OPTIMIZATION OF SALT SPRINKLING METHOD TO MINIMIZE ITS CONSUMPTION.

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1. Abstract

Salt (NaCl) is used today in most of the world to fight against icy and slippery roads. Taking the environmental effects to consideration, a minimisation of de-icing will cause of degradation of the environment and road users costs. Therefore the salt consumption should be limited as much as possible without this having an effect on passibility and safety.

Consequently, as an advantage the pre-wetted salt has been a successful method to fight against icy and slippery roads in Denmark. Challenging of further reduce the consumption, since 1998 The Road Directorate and The County of Funen have been carrying out a comprehensive measurement program in order to compare the use of salt as pre-wetted salt spread with disc and as brine spread with nozzles. 1800 spots were measured for residual salt with SOBO 20 in 1998 -99.

The results obtained to date show the following advantages for brine:

- Salt consumption can be reduced by approximately 30 %, simply because there are more residual salt when only saturated brine is used.
- The spreading speed can be increased to 80 km/h (the legal speed for lorries in Denmark).
- Spreading is identical in up to three lanes simultaneously (3 x 3.5 m). With disc, we do not have a uniform spreading. This experience has been tested and the results shows that out of 57 instance of salt spreading with disc, then 10 times has lost more then 40% of salt and 5 times more than 50%, because of unsymmetrical spreading.

To obtain a success with brine, further consideration will be essential:

- Have knowledge of and prevent stratification when mixing brine, because of rapidly spreading with freshwater instead of prevent stratification will certainly maximise the risk for an accident.
- Have knowledge of the spray speed to the rear from the side nozzles. The speed must be equivalent or higher than the speed of the vehicle forwards.

On the roads on which brine has been used in the County of Funen, brine has been the only salting method used, even in situations involving ice and snow.

With a contribution from the National Agency of Environmental Protection, Epoke, The Road Directorate and The County of Funen, the scope of these particularly measurements have been

continued and extend on the motor way south of Odense in the winter season of 2000/2001. With a strategy that permit to measure the values of Freezing point and residual salt amount, together with relevant parameters as salt concentration, water layer thickness, relative humidity, surface temperature, 24 sensors has been installed to achieve these detailed and definite measuring values.
Also visually observation has been achievable by installing two advanced camera equipped with infrared light to include the spreading at night. The spreading methods were divided as to East bound with pre-wetted salt and west bound with brine. The result from these measurements shows again that Brine is enhanced than pre-wetted salt for anti-icing.

2. Introduction

The purpose of using saturated brine (20 - 23%) for ice clearing is to decrease the use of salt (NaCl), in addition to maintain or increase the level of passibility and safety.
A new technique made it possible to spread brine from a wagon driving with 80 km/hour (50 mile/hour) in one lane to the lanes lying next to it, and it obtains a uniform spreading in all lanes.
The focus on this experiment is to consider the possibility to decrease the consumption of salt with a more improves and advanced method of spreading, as will be with Brine vs. Pre-wetted salt and by either operating with nozzles or disc.

3. Background

In Denmark, gravelling has been abandoned on larger roads several years ago. Gravelling is ineffective.

The gravel or the soil at a shoulder is expensive to remove afterwards as contaminated soil.
Dry salt is only used in a limited amount on larger roads in Denmark, usually only in snow conditions.

Pre-wetted salt has replaced dry salt in Denmark. The salt is mixed with saturated brine immediately before being spread with the spreading disc.

Saturated brine is some places in Denmark used with kombi-spreaders. With kombi- spreaders, it is possible to use either brine or pre-wetted salt. In Denmark, It is a known and accepted knowledge that by spreading brine, the dosage of salt can be further decreased.

In the first test described at Funen County, the use of brine with a dosage 20 ml/m^2 corresponding to 4.6 g NaCl/m^2 has been reliable in most situations. The liquid spreaders used nozzles to spread the brine, without having the option of spreading pre-wetted salt, was a define strategy in the test. The speed of the spreading vehicle could be raised to the speed limit for trucks (80 km/hour).

Snow clearing will only be mention briefly.
Utilising with pre- wetted salt and/or with brine will let the method of preventive spreading of salt before snow is a potential option. While snowing, the snow is removed mechanically by snowploughs. After snowing and snowploughing, salt is spread to remove the rest of the snow. In these situations 15 g/m^2 of pre-wetted salt normally would be used and with saturated brine, we have earlier only been able to use a dosage of 20 ml/m², now we are able to increase the dosage to 40 ml/m².

