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Effect of Sugar as an Additive on the Longevity of Salt on Pavements

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Abstract:

In winter maintenance of roads chemicals are applied to the road with the aim of ensuring that the friction is at an acceptable level so that the road is safe and accessible. Sodium chloride is a common used chemical due to its effect and price.

This thesis studies the effect of sugar as an additive has on the longevity of salt. The laboratory experiment conducted was new and unknown, so a scope of the thesis was also to develop the experiment and make a judgement over what could be changed in further work on the experiment. In the experiment asphalt substrates are applied with different salt/sugar solutions, and after it had dried the substrates were rinsed with water to simulate rain. Conductivity of the water that had been on the substrates was measured, and in that way the residual salt on the substrate could be calculated.

The results from the experiment showed that the more sugar was added, the more residual salt was left on the substrate. After first rinse in room temperature the NaCl/sugar mixes 90/10, 50/50 and 33/67 had respectively 27%, 46% and 81% more residual salt on the substrate than NaCl with no added sugar. After five rinses there was almost no difference between them. When moving the experiment into the ice laboratory, where NaCl with no sugar and NaCl/sugar 50/50 were tested, the results showed that NaCl/sugar 50/50 had an amount of residual salt after first rinse that was only 16% higher than NaCl with no sugar. However, compared to tests performed in room temperature, there was a difference after five rinses. NaCl/sugar 50/50 had at this stage 24% more residual salt left on the substrate than NaCl with no sugar. One possible hypothesis that explains the results might be that the dissolution rate is slowed down when sugar is added.

The experiment should be performed in an ice laboratory to ensure that it has the same temperature as out on the roads in the winter. Further development of the experiment should focus on how the water is applied and how to make it run off. The exactly same procedure for these operations is not possible for a human to repeat several times. To get a more reliable experiment the operations mentioned should be done in other ways.

Roger Ebersten

Preface

This report is written as a final work of my master degree at NTNU, and was performed at the Department of Civil and Transport Engineering, Faculty of Engineering Science and Technology. Additives to road salt is the subject of the thesis, and was chosen because I find it interesting how additives might reduce the amount of salt used on the roads. A reduction of the salt usage will lead to a reduction of the negative effects on the environment.

Since this was a new experiment I faced some challenges regarding how the different parts should be performed, which lead to a higher time consumption in the laboratory than expected. Also my limited knowledge of chemistry was a challenge, e.g. understanding the chemical processes.

Summary

In winter maintenance of roads chemicals are applied to the road with the aim of ensuring that the friction is at an acceptable level so that the road is safe and accessible. Sodium chloride is a common used chemical due to its effect and price. There is however negative impacts related to the use of salt, it is not good for the environment (like vegetation and groundwater). A reduction of the salt usage is therefore highly desirable. One way of reducing the salt applied on the roads, is to replace parts of it with other more environmental friendly substances that gives the same or better effect or/and an increased longevity. SafeCote is an additive that has been more and more used in the recent years in some countries of the world. According to the manufacturer this product both makes the salt more effective on lower temperatures and gives an increased longevity.

This thesis studies the effect of sugar (which is one of the components in SafeCote) as an additive has on the longevity of salt. To study this, it first had to be collected information about what has been done in this area before. Therefore the thesis presents an overview of literature on residual salt, like mechanisms that remove salt from the road and the believed effect of dissolution of salt in these loss mechanisms.

The laboratory experiment conducted in this thesis was new and unknown, so a scope of the thesis was also to develop the experiment and make a judgement over what could be changed in further work on the experiment. In the experiment asphalt substrates are applied with different salt/sugar solutions, and after it had dried the substrates were rinsed with water to simulate rain. Conductivity of the water that had been on the substrates was measured, and in that way the residual salt on the substrate could be calculated.

The results from the experiment showed that the more sugar was added, the more residual salt was left on the substrate. After first rinse in room temperature the NaCl/sugar mixes 90/10, 50/50 and 33/67 had respectively 27%, 46% and 81% more residual salt on the substrate than NaCl with no added sugar. After five rinses there was almost no difference between them. When moving the experiment into the ice laboratory, where NaCl with no sugar and NaCl/sugar 50/50 were tested, the results showed that NaCl/sugar 50/50 had an amount of residual salt after first rinse that was only 16% higher than NaCl with no sugar. However, compared to tests performed in room temperature, there was a difference after five rinses. NaCl/sugar 50/50 had at this stage 24% more residual salt left on the substrate than NaCl with no sugar. One possible hypothesis that explains the results might be that the dissolution rate is slowed down when sugar is added.

The experiment should be performed in an ice laboratory to ensure that it has the same temperature as out on the roads in the winter. Further development of the experiment should focus on how the water is applied and how to make it run off. The exactly same procedure for these operations is not possible for a human to repeat several times. To get a more reliable experiment the operations mentioned should be done in other ways.

Sammendrag

I vinterdrift av veier anvendes det kjemikalier i den hensikt å sørge for at friksjonen er på et akseptabelt nivå, slik at veien er trygg og framkommelig. Natriumklorid er mye brukt som kjemikalie på grunn av sin gode effekt og pris. Det er imidlertid negative sider ved å bruke salt. Det er skadelig for miljøet ved at det kan angripe vegetasjon og havne i grunnvannet. En reduksjon av saltforbruket vil derfor være svært ønskelig. En måte å redusere det på er å tilsette/erstatte deler av saltmengden med mer miljøvennlige stoffer som kan gi samme eller bedre effekt og/eller en lengre levetid. SafeCote er et tilsetningsstoff som har blitt mer og mer brukt de siste årene i noen deler av verden. Ifølge produsenten gjør produktet både at saltet er mer effektivt ved lavere temperatur og at det får en forlenget levetid.

Denne oppgaven ser på effekten sukker (som er en av komponentene i SafeCote) som tilsetningsstoff har på levetiden av salt. For å kunne studere dette, ble det først samlet inn informasjon over hva som har blitt gjort på dette området tidligere. Denne litteraturoversikten presenterer mekanismene som fjerner salt fra veien og den antatte effekten om oppløsningshastighet av salt i disse mekanismene.

Det gjennomførte laboratorieeksperimentet var nytt og ukjent fra før, så et av målene med oppgaven var også å utvikle dette. I eksperimentet blir asfalt påført ulike salt/sukker-løsninger som så tørker inn. Deretter ble asfalten skyldt med vann for å simulere regn. Det ble målt konduktivitet av vannet som det ble skyldt med, slik at mengden restsalt på asfalten kunne beregnes.

Resultatene fra eksperimentet viste at jo mer sukker som er tilsatt, jo mer salt vil være igjen på asfalten. Etter første skylling ved romtemperatur hadde NaCl/sukker-blandingene 90/10, 50/50 og 33/67 hhv. 27%, 46% og 81% mer restsalt enn hva NaCl uten tilsatt sukker hadde. Etter fem skyllinger var det så å si ingen forskjell mellom dem. I is-laboratoriet ble det testet NaCl uten sukker og NaCl/sukker 50/50. Her viste resultatene at NaCl/sukker 50/50 bare hadde 16% mer restsalt enn NaCl uten sukker etter første skylling. Derimot var det en forskjell etter fem skyllinger, i motsetning til testene utført i romtemperatur. NaCl/sukker 50/50 hadde her 24% mer restsalt igjen på asfalten enn hva NaCl uten sukker hadde. En mulig hypotese som kan forklare dette, er at oppløsningshastigheten blir tregere ved å tilsette sukker.

Eksperimentet bør utføres i et is-laboratorium for å sikre at temperaturen er lignende som hva den er ute på veiene på vinterstid. Videre utvikling av eksperimentet bør fokusere på hvordan vann blir påført og hvordan få det til å renne av. Det er ikke mulig for et menneske å gjennomføre disse operasjonene på nøyaktig samme måte hver gang. For å få et mer pålitelig eksperiment bør de nevnte operasjonene gjøres med andre metoder.

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1 Introduction

In Norway we have about 55 000 km of roads (national and country roads). These should have a sufficient and acceptable condition all year around. That requires a high standard of operation and maintenance, especially in the winter. In that time of year the weather gives us different challenges, and forces us to put down a lot of effort and resources to keep the roads drivable and safe. It is important to take advantage of past experience and research.

There are three different strategies for winter maintenance in Norway. These are winter road strategy, bare road strategy and closed road strategy. The latter is only an option when there are alternative routes available and if the road for the most is used in the summer months. A winter road strategy accepts snow and ice on the road, but has requirements regarding friction, ice sole thickness and the amount of loose snow on the road surface. Using a bare road strategy means that the road should be clear of snow and ice. (Statens Vegvesen, 2012)

While the winter road strategy only make use of mechanical snow removal like plowing, scarifying to remove the compact snow layer and gritting/sanding to increase the friction on the road, the bare road strategy also uses chemicals.

Salt and other chemicals are used for different purposes. One is to prevent that the water on the pavement freezes, called anti-icing. When the purpose is to melt the ice that is already present on the pavement, chemicals are used for de-icing. The third purpose is to prevent that snow settles and forming a compacted snow layer, which are more difficult to remove with mechanical removal. This is called anti-compaction. (Klein-Paste, 2013)

A lot of salt is used for these purposes, and in the winter 2013/2014 it was used 188 347 tons road salt in Norway (Sivertsen and Skolmli, 2014). This was a reduction from the last 3-4 winter seasons before. Still we want to reduce the amount of salt used even more because as we know it is not so environmentally friendly. At the same time we have to maintain the mobility and safety on the road. That is why *additives* have been introduced to the winter maintenance. These are supposed to increase the effect of the chemicals. Some of the additives used today are known as agricultural by-products (ABP), and are sugary products derived from among others corn and sugar beets. (Akin et al., 2013)

Research has been done to see if ABPs like sugar makes the salt more effective on lower temperatures. But so far it seems like there are just the manufacturers that

claim that the product is good for this purpose, no scientific results can substantiate this statement. Another effect additives might have is that they increase the longevity of the salt, so that it does not have to be salted that frequent. The latter is what going to be studied in this thesis. There are different mechanisms leading to loss of salt (explained later on in this thesis), one of them is the presence of water on the pavement. One hypothesis on how to reduce the salt usage is to add ABP to increase the longevity of the salt on the road, for example in cases like when a lot of water is present. At least, this is what the manufacturers of the mixes with chemicals and additives say are another benefit (in addition to improved performance on lower temperatures).

