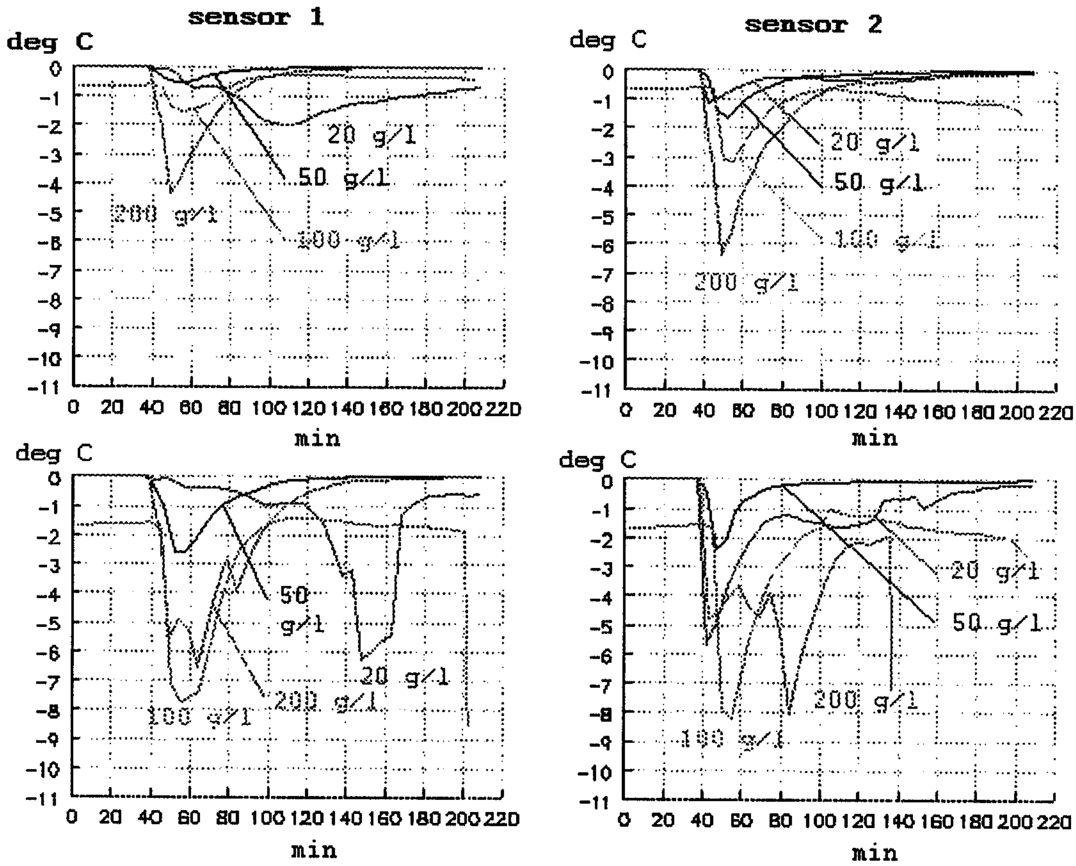

Figure 3. Freezing temperature measurement results.

Figure 4 shows and example of actual salt measurement results on a road during winter 1995 in Finland. During the three days shown in the figure, the weather conditions were rather bad, snow and sleet, temperature near 0 degrees C. There were four saltings, which can be seen clearly in the graph. It is also obvious that the freezing temperature, T_r, computed with constant, quite large, layer thickness, is more informative about the safety of the road, than the actual freezing temperarture.

4. Conclusions

Practical monitoring of the amount of salt spread on the road surface is technically a very difficult task, but not impossible by any means. The most critical technical challenges are in sensor design, especially in durability and in keeping the price of the sensor at a reasonable level. The best approach this far is to continuously monitor several physical quantities on the road at the same time.

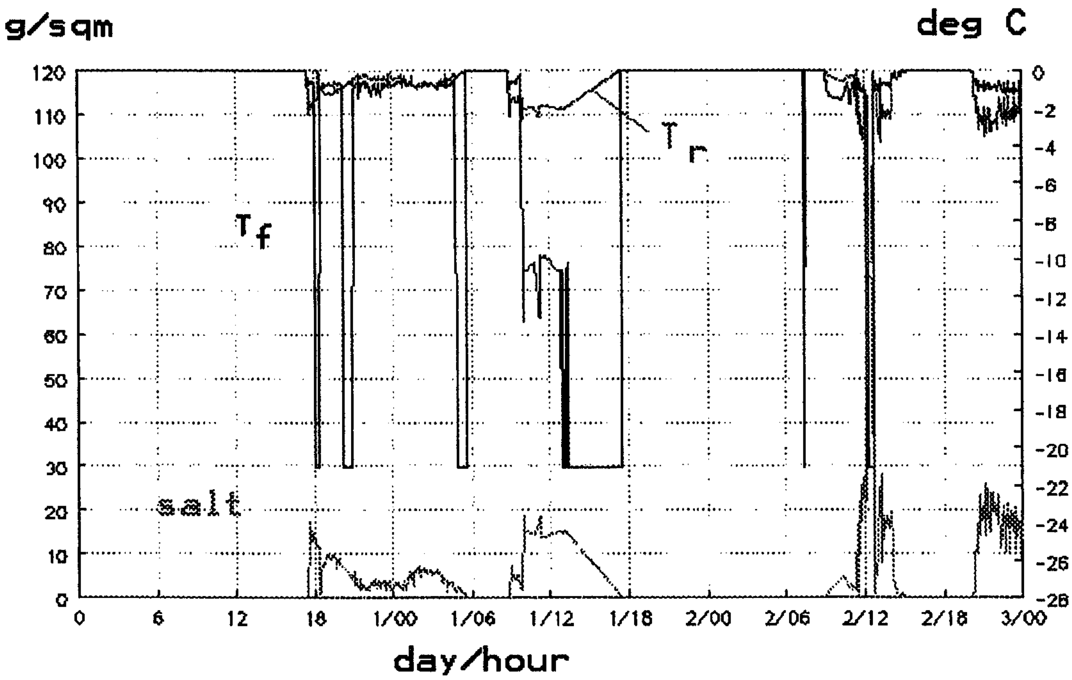

Figure 4. Salt amounts registered during 3 days on a road in Finland in March 1995

The freezing temperature of the road surface turns out to be a difficult concept. The difficulty is not only a matter of definition, but also a question of what would be the most useful quantity to indicate the safety of the salted road against getting slippery. The actual freezing temperature, whatever definition we use, is not very good for that purpose. It does not always tell, how much salt there really is on the road, as it is low with tiny amounts of salt, as long as the layer of water on the road is also very thin. More often than not, the road becoming slippery is associated with some event of increasing moisture, either precipitation or condensation. In these cases the freezing temperature rapidly rises with the event and its initial value has a little meaning. Giving the amount of salt per unit area directly is much better, though perhaps not so descriptive as a value expressed as a temperature. A freezing temperature value computed by using the measured amount of salt on the road and some fixed, quite large, value for layer thickness, such as 0.5 mm, is perhaps a best alternative. It could be called a 'safety temperature'.