These tests clearly indicates that dry salt leaves a relatively small amount of residual salt, pre-wetted salt a medium amount, while saturated brine leaves a relatively large amount of residual salt.

County of Funen has in recent years used between 5,000 and 18,000 ton of salt (NaCl) per year, for ice

clearing. In other words, it is between 0.5 and 2 kg/m² traffic area per year.
The amounts are so large that the consumption causes worrying for the ground water. Likewise, there have been investigations showing a negative effect of plantations close to the road.

4. Saturated Brine

The basis idea has been to create a spreading technique that ensures a uniform spreading on 3 traffic lanes – i.e. a 10.5 metre cross section – without disturbing the traffic. This is obtained with a construction, where spreading from a bar accounts for the lane used by the vehicle (about 3.5 metres). Side nozzles pointing backwards obtain spreading of brine on the two adjacent lanes. To prevent atomisation of the jets from the side nozzles has being optimised to spread a continuous thick jet that results in larger drop. Furthermore the nozzles are adjusted so the speed of the jet is the same as or higher than the speed of the wind along the vehicle. This diminishes the influence of the wind. The speed of spreaders is 70 "80" km/h as this is the legal speed for truck driving in Denmark.

The options of regulation have been limited on the prototypes of brine spreaders equipment that Funen County has used up until the winter 2000 -2001. An improvement since we were only able to spread with 20 ml/m² and use either all or none of the side nozzles on the one side of the vehicle. Alternatively, this has resulted in very simple and cheap spreading equipment, considering the performances of a high technology spreaders **.**The driving speed is measured with GPS and radar from this the amount to spread is adjusted. This results in an accurate spreading dosage. Now, County of Funen and the Road Directorate have equipment that can spread from 10 ml/m² to 40 ml/m².

The County of Funen has constructed a mixing Plant with a 280m³ container, where the outlet is from the surface and in the mixing phase the brine is circulated to the bottom of the container. Circulation continues until the surface level has a salt concentration of 20%.

Dissolving of the salt takes place directly in the container. In the container there is mounted a forceful propeller mixer that starts, when mixing is required. When freshwater has been filled in the container, salt is added directly in front of the propeller, which prevents an immediate sedimentation. In practise, the system is functional even though the plant is very simple. Funen County uses vacuum salt for the brine.
The stratification is essential while mixing is on process! Brine has a higher density than freshwater. This lead to a very stable stratification, if saltwater and freshwater are brought together without controlled mixing process. It is the same situation if two portions of brine with different concentrations are brought together.

> ***"If you do not have the know how about stratification and you do not prevent stratification during a mixing process, than of rapidly spreading with freshwater instead of prevent stratification will certainly maximise the risk for an accident"***

In the large mixing plant of Funen County, regularly ground water is used for Brine. Simply because the plant is far from the sea and there is no local lack of ground water. The news media have of course questioned the use of "drinking water" for brine. During the winter, 1999/2000 less than 10.000 m³ of water was spending, covering app. 20% of the required need for the highways.
In a smaller plant, on the island Ærø, seawater is used instead of ground water. This also gives the advantage of 3% salinity in the seawater. This plant has been working for 2 years without any problems.
Other means of supplying water has been taken into consideration. The used water could also be an industrial waste product, containing e.g. $CaCl_2$ or another de-icing chemical.

5. THE TEST PERIOD 1998 - 1999

Accomplished of tests have been on highways with two lanes. The climate is typical coastal and the roads are less than 100 m above sea level. The roads are typical Danish hot rolled asphalt concrete roads, with a wearing course of max. 8 mm gravel size at the measuring points. The measuring points are placed on rural roads and chosen to give a reasonable uniformity between the brine spread sections and the reference sections for the sake of geographical orientation, distance to the coast, type and age of the wearing course and intensity of the traffic are as following:

Brine sections:	Road no. 206, km 8.0 and 8.5 (Annual average daily traffic) ADT = 7200 (Equivalent average daily 10 tons axles) E_{10} = 575 Road no.714 as reference. Road no.602, km 54.0 and 54.5; ADT = 1300; E_{10} = 50 Road no.730 as reference.
Pre-wetted salt sections:	Road no.714, km 8.8 and 9.3; ADT = 5300; E_{10} = 250 Road no.730, km 3.0 and 3.5; ADT = 1900; E_{10} = 110.