This study is going to examine if there are any increase in longevity as claimed, and then by looking at the dissolution process after application. The hypothesis that will be tested is as following: additives slow down the dissolution rate of dried salt and in that way the salt will stay longer on the road (dissolved salt leaves the road faster). In this experiment one additive will be used, sugar. Different compositions of sugar and salt will be tested to see if there are any differences in the amount of residual salt. The experiment and the setup for this are new and unknown from before, so this study also has a scope about finding pros and cons and developing the conducted experiment.

2 Theory

2.1 How salt works

Freezing point depression and Blagden's law

Water that lays on the pavement might in the winter freeze and then lead to slippery driving conditions. The tires will not get sufficient road grip due to low friction, and this can cause dangerous situations. Chemicals like salt can then be applied to the pavement to prevent that water freezes. This make the water get a lower freezing point, in other words there is happening a freezing point depression. This application of salt is called anti-icing. Common anti-icing chemicals are sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), calcium magnesium acetate (CMA) and potassium formate (KCOOH). But what is actually happening when one of these chemicals (or others) is applied to the wet pavement?

The freezing point of the water is lowered no matter what kind of molecules or ions that are added and dissolved (Atkins and De Paula, 2010). This is called colligative properties, and means that only number of molecules per volume of water matters. Concentration of the salt used can be determined by using a phase diagram for the specific salt, which is created after experiments in the laboratory. Figure 1 Figure 1shows the phase diagram for sodium chloride dissolved in water. We can see that the freezing curve gives the freezing temperature as function of the salt concentration. The freezing point decreases until it meets the solubility curve. From that point no more sodium chloride will dissolve, we often say that the solution is saturated. The lowest freezing point possible with this salt is then reached. This point, where the two curves meet, is called the eutectic point. For sodium chloride the eutectic point is about – 21°C with a 23 weight percent (wt.%) concentration.
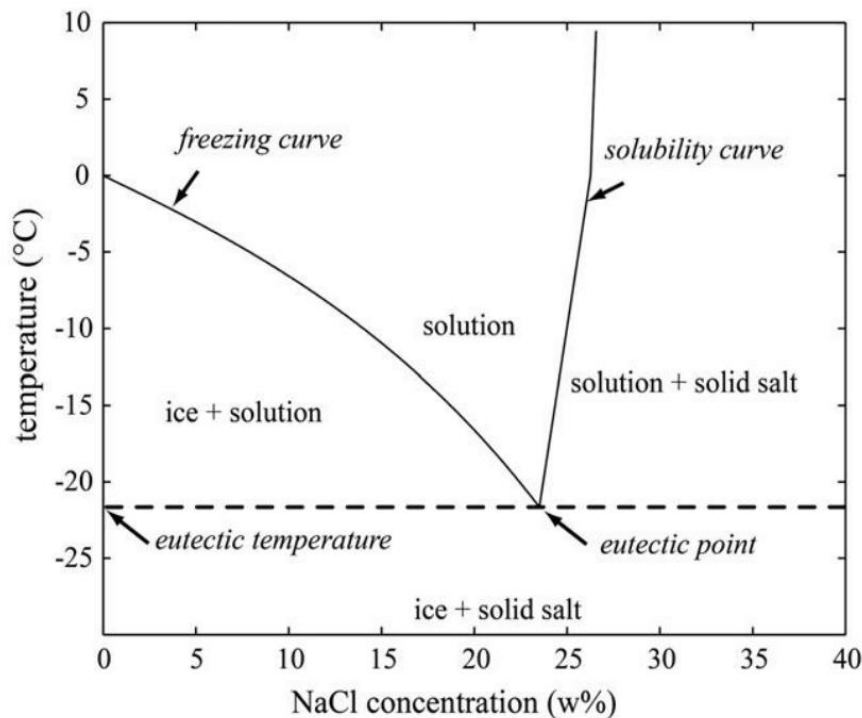
Figure 1 Phase diagram of sodium chloride and water (Klein-Paste and Wåhlin, 2013)

In addition to what explained above, chemicals can also retard the freezing process. When the saline water has reached its freezing point, the first crystals can start to form. The ice that is formed does not easily accept other molecules "entrance", hence the salt molecules gets excluded and is only present in the saline water. In this remaining solution less water will be present, while there is the same amount of salt molecules as before. The salt concentration will then increase as more ice forms, and the freezing temperature will decrease. This theory can be transferred to practice out on the road, in that way that the water takes longer time to freeze. (Klein-Paste, 2013)

For a quite a long time it has been known that saline water does not freeze at the same temperature as pure water. One obvious example of this is sea water. It will not freeze when the temperature is just below $0°C$. The difference between pure water and sea water is of course the salinity. This is what makes the sea water have a lower freezing point (together with some other factors to). As previously mentioned this applies to all molecules and ions that can be dissolved in water.

In the 18th century a scientist named Charles Blagden did some experiments on how dissolved salt and other substances affected the freezing point of water (Reif-Acherman, 2009). He discovered that the freezing point of a solution decreases

proportional to the concentration. Today this is known as Blagden's law, and equation 1 expresses this:

$$\Delta T_F = K_F \cdot b \cdot i \tag{1}$$

where

ΔT_F = is the freezing point depression ($T_{F(pure\ solvent)}$ - $T_{F(solution)}$) [°C].

K_F = is the cryoscopic constant [kg · °C/mol], and depends on the properties of the solvent. For water K_F = 1,853 kg · °C/mol.

b = is the molality [mol solute /kg solvent].

i = is the van't Hoff factor, which is the number of ion particles the solute splits into. E.g. when NaCl (s) is dissolved into water, it forms the ions Na^+ (aq) and Cl^- (aq). In this case the van't Hoff factor is 2.

Equation 1 clearly shows that the freezing point depression is proportional to the molal concentration of the solute. (Moore et al., 2010)

2.2 How salt is used in winter maintenance of roads

In winter maintenance of roads salt are applied on the pavement for different purposes. These are:
- Anti-icing
- Anti-compaction
- De-icing

These will be described in the next sections.

Anti-icing

When water is present on the pavement and there is expected a decrease in temperature salt is applied to prevent the water from freezing, the same goes for when there is moist air. The process of how the salt works in this purpose is described under the previous section about freezing point depression.

Anti-compaction

After and during snowfall the snow can form a hard and compact layer on the pavement, which is not easy to remove by mechanical methods. By applying chemicals before, during and after snowfall the snow will not be able to form such a compacted layer and the snow plows can remove the snow without much difficulty.

Traffic compresses the snow with its load, and makes a hard and slippery layer. The snow crystals are close to each other, and as more and more traffic and load drives over it, the stronger the bonds between the crystals get. In wet snow the crystals can more easily form bond with each other. This process is called sintering. The snow also bonds with the pavement (adhesion). It is found that salt (or other chemicals) weakens these bonds when applied. So far it is not known what kind of mechanisms that really takes place behind this, and thereby it is difficult to say how much salt is needed to weaken the bonds in the snow sufficiently so that it can be removed by snowplows.

De-icing

Unlike anti-icing, where the purpose is to prevent water from freezing, the purpose of de-icing is to melt the ice that is already present on the pavement. Chemicals are applied to restore a bare road. This works only on thin ice layers. Thick ice/snow layers will not melt, but chemicals make the mechanical removal easier.

In pure water-ice solution the phase transition from ice to water happens at 0°C. To start the phase transition from ice to water, energy needs to be added to bring the ice to its melting point. The melting point is the temperature where both the liquid and the solid phase can exist in equilibrium. Ice molecules move slowly and are more bound to each other than water molecules, which have more energy and moves faster and more freely compared to their neighbors.

The only way for the ice molecules to obtain the energy needed is to steel it from its surrounding molecules. The surrounding molecules will then loose energy and move more slowly, and some of them will freeze. When the rate of freezing is the same as the rate of melting, and the amount of both ice and water will not change, the ice and water are said to be in dynamic equilibrium with each other.

To de-ice roads the phase transition has to start at a lower temperature than 0°C. Adding chemicals like salt make this happen, since salt have a much lower freezing temperature than water. Then the point of equilibrium is moved down on a lower temperature. As more and more ice is melted, the saline water gets diluted and the system reaches a new equilibrium. Further melting on the road takes place because of the system is now colder than the surroundings (air and pavement).

In recent years there has been research on what other effects salt and other chemicals can have except from freezing point depression. Klein-Paste and Wåhlin (2013) show in their study that chemicals also have the property that it weaken the ice that has already formed. Pure water that freezes gets really strong. The ice crystals are strongly bonded to each other. But when a salt solution freezes, some of it will not freeze. This unfrozen liquid with dissolved salt will be located in small pockets in the ice. These pockets are called brine pockets. Because of pockets in between the solid ice, it is much weaker. This weakening of the ice means that the traffic itself can break the ice, when the amount of salt present is sufficient.

2.3   Residual salt – a literature overview

When we put salt on the road we want it to work quick and have a good effect, but also that it works for a long time. The longer the salt can be on the road, the less frequently it is needed to add more on the road. And as we know there are some environmental aspects by spreading chemicals out on the roads to. The salt can find its way to drinking water supplies for animals and humans, and also harm plants. Corrosion of cars is also a problem. So by reducing the amount of salt on the roads, these negative effects will be reduced too.

As previously mentioned, there are some thoughts today about additives like ABP increases the effect of salt on the road. Some countries in the world use ABP as an additive to salt, like USA, Canada and UK. Increased ice melting capacity, longer longevity, and less corrosion damages are claimed to be some of the advantages by using these ABPs in a mix with salt. But for the most these are the producers' words. Anecdotal evidence is not enough; to ensure that is really has a positive effect on winter roads more scientific testing have to be done.

This chapter describes some studies that were conducted to learn more about how residual salt is affected by different mechanisms and factors, and how additives might lead to a smaller loss of salt. It should be mentioned that the following studies are all experiments performed out in the field.

"The Amount of Salt on Road Surfaces after Salt Application – a Discussion of Mechanisms and Parameters" - (Lysbakken and Norem, 2008)

In this study, which is a part of a PhD thesis described later, there were conducted field observations to understand what mechanisms that remove salt from the road, and also what kind of factors that influence these mechanisms.

Amount of salt and water present on the road, weather parameters, traffic data and data from maintenance trucks were measured on E6 south of Trondheim, Norway. The road is of a standard that requires a bare road strategy when it comes to winter maintenance. Spreading methods were mostly prewetted salt or dry salt.

Data that was collected:
- Data from maintenance trucks (time of salting, application rate, spreading method etc.)
- Traffic data (classification and number of vehicles on hourly basis)
- Weather parameters (air and road temperature, humidity, precipitation)
- Water on road surface
- Amount of salt

The instrument used to measure residual salt on the road surface was a SOBO20. It calculates the amount of salt by using the relationship between electrical conductivity and salt concentration. By adding a fluid when it is placed towards the road surface, the instrument measures the conductivity of the fluid and the output result is given in amount of salt in gram/m^2.

A Wettex-cloth was used when measuring the moisture. It was placed on the road surface to absorb water. The amount of water was then calculated by weighing the cloth before and after it had absorbed water, and by knowing the area of the cloth. These values were given in g/m^2.

In the study three mechanisms leading to loss of salt after application were presented:

- **Blow off.** Solid salt that is removed from the road by the wind or/and turbulence caused by the traffic. It is dependent on the number of vehicles, what type they are and which speed they have. Snow, ice and wetness may also affect this mechanism, together with the pavement texture.
- **Spray-off.** Dissolved salt that is removed by the traffic. If there is enough water on the road surface, the wheels will splash water and that causes this spray-off mechanism. It is dependent on different parameters as traffic volume, speed, surface texture and quantity of water present. Wind will also have an impact on the spray-off.
- **Run-off.** Dissolved salt that are removed from the road by drainage. This happens when the volume of water on the road is large enough so that it drains away. Parameters like cross-fall and rutting will decide *the amount* of water that runs off, and the pores in the pavement surface decides *when* the water is able to run off (they have to be saturated).

The results from the field observations showed that the amount of water present on the pavement had a fairly big influence on the loss of salt. In addition to the mechanisms mentioned the water present on the road surface controlled the amount of dissolved salt. A wet road surface both dissolve more salt and leads to a higher spray-off effect compared to a moist road surface.

"SaltSMART: Reduction of salt consumption by using additives – field experiments winter 2007/08" - (Klein-Paste, 2008)

This study was conducted in the northern part of Norway as a part of the Norwegian public roads administrations "SaltSMART" project. With focus on the longevity of the salt, there was tested out in the field if additives can help increase the longevity of sodium chloride on the road.

The mechanisms lead to loss of salt are often distinguished between initial loss and loss after application. The initial loss is caused by wind and turbulence from the spreading vehicle that makes the salt end up elsewhere than on the road, or salt grains that bounce off the road. This study focuses on loss mechanisms after application, because these are easier to detect and measure. These mechanisms are the ones presented in the previous presented study.

The hypothesis of the study was that additives could increase the longevity of salt when the salt is, or have been, dissolved, and only when a small amount of water is present (defined as $<100 g/m^2$).

The testing area was a 1.4 km distance of a 4-lane road, where it was operated with a bare road strategy. This strategy does not normally allow snow and ice on the road, and to ensure that this is fulfilled chemicals need to be applied together with mechanical removal. The 1.4 km stretch was divided into two sections, a test section where it was spread sodium chloride solution *with* additives and a reference section where it was spread sodium chloride solution *without* additives. The additive used was a product called SafeCote, a by-product from sugar production (ABP) which is more and more used on the roads in other parts of the world. It contains a mix of environmental friendly ingredients, according to the manufacturer.

There was applied mixture of 50 V% sodium chloride solution (25 wt.%) and 50 V% SafeCote on the test section. On the reference section it was applied a 25 wt.% sodium chloride solution.

There was measured residual salt in the right wheel track and in between both wheel tracks (SOBO20), moisture measurement in the same places (Wettex-cloth), and also temperature in air, road and dew point.

5 observation periods were conducted, and the weather and wetness of the road surface were different from period to period. It was observed that when both salt and additive was dissolved on a wet surface, the loss was due to the mechanisms spray-off and probably run-off. In this case the additive did not make the salt stay longer on the road.

It is also worth mentioned that in one of the tests, it was measured a precipitation of 1 mm, which is 1000 g/m^2. The loss of salt was most rapid in this period.

In an observation period with a low amount of water on the road, the salt on both the test- and reference section had a durability of more than 30 hours and 20 000 vehicles. The road was wet during application, but almost no spray-off was registered. After about 2 hours the road was dry.

The results of this study showed that neither on wet or dry road surface was there found any difference in longevity of sodium chloride with or without Safecote as additive.

"Prediction of salt on road surface" - (Blomqvist et al., 2011)

Here the objective was to find and develop a model that could show the amount of residual salt on the road. The study used an empirical model developed in Sweden and data from Danish road weather stations that could measure residual salt, freezing point temperature and water thickness using sensors in the wheel tracks, together with information about different callouts. The latter is information like reason for the callout and what dosage and method was used. 18 cases were studied and used to model the amount of residual salt on the road. Prewetted salt was used in all these cases and the weather conditions were mainly in the presence of rime.

The equation for the empirical model developed in Sweden (Blomqvist and Gustafsson, 2004) described the residual salt in the wheel tracks as a function of traffic (equation 2):

$$RS = S \cdot e^{-k \cdot PC_{eq}} \qquad (2)$$

where

RS = residual salt in wheel tracks, [g/m^2]
S = salt dosage (spreading),]g/m^2]
k = coefficient for the salt decrease, influenced by road surface conditions
PC_{eq} = accumulated private car equivalents

Vehicles have different lengths, and longer vehicles do influence more on the loss of salt than private cars due to the number of wheels. Vehicles with a length between 580 and 1250 cm were therefor multiplied with a factor of 6, while those longer than 1250 cm were multiplied with a factor of 8.

By studying the 18 cases there was found a relationship between the values for coefficient for salt decrease (k) and the mean water thickness in the wheel tracks (W). This relationship could be described as:

$$k = a \cdot W^b \qquad\qquad (3)$$

where a and b are constants (a = 444,19 and b = 1,49).

The positive trend of the function means that the more water is present on the road surface, the faster the salt decrease in the wheel tracks.

Equation 2 and equation 3 combined gave a new equation, which then could predict the amount of residual salt in the wheel tracks by only knowing the salt dose uses (S), traffic amount (PCeq) and wetness of the road (W):

$$RS = S \cdot e^{(444,19 \cdot W^{1,49} \cdot PC_{eq})} \qquad\qquad (4)$$

Equation 4 was then transformed into a nomogram as a tool to understand the durability of residual salt present in the wheel tracks.

"Salting of winter roads – the quantity of salt on road surfaces after application" - (Lysbakken, 2013)

This study had a scope of find out more about how different conditions affect the amount of salt on the road surface after application by conducting field observations. Identifying the processes and factors behind the changes are also a part of the scope. This is a thesis for degree of Philosophiae Doctor and the study "The Amount of Salt on Road Surfaces after Salt Application – a Discussion of Mechanisms and Parameters" (Lysbakken and Norem, 2008) described previously in this chapter are

a part of this thesis. The results presented here are from the same field observations as in the mentioned study.

After application measurements were conducted every 30 minutes, and after 3 hours the measurement cycle was changed to every 60 minutes. SOBO20 was used to measure salt in the outer wheel tracks and in the middle of the wheel tracks in each lane. Wettex-cloth measured the amount of water on the road, and was conducted each time salt was measured. These measurements were used to classify 3 types of water conditions on road: Dry (0 g/m^2), moist (0-100 g/m^2) and wet (>100 g/m^2).

Road weather information system (RWIS) station together with handheld equipment was used to measure air temperature, humidity, roads surface temperature and precipitation. Maintenance data as position of the vehicle and information like

- Time of salting
- Application rate
- Spreading method
- Spreading width
- Spreading pattern
- Whether plowing is carried out

were also needed to be able to study residual salt on the road.

As mentioned in the overview of "The Amount of Salt on Road Surfaces after Salt Application – a Discussion of Mechanisms and Parameters" the results from the measurements showed that the presence of water on the road clearly affects the amount of salt measured after application. A higher amount of water dissolves salt more rapidly, and also leads to a loss that is more rapid, compared to a moist surface. After about 200-400 vehicles on wet surface the measured salt value was equal to the value measured before application.

This study also presented a model for the amount of salt on the road, where it is assumed that dissolution and loss process are independent. Other assumptions/simplifications made are that there is no run-off and that are a linear relationship between time and traffic. The model provides an acceptable fit to the data from the field observations.