During the test, salt spreading has been following the usual guidelines in County of Funen. Preventive de-icing is with a dosage of 10 g/m² pre-wetted salt (7.6 gram NaCl) or 20 ml/m² brine (4.6 gram NaCl).
Measurements are achieved from six spots across the road at the measuring points. The spots are placed on ½ m, 1½ m and 2½ m from the centreline of the road. The measurements are additionally repeated 500 m from the first spots. Measurements are obtained 2, 5 and 10 hours after spreading of salt/- brine. At every new quantity, the measurement points are moved 10 metres down the road to avoid interactions from the previous measurement. The amount of residual salt is performed by the electric power of resistance with a so-called salt stick (SOBO 20) SOBO 20 - a device for the rapid measurement of the quantity of salt on the road surface and the results are given in whole figures as g/m². The results are written in a paper frames and later saved in a computer database.

6. TEST RESULTS 1998-99

Totally, app.1800 measurements of residual salt were obtained during the winter 1998-1999. The results from these measurements have been analysed in several ways to gain knowledge of, how salt is degraded/removed dependent on the spreading method and traffic intensity.

During the examination of results from a cross section (data set), we found a variation between 15 and 50%**.** The following statistical analyses were performed under the assumption that the results from the cross sections 500 metres apart are the same for the sake of the spreading and degradation of salt.
Data from the situations with preventive saltspreading because of expected frost has been the subject of an analysis of variance with the following result: 80 % correlation and 1 g/m² variance on the means of every single data set. (This indicates a good accordance between the two cross section results).
The conclusion according to this is *"**that the measurements of residual salt give a useful picture of the residual amounts on the roadway"***
From the many single measurements that have been obtained, a collective statistical analysis of the methods of spreading and the distribution of salt has been carried out simply by comparing the mean values of all the residual salt measurements 2 hours after the spreading.

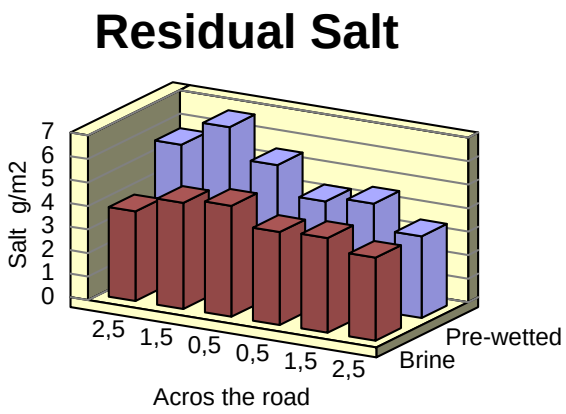


Figure 1 Cross distribution 2 hours after spreading.

"Please noticed that the dosage has been 7.6 g NaCl/m^2 as pre-wetted and only 4.6 g NaCl/m^2 as brine"

It is obvious that the brine spreader performs the most even distribution across the road. Here with pre-wetted 2 hours after spreading we have already vanished 20% of the salt (and only 5% with Brine) because of unsymmetrical (uneven) spreading.
The following models and diagrams are based on the mean value of the 12- salt stick measurements (SOBO 20) that have been obtained at the same time at each measure location (without thinking of the unsymmetrical spreading). The models include data from the preventive actions against slippery roads, but not against snow or glaze.

The model for degradation of salt, primarily as a function of time [2] is an analysis of variance, including road no., time and a simple traffic model (only differentiating between low and high traffic periods).

The model shows only little dependence of residual salt to traffic. See table 1.

Table 1 Relative amount of residual salt as a function of time and traffic intensity

	Low traffic periods			High traffic periods		
Road no. / method	**2 hours**	**5 hours**	**10 hours**	**2 hours**	**5 hours**	**10 hours**
206 / brine	**0,89**	**0,69**	**0,47**	**0,84**	**0,64**	**0,42**
714 / pre-wetted salt	**0,68**	**0,54**	**0,38**	**0,54**	**0,40**	**0,25**

The analysis shows statistical significance for the mean value of the relative residual salt is higher for brine than pre-wetted salt.
This result is supported by another analysis at the same. It showed a strong significance (>99%) that the difference between the two methods is not coincidental, and that brine spreading results in general higher relative residual salt amount on the roads [3].