The model in equation 5 is a combination of a function for amount of dissolved salt (S_D) and a function describing the loss of salt (S_L):

$$S_M = S_D - S_L = S_R + C^* \cdot \left(1 - e^{-\frac{K_D}{m}Tr}\right) \cdot W - S_A[1 - e^{\ln(1-K_L)Tr}]$$

(5)

Where

S_M = measured salt with SOBO20, [g/m^2]

S_R = residual salt (at time of spreading), [g/m^2]

C^* = equilibrium saturation at the given temperature

K_D = dissolution mass transfer coefficient

Tr = accumulated traffic

m = describes the relationship between time and traffic

W = amount of water on the road surface, [g/m^2]

S_A = available salt on the road surface after spreading [g/m^2]

K_L = portion loss of existing salt on the road caused by each vehicle (blow-off and spray-off)
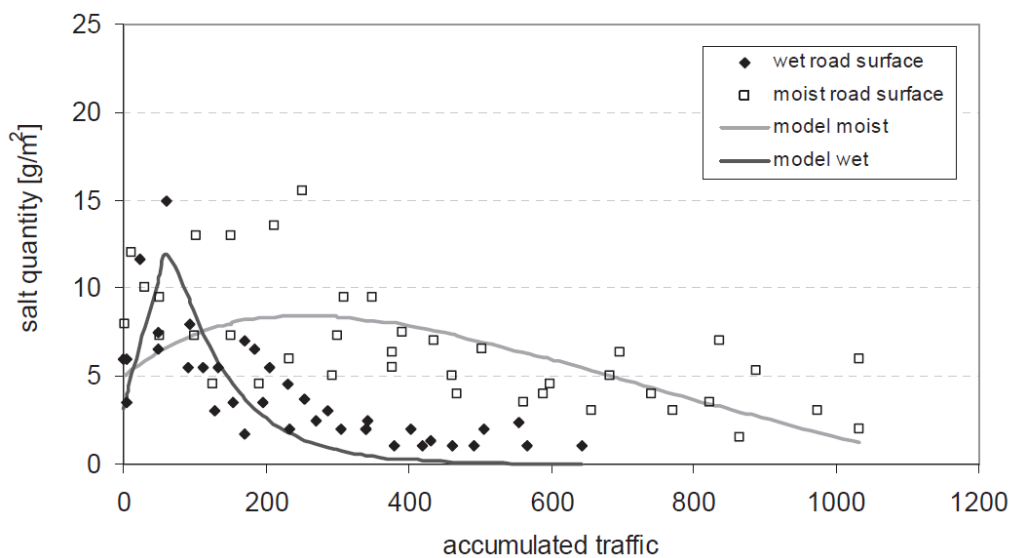
Figure 2 The model for the amount of measured salt and data from lane 1 from all field observations (Lysbakken, 2013)

Figure 2 graphically shows how the model fits the data from one of the lanes from the field observations, and shows that the loss of salt and dissolution of salt is higher on a wet road surface than on a moist surface.

"Modelling residual salt - MORS" - (Eram et al., 2013)

In 2011 a project called "Modelling Residual Salt" (MORS) was started with Denmark, Sweden, Iceland and Norway participating. The objective was to develop an operational tool or a model that could predict the duration of a salt measure under different road conditions. This could help keeping the amount of salt on an optimal

level, not too less which causes slippery conditions and not too much which is not good for the environment. Field experiments were conducted on a test track in Bygholm, Denmark. A 10% salt solution was spread under controlled circumstances, and the traffic consisted of passenger cars with a speed of 50-100 km/h.

There were conducted different measurements, these were:

- Residual salt was measured with a SOBO20
- The amount of water on the road surface was measured with a Wettex-cloth
- Salt concentration. This was measured with a refractometer. This instrument need one drop of the liquid, and can by reading from a scale one can find the value for the concentration.
- Collection of splash and spray from the spreading vehicle and the traffic was done with petri dishes. These were placed on the lane edge and outside the road in a certain distance from the edge.
- Moisture on the surface was measured with a contact free sensor. This instrument measured at a high frequency, which resulted in a measuring point density of 3-5 cm.

The study defined a model on how residual salt on a pavement is influenced by different processes and factors. There were identified 5 other processes that brought mass (water, salt solution and solid salt) in and out of the system, in addition to the three loss mechanisms blow-off, run-off and splash+spray-off:

- Spreading of solid salt
- Spreading of salt solution
- Evaporation of liquid on the pavement
- Condensation of moisture on the pavement
- Precipitation: rain, sleet or snow

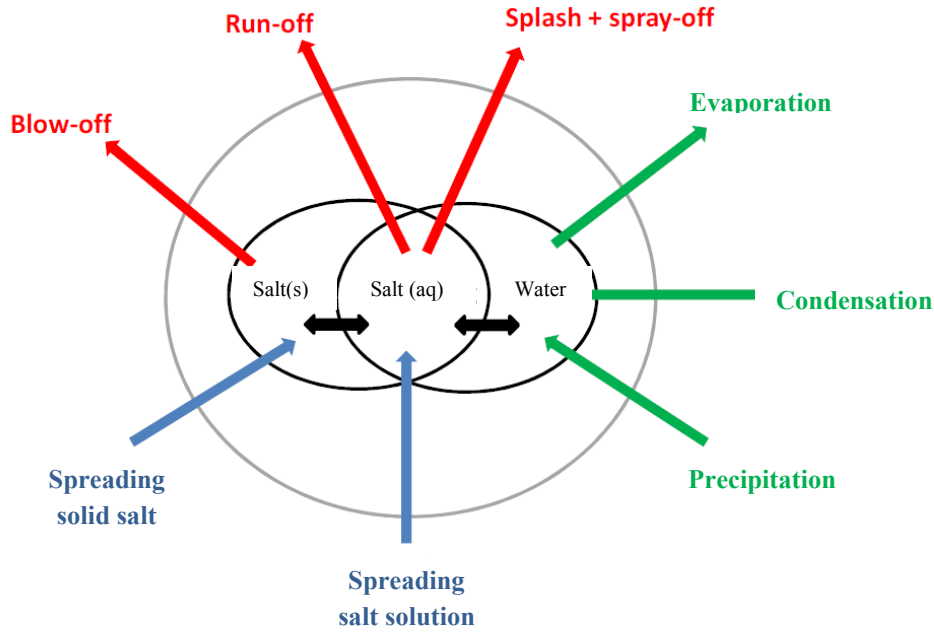All the processes were presented in a figure, like Figure 3.

Figure 3 Model concept for residual salt (Eram et al., 2013)

In addition to these 8 processes, there was found two processes that changed the mass of water, salt solution and undissolved salt.

- Dissolution
- Crystallization

After the field experiments were conducted, there was found that the processes run-off and spray-off were very important for the amount of residual salt. Models for these two were presented in the study. The model for run-off was a previously used model (Viessmann and Lewis, 1989) with some small modifications. It takes into account precipitation, roughness of the road surface, road width and slope. Equation 6 expresses the run-off intensity:

$$q = \frac{C}{n} \cdot S^{1/2}(D)^{5/3}[1 + 0{,}6(\frac{D}{D_e})^3]^{5/3}$$

(6)

q = run-off, [mm/hour]
C = empirical constant
n = Manning's roughness coefficient. Asphalt = 0,012
S = slope, [m/m]
D = average amount of liquid in the area, [mm]
D_e = amount of liquid at equilibrium, [mm]

D_e was calculated by using equation 7:

$$D_e = \frac{B \cdot i^{0,6} \cdot n^{0,6} \cdot L^{0,6}}{S^{0,3}}$$

(7)

B = empirical constant
i = rainfall intensity, [mm/hour]
L = length of area in the flow direction, (Half the width in case of roof pitch)

This model was run every 5 minutes, then with new values for D_e, D and q. By the use of continuity equation for the whole system the value of "the new" amount of liquid (D_2) could be calculated by adding the difference between rainfall and run-off to "the old" amount of liquid (D_1), expressed in equation 8:

$$D_2 = D_1 + i - q$$

(8)

D_0 was measured with a sensor or by setting it equal to 0.

The collected data from Byghom were put in the described run-off model, and the results were satisfactory.

The model for the splash and spray mechanism was an empirical model. In this model the calculation of loss of salt per vehicle were based on the amount of liquid on the pavement, salt concentration and crosswind. Equation 9 describes the loss of salt caused by the mechanism splash and spray, and by integrating it one can find the amount of salt that ended up between the edge of the lane and 10 meter out from the lane:

$$Dep = S \cdot e^{-k \cdot dist}$$

(9)

where

Dep = deposition of salt at a certain distance
S = deposition of salt at the edge of the lane, [m] (distance=0)
$-k$ = model constant that determines the decay of deposition
$dist$ = distance from edge of the lane, [m]

The study revealed that more salt is removed from the road by run-off than previously believed. Also, the water seemed to start run off at a lower amount. Although it has to be mentioned that the test track was repaved and got a low texture, so this might affect the run-off mechanism. Further development of this model should take into account more of the processes that influence on the amount of liquid on the pavement, like evaporation and condensation.

3 Method

3.1 Lab experiment - setup and implementation

The objective of this study is to find out if sugar can make the salt stay longer on the road. There are as mentioned different mechanisms that lead to a loss of salt, several of them through loss in solution. In this study it will be tested the ability of sugar to reduce the rate which dried-in salt can dissolve. As studies described in chapter 2.3 dissolved salt leaves the road more rapidly, and thereby reducing the dissolution rate will reduce the loss of salt. The added sugar in this experiment is sucrose.

Salt and sugar were put on circular substrates with a diameter of about 145 mm. The substrates were of the material asphalt concrete.

The circular asphalt substrates were placed on a table like Figure 4 shows. Three adjustable screws were ensuring that the substrates were leveled correctly so that the solution would not settle on just one side/part of the asphalt surface; it would have an even thickness all over. A stainless steel plate at the bottom of the substrate made it easier to level.
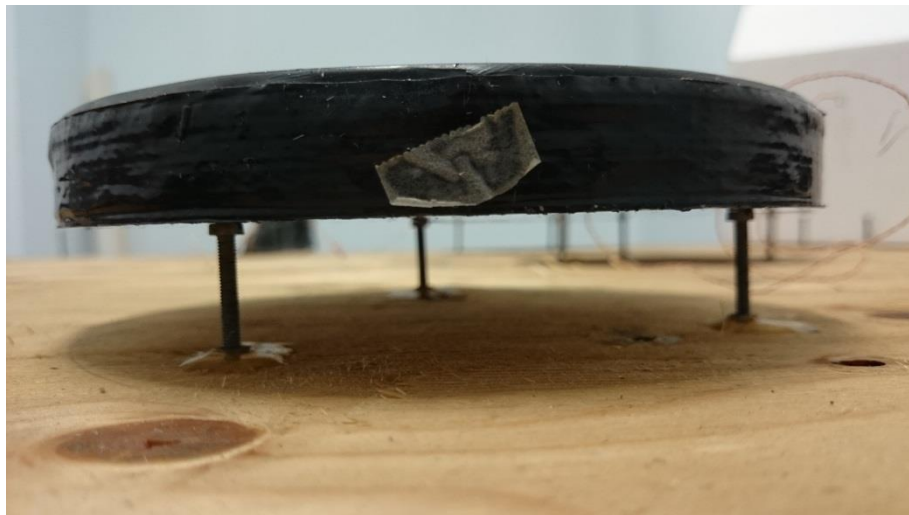
Figure 4 Setup for the substrates

3.2 Spraying solutions

The sugar and salt were applied on the substrates as a solution. Spraying the solution with a spray bottle ensured that the sugar and salt were spread evenly over the substrate surface. During spraying the substrates were placed on a weight to

ensure that the amount of solution sprayed was exactly as wanted (Figure 5). A typical salt dosage applied out on the roads is 20 g/m^2, and together with the substrate diameter it was calculated how much salt this would correspond on the substrates. When mixing the solutions it was also taken into account challenges regarding practical parts. The latter was about that a solution did not have a too long drying time (due to too much liquid), and also to avoid that the solution overflowed during transportation from the weight to the table where it was going to dry. The amount of solution was chosen to 10 g. A rubber gasket ring around the edge would keep the solution on the substrate.

Figure 5 Spraying of solution

3.3 Rinsing

After the solutions had dried for 24 hours, water could be applied. At this time there were only salt crystals present (solid salt), the water from the solution had

evaporated. The substrates were put on a weight and distilled water was sprayed on evenly with a spray bottle. This was done to simulate rain and get the following dissolution process. A piece of paper was hold against the spraying direction so that no water ended up directly on the weight. If this was still not enough, the droplets on the weight around the substrate were wiped up with some paper.

The amount of water was 8 g, that indicates about 0,5 mm of rain. 60 seconds after the spraying was started (about 30-40 seconds after the spraying was done) the substrate was turned so that the water fell into a beaker. The weight of the content in the beaker was weighed and then poured into a bottle. The loss, liquid left in the beaker, was also weighed to ensure that the calculated salt left on the substrate was correct. Next spraying was started 2 minutes and 30 seconds after previous spraying, which means a cycle time of 3 minutes and 30 seconds.

This process was repeated until 5 rinses were done (5 bottles). By measuring conductivity of the content of these bottles one could find the amount of salt that was in the bottle, and thereby also find the residual salt on the substrate after each rinse.

3.4   Change of parameters

After doing the experiment in room temperature (22℃), it was moved into an ice laboratory to get a colder environment for the processes and thus more realistic considering the conditions out on the roads in the winter. Temperature was here 3 ℃, and the humidity was about 60-70 %. Not all solutions that were tested in room temperature were tested in the ice laboratory; a selection was made, based on the results from the tests in room temperature and due to a limitation of time.

Not only different solutions were tested, also other parameters could be changed during the experiment. Like mentioned, temperature and humidity was changed when moving the experiment from room temperature and into the ice laboratory. A last parameter that was changed in this experiment was the time the solution was drying before spraying with water. The longer a solution dries, the less liquid is left on the substrate. In the ice laboratory it was discovered that the solutions needed more time to dry than in room temperature. Therefore the drying time was increased to 72 hours. Tests with this drying time had to be performed in room temperature as well, so that the results could be compared. Table 1 shows the number of substrates done on each combination of parameters.

Table 1 Number of substrates tested with different parameters

wt. % sugar	Room temperature (22℃)		Ice laboratory (3℃)	
	24 hours	72 hours	24 hours	72 hours
0	3	3	7	4
10	8	-	-	-
50	7	4	4	4
67	7	-	-	-

3.5 Conductivity

The conductivity of the content of the bottles was measured with a conductivity meter, more specifically a Mettler Toledo SevenGo. The instrument could only make a measurement if there was a sample of at least 50ml, therefore dilution was necessary. This diluent of distilled water was weighed, so that the masses of dilution and liquid from the substrate were known.

An electrode was placed down in the sample and the measurement could start. The values on the instrument was given in mS/cm or μS/cm (S=Siemens). 5 measurements were done for each of the samples, and then the mean of these was used in the calculations. The conductivity value was converted into concentration by using equation 10, as explained in the next section. Between every sample the electrode needed to be dipped in distilled water so that there was no residue left on the electrode from previous sample.

To say what amount of salt there was in a bottle, a calibration curve had to be made. By making solutions with a known concentration and measure these conductivities, one can get a value for the concentration of any conductivity that is measured. These values could be put in a diagram in Microsoft Excel. By putting the known concentration values on the x-axis and the measured conductivity values on the y-axes, one can add a trendline and get the function for this. Figure 6 displays the diagram. The function was used to find the correlative concentration for the conductivity measured. Then it first had to be "turned around", since it was the concentration of salt and not the conductivity that was unknown.

The function for the concentration c when the conductivity σ is known can then be expressed as equation 10:

$$c = -\sqrt{\frac{1}{1430,2}\left(0,067 + \frac{19175^2}{5720,8} - \sigma\right) + \frac{19175}{2860,4}} \qquad (10)$$
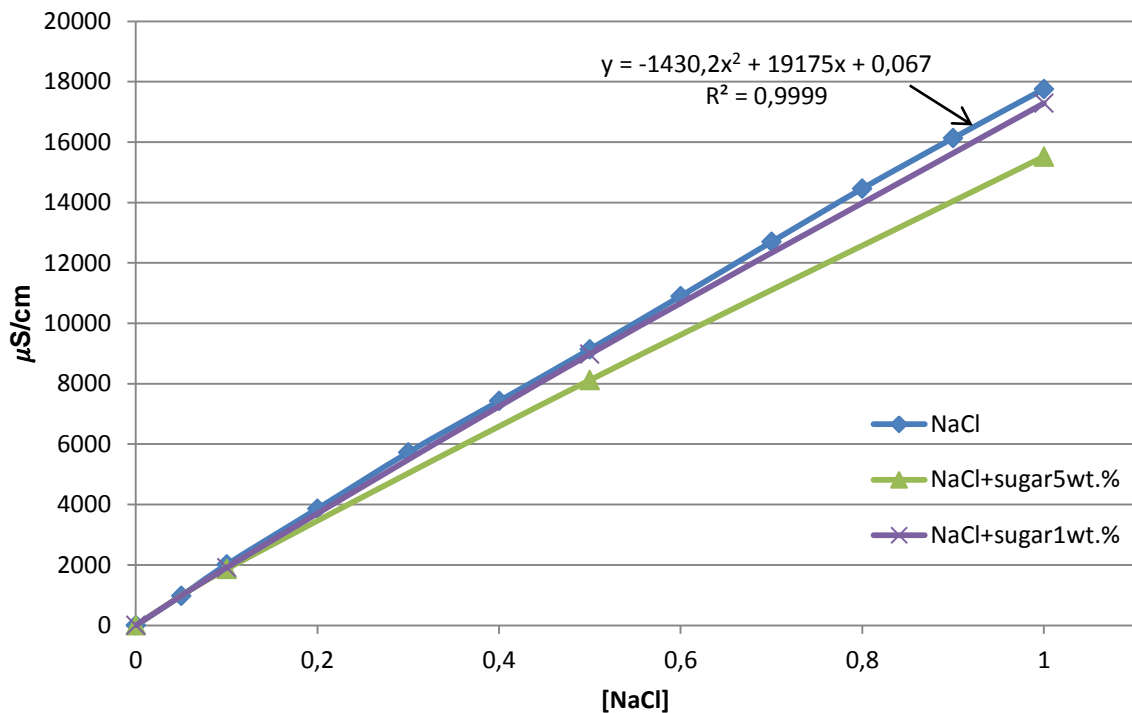
Figure 6 Calibration curves for NaCl and Mixes of NaCl/sugar

When doing the measures for the calibration curve, it was found a difference in conductivity of pure NaCl solution and a solution with both NaCl and sugar. It turned out there was a lower conductivity in the solutions with sugar. That means that sugar come into play for the conductivity of the solution, although it is a non-electrolyte. With this decrease in conductivity value, it seems like it makes the solution less conductive. The conductivity values from the substrates with NaCl and sugar then may be a bit deceptive. By looking at the differences of the curves in Figure 6, the values for salt concentration will probably be a bit underestimated when increasing the portion of sugar in the NaCl/sugar mix.

4 Results and discussion

Total 57 tests were performed, with varying the parameters temperature (ice laboratory), salt/sugar fraction and drying time like shown in Table 1. Of these 57, 6 was not considered as a part of the results due to errors on the substrates, like substrate had not dried sufficiently or human errors by the person who performed the tests (author).

Figures are used to graphically represent the results from the different parameters compared to each other. There are in the chosen comparisons shown both a figure that shows the value of residual salt, and a figure that shows the value of loss of salt for each rinse. So they show the same results, only presented in two different ways. The values in the diagrams are the mean of 4 or more values (up to 8, Table 1) and confidence intervals are calculated by first calculating standard deviation.