If a linear or exponential regression analysis is carried out compared to time, the regression curve for degradation of brine on the carriageway [1] for road no. 206 (brine) approaches the following formula:

$$Y = 0{,}88 - 0{,}042 * X$$

This result indicates that approximately 85-90 % of the spread brine ends up on the carriageway.
In the same way the regression curve for road 714 (pre-wettet) approaches the following formula:

$$Y = 0{,}63 - 0{,}030 * X$$

This result indicates that approximately 60-65 % of the spread pre-wetted salt ends up on the carriageway.

In this part the results of the linear regression analyses has importance with the traffic intensities (TI) for the residual salt quantity [4]. TI is a dimension of vehicles passing.

The analysis has made separately on each road. According to table 2, it becomes evident for the road no. 206 and 714, that the traffic intensity (TI) has an effect on the relative residual salt quantity. The degrees of explanation are respectively 16.0 - 18.1%. This make TI to the best clarify single factor. The TI gives no significant explanation to the residual salt quantities on road no. 602 and 730 (low traffic).

This difference of explanation in the variation between the residual salt quantities and between high and low traffic roads can be explained in the following way:

> "*Only relatively high traffic intensities have an effect on the salt degradation. The effect on the low intensity roads is very small compared to other factors"*

Table 2 Explanation of the traffic intensity's variance on the relative residual quantity of salt.

Road no.	Explanation of variance [%]	Level of significance (Pr>F)
206	**16.0**	**<0,0001**
602	**0.8**	**0,57**
714	**18.1**	**<0,0001**
730	**0.2**	**0,75**

For road no. 206 (brine) a formula is made for the residual salt

Residual salt in % = - 0,01% x TI + 88%

For road 714 (pre-wetted salt) this formula is made:

Residual salt in % = - 0,01% x TI + 64%

Apparently, 85-90% of the NaCl from the brine, lands on the carriageway at the spreading and binds so hard to the surface that the traffic must wear it of, while only 60-65% of the NaCl from the pre-wetted salt lands, binds to the surface, and does any good to the traffic.

7. Unsymmetrical (Uneven) Spreading with Disc

According to figure 1, because of unsymmetrical spreading with pre-wetted salt the result will be lost with 20% of each dosage. This result has practically led road authorities to be more focus on adjusting of the salt spreaders, although it is common knowledge that it is very difficult to obtain a symmetric distribution, when using a spreading disc.

At the summer 2000, the Road Directorate and the Counties of Denmark have proved the spreading from 3 salt spreading machines with spreading Disc [5]. The spreading proved was:

- Vacuum Salt as Dry Salt, 30 km/h
- Vacuum Salt as Pre-wetted Salt, 45 km/h
- Vacuum Salt as Pre-wetted Salt, 60 km/h
- Sea Salt as Pre-wetted Salt, 45 km/h
- Sea Salt as Pre-wetted Salt, 60 km/h

All proved as symmetrical spreading from +2 m to -2 m and from +4 m to -4, and as asymmetrical spreading from +3 m to -1 m and from +6 m to -2 m.

The dimension of salt quantity across the spreading zone was a mainly interested value to measure. The results do not seem to be an acceptable illustration of a symmetrical spreading, as we had expected!

Assuming that the definition is, that the salt amount, which is measured on the 2 meter across the wanted centreline, has an even distribution across the road, we have ***out of 57 drives with spreading disc, 10 drives have lost more then 40% of the salt and out of this, 5 drives more than 50%, because of unsymmetrical spreading***. There were no differences between dry salt, pre-wetted salt, vacuum salt or sea salt!

Assuming that occasionally the lost will be 50% because of unsymmetrical spreading, than means that we are required to have 100% more salt than necessary on the road, to insure that there is salt enough on both sides of the road.

A new measurement and presentation was used with highly developed camera that illustrate dimension of salt quantity in percentage on all test field with an area of 10 * 14 square meters. Reference measurement has been made with SOBO 20, just after spreading with disc. In addition, in the table below is shown the 5 measurement with more than 50 % lost salt.

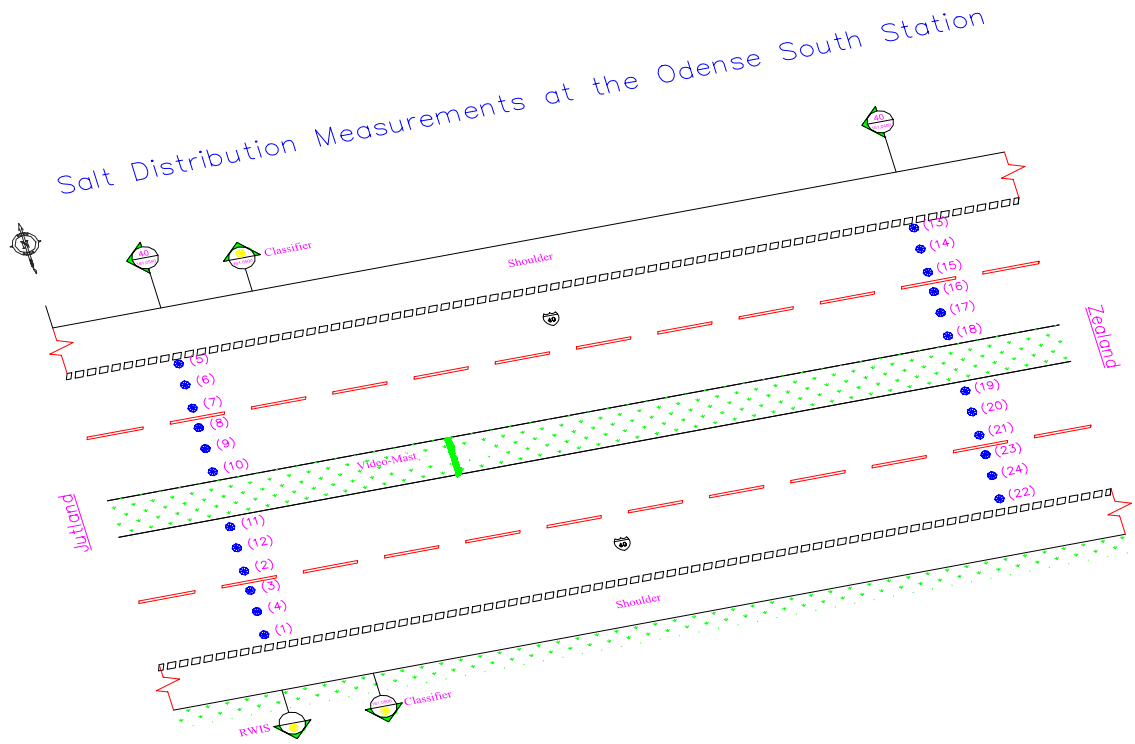
Table 3 Examples with more than 50 % lost because of unsymmetrical spreading with disc.

Salt distribution												
Spreading zone +6 -2												
	+8	+7	+6	+5	+4	+3	+2	+1	-1	-2	-3	-4
Measured salt	**0,5**	**0,3**	**0,3**	**6,8**	**59**	**24,4**	**4,4**	**0,6**	**1,3**	**1,1**	**0,6**	**0,4**
			Here the lost is 63%									
Spreading zone +4 -4												
	+6	+5	+4	+3	+2	+1	-1	-2	-3	-4	-5	-6
Measured salt	**5**	**13,3**	**30**	**30**	**28,5**	**15,7**	**13,7**	**6,7**	**4**	**4**	**3**	**1,7**
			Here the lost is 57%									
Spreading zone +3 -1												
			+5	+4	+3	+2	+1	-1	-2	-3		
Measured salt			**0**	**0**	**1,3**	**5,7**	**22**	**21**	**11,7**	**4**		
			Here the lost is 54%									
Spreading zone +2 -2												
			+4	+3	+2	+1	-1	-2	-3	-4		
Measured salt			**0**	**1**	**5,3**	**18**	**20**	**36**	**23**	**10,7**		
			Here the lost is 56%									
Spreading zone +2 -2												
			+4	+3	+2	+1	-1	-2	-3	-4		
Measured salt			1	1,3	4,7	8,7	15,7	18,3	23	16		
			Here the lost is 57%									