Room temperature – all fractions

Here were 4 different fractions of salt and sugar tested in room temperature (22℃) with 24 hours drying time.
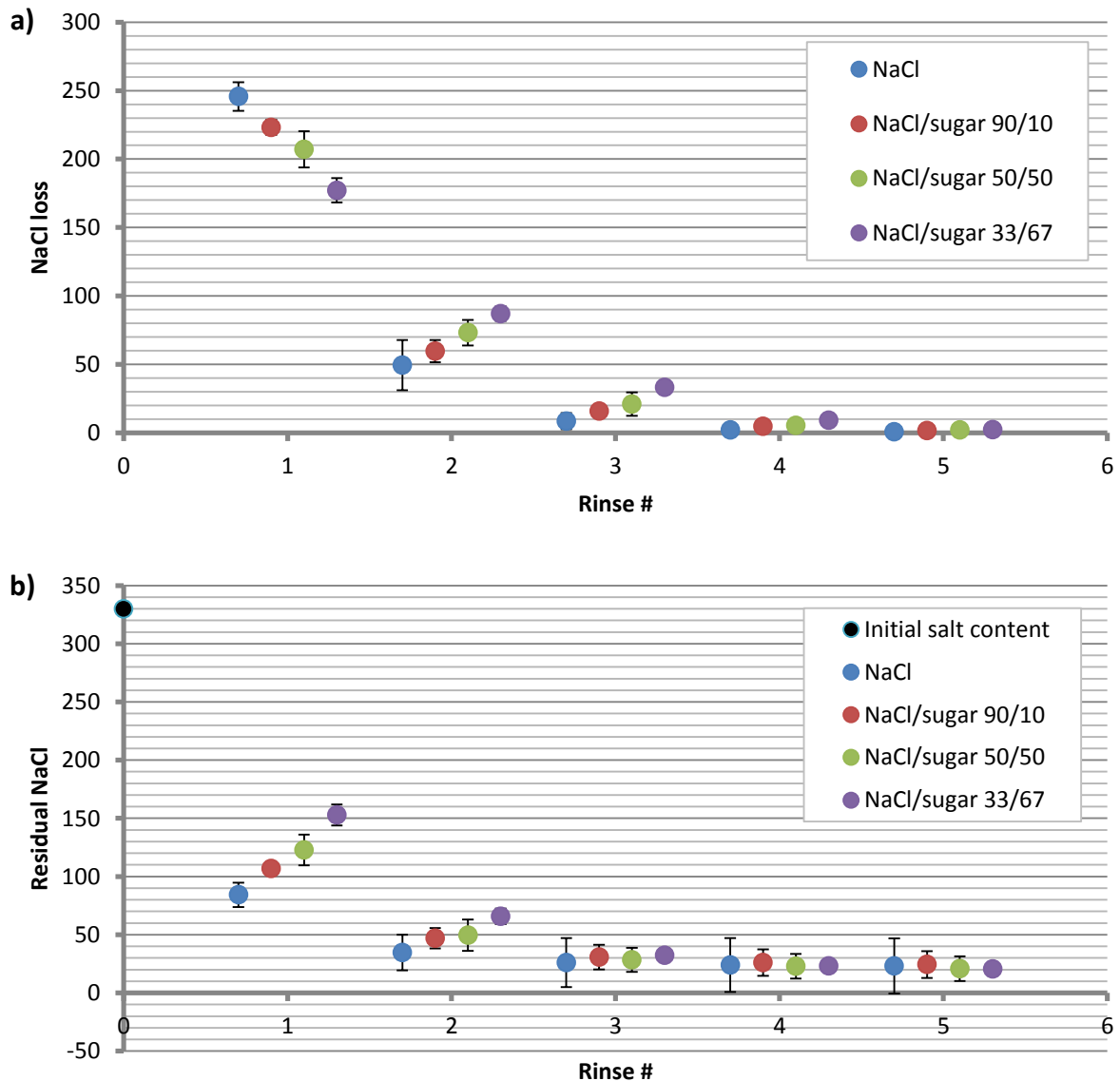
Figure 7 a) NaCl loss b) residual NaCl in room temperature with drying time of 24 hours

Not surprisingly it was the NaCl with no sugar that had the greatest loss on the first rinse, while the NaCl/sugar with a 33/67 distribution had lowest loss of the four fractions. Figure 7 a) shows that the more sugar was present in the solution, the less salt disappeared from the substrate on first rinse. If one look at the next rinses, it seemed like the NaCl with no sugar did not get reduced as much as the others. Actually it is turned the other way around compared to the first rinse, where solution with no sugar has the biggest loss. The reason for that it was turned the other way around on second rinse (and the following) is believed to be because of that NaCl/sugar 33/67 had more salt left after first rinse was done, and then there was more that could disappear compared to NaCl with no sugar that had lost more salt on first rinse. On the first rinse NaCl/sugar 33/67 loses 28% less salt than NaCl with no sugar. And on second rinse the first mentioned loses 76% *more* than the other.

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This can also be seen by looking at Figure 7 b) that shows residual salt. On the first rinse more salt of the NaCl/sugar 33/67 was left, compared to NaCl with no sugar. But after two rinses the difference between them are reduced (in mg). NaCl/sugar 33/67 had a reduction of about 57% from first to second rinse, and NaCl with no sugar had a reduction of 59%. So actually there was no difference in reduction between these two fractions from first to second rinse. The amount of residual salt of the NaCl/sugar 33/67 on the first and second rinse was respectively 81% and 89% more than NaCl without sugar. In the following rinses the difference between these two got reduced for every rinse, and on the fifth rinse there was almost no difference between them. The amount of residual salt for the first rinse for NaCl/sugar 90/10 and 50/50 was respectively 27% and 46 % more than NaCl with no sugar.

So the results from the tests done in room temperature show that sugar seem to have an effect only on the first rinse and second rinse. In third, fourth and fifth rinse the loss of salt for each rinse was greater compared with the NaCl with no sugar, and then they both ended up on about the same residual salt value at the end.

As mentioned in chapter 3.4, the presence of sugar influenced on the conductivity by reducing it, which then lead to an underestimation of salt concentration. The reason why the mixes of NaCl and sugar on first rinse lost less salt than what NaCl with no sugar lost can not only be due to this underestimation. If that was the only reason, the loss of salt would not have been turned the other way around on second rinse. Then the difference between the NaCl/sugar mixes and NaCl would have been bigger (the points for mixes with sugar content would have been moved higher) in this stage, and meant that for example NaCl/sugar 50/50 had lost almost the same amount of salt as its initial content was (330mg). So underestimation alone cannot be the reason for the differences, it has to be that sugar made less salt disappear from the substrate on the first rinse.

Ice lab – 0 and 50 wt. % sugar

It was tested NaCl with (50/50) and without sugar in the ice laboratory as described in the Method chapter. The results from the tests with a drying time of 24 hours showed that there was almost no difference between the two tested fractions. The reason for this was probably because of a too short drying time. The solutions seemed to need more time in the ice laboratory, where the temperature was lower. This could clearly be observed, and Figure 8 shows how the liquid on the substrate reflects the light which indicates that the solution has not dried sufficiently.

Figure 8 Substrate 24 hours after sprying of NaCl in the ice laboratory

Comparison: room temperature vs. ice laboratory

The aim of the experiment was to measure the ability of sugar to reduce dissolution rate of dried-in salt. Therefore the drying time in the ice laboratory had to be increased. The drying time chosen was 72 hours, as previously mentioned, and this also had to be performed in room temperature so that the results could be compared.
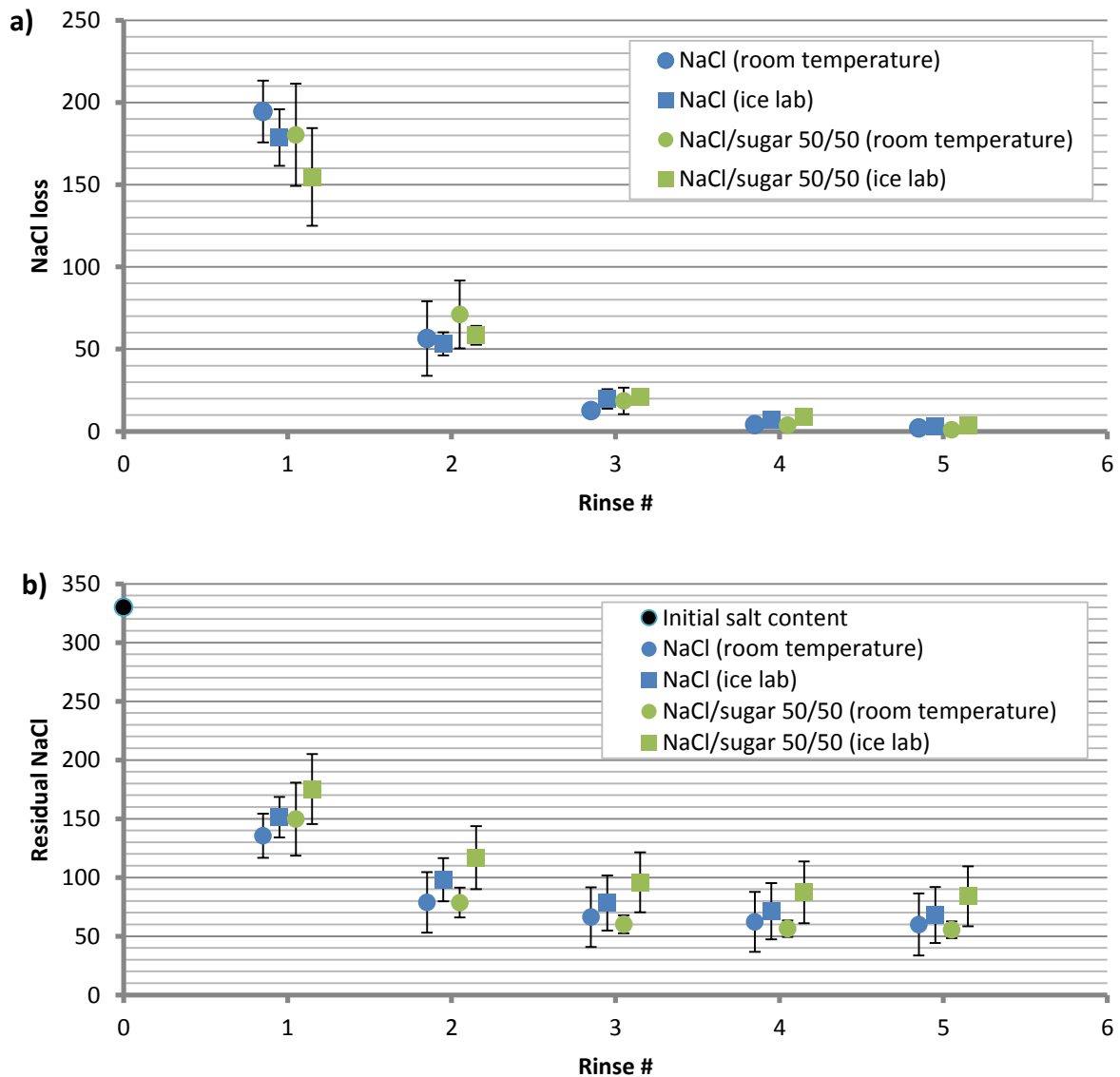
Figure 9 a) NaCl loss and b) residual NaCl in room temperature and ice laboratory with drying time of 72hours

In the ice laboratory the loss of salt is greatest on NaCl with no sugar on first rinse, as Figure 9 a) shows. NaCl/sugar 50/50 had approximately 13% less salt lost than NaCl with no sugar at this stage. On second rinse in same temperature, the loss was greater from NaCl/sugar 50/50, about 10% more than NaCl with no sugar this time. Why it here disappeared more salt from NaCl/sugar 50/50 than NaCl with no sugar was because it did not lose as much on first rinse. On third rinse there are almost no differences between the two fractions in the ice laboratory, and in the two last rinses very small amounts of salt are lost.

By looking at Figure 9 b) for residual salt on the substrate, it is clear that out of the two fractions in the ice laboratory NaCl/sugar 50/50 had most salt left on all of the five rinses. On the first rinse NaCl/sugar 50/50 had 16% more salt left than NaCl with no sugar, and on second rinse it had 19% more. After five rinses the difference between the fractions tested in ice laboratory had increased a little, at this stage NaCl/sugar 50/50 had about 24% more salt left on the substrate compared to NaCl with no sugar.

Take a look at the same fractions in room temperature; it is still NaCl with no sugar that had the greatest loss of salt on first rinse (Figure 9 b). NaCl/sugar 50/50 lost about 7% less salt compared to NaCl with no sugar. Like in the ice laboratory it was the opposite on second rinse, NaCl/sugar 50/50 had the greatest loss at this stage with 26% more than NaCl with no sugar. While there was almost no difference between the two fractions on third rinse in the ice laboratory, there was on same rinse in room temperature lost 46% more salt from the NaCl/sugar 50/50 compared to NaCl with no sugar. In the last two rinses there was almost no loss of salt.

Residual salt (Figure 9 a)) for the ones tested in room temperature shows that NaCl/sugar 50/50 only had most salt left on the first rinse, 11% more than NaCl with no sugar. On second rinse there were no difference, but on third NaCl with no sugar had most salt left. Here NaCl/sugar 50/50 had lost an amount that was 9% less than NaCl with no sugar. This difference remains to fifth rinse is done.

When comparing the tests performed in ice laboratory with the tests performed in room temperature Figure 9 a) clearly shows that NaCl/sugar 50/50 performed in ice laboratory had the highest amount of residual salt over all five rinses. And when looking at how much salt is lost on first rinse, less salt is lost from the NaCl/sugar mix in the ice laboratory compared to the same mix in room temperature.

The differences in residual salt of the different fractions tested might be explained by dissolution rate.

Dissolution rate

When solid salt is put on the road it dissolves in the water that is present on the road. This applies both when the pavement is wet with no ice and when ice is present. In the latter, salt dissolves in the film of liquid on the ice surface. It can also be put on a dry surface, before snowfall. Then the solid salt will dissolve in the liquid after the first snowflakes have melted due to the warm road surface.

The faster the salt dissolves, the more effective it is. That is of course also the case for other chemicals and additives. The rate of this dissolution is therefore quite

important when searching for the best de-icer. At the same time a faster dissolution rate will make the salt leave the road faster. Dried-in salt which dissolves fast when water is applied will then go along with the water into the ditch, and then it will not have any positive effect at all.

The dissolution rate depends on the level of undersaturation, which is the driving force of the process. Experiments have been carried out to find an expression for how fast a solute dissolves and in terms of dissolution rate (R_D) an equation was derived (Mullin, 2001). Equation 11 shows this expression:

$$R_D = K_D \cdot \Delta C \tag{11}$$

where K_D and ΔC are respectively overall mass transfer coefficient and mean undersaturation (C-C*=[solution concentration] – [equilibrium saturation at the given temperature]).

There are also some other factors that affect the dissolution rate; surface area of the particles, temperature and the presence of stirring. An increase in one or both of the first two will lead to an increase of the dissolution rate. Stirring will increase the speed of the process because it brings fresh portions of the solvent in contact with the undissolved solid. On the road, the vehicles will work as a stirring mechanism when wheels drive over the chemicals over and over again.

The explanation of why the sugar made the salt stay longer on the substrate might be due to a slower dissolution rate compared to NaCl with no sugar. When the water was sprayed on the first rinse it took longer time for the salt in the dried NaC/sugar mix to dissolve, and then less salt was lost. After one more rinse more salt disappeared because it had gone a longer time and then more of the sugar/salt could dissolve in the water that was present on the substrate after first rinse together with what was applied on second rinse. The difference in residual salt between NaCl with no sugar and the NaCl/sugar mix increased when the sugar content in the mix increased, which may mean that the higher the sugar content, the slower the dissolution rate. In the ice laboratory the differences in residual salt between the NaCl/sugar mix and NaCl were bigger than it was in room temperature, which might be due to that the dissolution process is even slower when the temperature is lower.

Evaluation of the experiment and recommendations for future work

When it comes to the experiment itself and the setup, it probably has a lot of potential. This is the first experiment that simulates how fast dried-in salt on the road will dissolve when water is applied (rain) and how additives might slow down this

dissolution process, as far as the author and the institute knows. That caused some challenges, due to lack of experience with the experiment setup. This thesis was therefore also about finding and developing an experiment that can simulate the conditions from out on the road, but at the same time be feasible at a reasonable time and with limited resources.

The simulation of rain is done by spraying on some water before turning the substrate so that the water left the substrate. This is an operation that is impossible for a human to repeat in the exactly same way over many substrates (such as speed of the turning and the angle). To make the conduct of the experiment more reliable the application of solution and water and the run-off should be done in other ways. One possible setup could be to install a larger size of a substrate on a table where the angle can be adjusted. Then the solution can be applied and dry when the table is at 0° , and when water is applied the table can be adjusted to a given angle. The water can be applied from the highest point by e.g. a hose with holes of any kind. In this way the operations will be repeated in the same way for each test.

When it comes to the environmental conditions for the experiment, it should be performed in a colder environment such as the ice laboratory. Out on the roads salt is spread when temperature is low, so room temperature is not realistic at all. This was confirmed by the differences in results from room temperature and ice laboratory.

5 Conclusion

The experiment in this thesis was conducted to see if sugar could increase the longevity of dried-in salt on the road by slowing down the dissolution process. Salt was dried-in on a substrate and rinsed 5 times with water, and then the residual salt could be calculated. There were performed tests of different NaCl and sugar compositions in room temperature and in an ice laboratory, and with two different drying times. The following conclusions could be drawn:

- The more sugar was added, the more residual salt remained after the first rinse in room temperature (22℃). For the NaCl/sugar mixes 10/90, 50/50 and 33/67 the amount of residual salt was respectively 27%, 46% and 81% higher than NaCl with no sugar.
- After first rinse in ice laboratory (3℃). NaCl/sugar 50/50 increased the residual salt by 16% compared to NaCl with no sugar.
- In the ice laboratory the mix NaCl/sugar 50/50 had 24% more residual salt than NaCl with no sugar after five rinses. The same result could not be detected in room temperature.
- Differences between the results in room temperature and in the ice laboratory indicate that experiment of this type should be performed in a cold environment that is similar to out on the road in terms of temperature.

6 References

AKIN, M., HUANG, J., SHI, X., VENEZIANO, D. & WILLIAMS, D. 2013. Snow removal at extreme temperatures.

ATKINS, P. & DE PAULA, J. 2010. Physical Chemistry, Vol. 2. WH Freeman & Co., New York.

BLOMQVIST, G. & GUSTAFSSON, M. 2004. Patterns of Residual Salt on Road Rurface, Case Study. *Transportation Research Circular Number E-C063, Transportation Research Board***,** 602-608.

BLOMQVIST, G., GUSTAFSSON, M., ERAM, M. & ÜNVER, K. 2011. Prediction of salt on road surface. *Transportation Research Record: Journal of the Transportation Research Board,* 2258**,** 131-138.

ERAM, M., BLOMQVIST, G., THORDARSON, S. & LYSBAKKEN, K. R. 2013. Modelling Residual Salt-–MORS.

KLEIN-PASTE, A. 2008. SaltSMART: reduksjon av saltforbruk ved bruk av tilsetningsstoffer-feltforsøk vinter 2007/08.

KLEIN-PASTE, A. 2013. Road Salting Theory.

KLEIN-PASTE, A. & WÅHLIN, J. 2013. Wet pavement anti-icing—A physical mechanism. *Cold Regions Science and Technology,* 96**,** 1-7.

LYSBAKKEN, K. R. 2013. *Salting of winter roads: the quantity of salt on road surfaces after application,* Trondheim, Norges teknisk-naturvitenskapelige universitet.

LYSBAKKEN, K. R. & NOREM, H. The amount of salt on road surfaces after salt application: A discussion of mechanisms and parameters. Seventh International Symposium on Snow Removal and Ice Control Technology in 2008, 2008.

MOORE, J., STANITSKI, C. & JURS, P. 2010. *Chemistry: The Molecular Science*, Cengage Learning.

MULLIN, J. W. 2001. *Crystallization*, Butterworth-Heinemann.

REIF-ACHERMAN, S. 2009. The pre-history of cryoscopy: what was done before raoult? *Quimica Nova,* 32**,** 1677-1684.

SIVERTSEN, Å. & SKOLMLI, I. O. 2014. Mengderapportering vinteren 2013/2014.

STATENS VEGVESEN 2012. Håndbok R610: Standard for drift og vedlikehold av riksveger.

VIESSMANN, W. & LEWIS, G. 1989. knapp, JW: Introduction to Hydrology. Harper Collins.

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MASTEROPPGAVE
(TBA4940 veg, masteroppgave)

VÅREN 2015
for
Roger Ebersten

Effekt av tilsetningsstoffer på levetid av salt

BAKGRUNN

I Norge har vi et riks- og fylkesvegnett på 55 000 km. Disse vegene skal driftes og vedlikeholdes året rundt, slik at de er både kjørbare og trygge. Med de vintrene vi har i dette landet gir det oss store utfordringer i denne årstiden. Det kreves store ressurser og mye kunnskap om vinterdrift for å få dette til.

Det brukes to hovedstrategier for vinterdrift i Norge i dag, strategi vinterveg og strategi bar veg. Førstnevnte aksepterer snø og is på vegen, men har krav til friksjon, issåle-tykkelse og mengde løs snø. Snøen blir fjernet mekanisk med plog, og issålen blir fjernet ved å høvle. Det brukes også strøsand for å bedre friksjonen. Strategien bar veg handler om at vegen stort sett skal være fri for snø og is, derav navnet bar veg. Her brukes det salt til ulike «formål»; hindre at vannet på vegen fryser til is (1), smelte islaget på vegen (2), og hindre at snøen «legger seg» ved snøfall og på den måten gjøre det enklere å brøyte og samtidig unngå et kompaktert snølag (3).

Saltet bidrar altså til å øke friksjonen. Mekanismene i de ulike «formålene» er følgende: senker frysepunktet til vannet og hindrer det dermed fra å fryse (1), smelter is og bryter bindinger mellom is og asfalt (2), og reduserer styrken mellom bindingene til snøkrystallene og mellom snøkrystallene og asfalt (3). Det er sistnevnte mekanisme vi vet for lite om i dag.

Det brukes store mengder salt til de formålene som er beskrevet. Vinteren 2013-2014 var forbruket av vegsalt på 188 347 tonn (Vegdirektoratet, 2014). Dette er noe man ønsker å redusere som følge av miljøkonsekvensene. Det har da tidligere blitt sett på hvordan tilsetningsstoffer kan påvirke saltet, enten det bedrer virkningsgraden til saltet eller om det forlenger levetiden. Ved våt vegoverflate foregår salttapet ved sprut fra kjøretøy og naturlig avrenning. Hvor mye som går tapt og om tilsetningsstoffer reduserer dette tapet er noe som er lite belyst.

OPPGAVE

Målsetting og hensikt

Målet med oppgaven er å bruke et nytt laboratorieforsøk til å se på hvilken effekt tilsetningsstoffer kan ha på saltets levetid på vegen, og på den måten redusere saltforbruket.

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Beskrivelse av oppgaven

1. Samle inn informasjon fra litteraturen om hva som er forsket på innenfor dette området tidligere, og gi en beskrivelse av hvordan salt fjernes fra vegoverflaten og hvordan bruk av tilsetningsstoffer påvirker dette.
2. Gjennomføre og videreutvikle et laboratorieforsøk for å undersøke hvordan levetiden til saltet påvirkes av tilsatser av sukker i forskjellige blandingsforhold.
3. Analysere resultatene og diskutere hvordan tilsetningsstoffene innvirker på levetiden til saltet, samt gi anbefalinger til hvordan laboratorieforsøket kan forbedres.

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GENERELT

Oppgaveteksten er ment som en ramme for kandidatens arbeid. Justeringer vil kunne skje underveis, når en ser hvordan arbeidet går. Eventuelle justeringer må skje i samråd med faglærer ved instituttet.

Ved bedømmelsen legges det vekt på grundighet i bearbeidingen og selvstendigheten i vurderinger og konklusjoner, samt at framstillingen er velredigert, klar, entydig og ryddig uten å være unødig voluminøs.

Besvarelsen skal inneholde
➢ standard rapportforside (automatisk fra DAIM, http://daim.idi.ntnu.no/)
➢ tittelside med ekstrakt og stikkord (mal finnes på siden http://www.ntnu.no/bat/skjemabank)
➢ sammendrag på norsk og engelsk (studenter som skriver sin masteroppgave på et ikke-skandinavisk språk og som ikke behersker et skandinavisk språk, trenger ikke å skrive sammendrag av masteroppgaven på norsk)
➢ hovedteksten
➢ oppgaveteksten (denne teksten signert av faglærer) legges ved som Vedlegg 1.

Besvarelsen kan evt. utformes som en vitenskapelig artikkel for internasjonal publisering. Besvarelsen inneholder da de samme punktene som beskrevet over, men der hovedteksten omfatter en vitenskapelig artikkel og en prosessrapport.

Instituttets råd og retningslinjer for rapportskriving ved prosjektarbeid og masteroppgave befinner seg på http://www.ntnu.no/bat/studier/oppgaver.

Hva skal innleveres?
Rutiner knyttet til innlevering av masteroppgaven er nærmere beskrevet på http://daim.idi.ntnu.no/. Trykking av masteroppgaven bestilles via DAIM direkte til Skipnes Trykkeri som leverer den trykte oppgaven til instituttkontoret 2-4 dager senere. Instituttet betaler for 3 eksemplarer, hvorav instituttet beholder 2 eksemplarer. Ekstra eksemplarer må bekostes av kandidaten/ ekstern samarbeidspartner.

Ved innlevering av oppgaven skal kandidaten levere en CD med besvarelsen i digital form i pdf- og word-versjon med underliggende materiale (for eksempel datainnsamling) i digital form (f. eks. excel). Videre skal kandidaten levere innleveringsskjemaet (fra DAIM) hvor både Ark-Bibl i SBI og Fellestjenester (Byggsikring) i SB II har signert på skjemaet. Innleveringsskjema med de aktuelle signaturene underskrives av instituttkontoret før skjemaet leveres Fakultetskontoret.

Dokumentasjon som med instituttets støtte er samlet inn under arbeidet med oppgaven skal leveres inn sammen med besvarelsen.

Besvarelsen er etter gjeldende reglement NTNUs eiendom. Eventuell benyttelse av materialet kan bare skje etter godkjennelse fra NTNU (og ekstern samarbeidspartner der dette er aktuelt). Instituttet har rett til å bruke resultatene av arbeidet til undervisnings- og forskningsformål som om det var utført av en ansatt. Ved bruk ut over dette, som utgivelse og annen økonomisk utnyttelse, må det inngås særskilt avtale mellom NTNU og kandidaten.

(Evt) Avtaler om ekstern veiledning, gjennomføring utenfor NTNU, økonomisk støtte m.v.
Beskrives her når dette er aktuelt. Se http://www.ntnu.no/bat/skjemabank for avtaleskjema.

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Helse, miljø og sikkerhet (HMS):
NTNU legger stor vekt på sikkerheten til den enkelte arbeidstaker og student. Den enkeltes sikkerhet skal komme i første rekke og ingen skal ta unødige sjanser for å få gjennomført arbeidet. Studenten skal derfor ved uttak av masteroppgaven få utdelt brosjyren "Helse, miljø og sikkerhet ved feltarbeid m.m. ved NTNU".

Dersom studenten i arbeidet med masteroppgaven skal delta i feltarbeid, tokt, befaring, feltkurs eller ekskursjoner, skal studenten sette seg inn i "Retningslinje ved feltarbeid m.m.". Dersom studenten i arbeidet med oppgaven skal delta i laboratorie- eller verkstedarbeid skal studenten sette seg inn i og følge reglene i "Laboratorie- og verkstedhåndbok". Disse dokumentene finnes på fakultetets HMS-sider på nettet, se http://www.ntnu.no/ivt/adm/hms/. Alle studenter som skal gjennomføre laboratoriearbeid i forbindelse med prosjekt- og masteroppgave skal gjennomføre et web-basert TRAINOR HMS-kurs. Påmelding på kurset skjer til sonja.hammer@ntnu.no

Studenter har ikke full forsikringsdekning gjennom sitt forhold til NTNU. Dersom en student ønsker samme forsikringsdekning som tilsatte ved universitetet, anbefales det at han/hun tegner reiseforsikring og personskadeforsikring. Mer om forsikringsordninger for studenter finnes under samme lenke som ovenfor.

Oppstart og innleveringsfrist:
Oppstart og innleveringsfrist er i henhold til informasjon i DAIM.

Faglærer ved instituttet: Johan Wåhlin
Veileder (eller kontaktperson) hos ekstern samarbeidspartner: Alex Klein-Paste (NTNU) og Kai-Rune Lysbakken (SVV)

Institutt for bygg, anlegg og transport, NTNU
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Underskrift

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Faglærer