8. TEST RESULTS 2000-01

With a contribution from the National Agency of Environmental Protection, Epoke, The Road Directorate and The County of Funen, the scope of these particularly measurements have been continued and extend on the motor way south of Odense in the winter season of 2000/2001. With a strategy that permit to measure the values of Freezing point and residual salt amount, together with relevant parameters as salt concentration, water layer thickness, relative humidity, surface temperature, 24 sensors has been installed to achieve these detailed and definite measuring values.
Also visually observation has been achievable by installing four advanced camera (two for each site) quipped with infrared light to include the spreading at night. The spreading methods were divided as to East bound with pre-wetted salt and west bound with brine. The result from these measurements shows again that Brine method is improved than pre-wetted salt as for anti- icing.

Figure 2 Presentation of the test field on the motorway



The measurements will contribute to supplementing and extending the model for the influence of traffic on salt breakdown, which was created on the basis of previous measurements. Among other things, this is because the traffic figures for the fast and slow lanes of the motor way are very different. This reality can also be used to reduce salt consumption further.

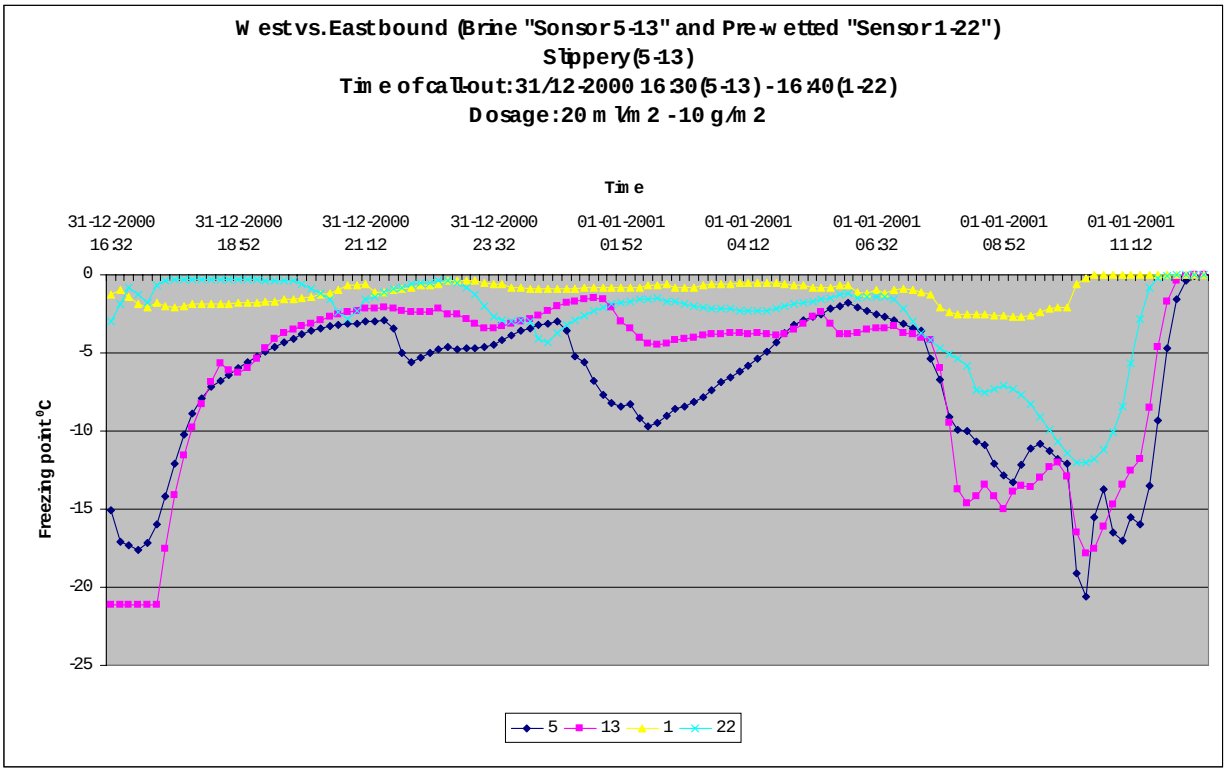


Figure 3 Comparison of freezing point compare for both methods at each bound and respectively for slow lane

Unfortunately, the values of salt amount are not clarified yet, and therefore are still under further validation. But the result and quantity of freezing point still permit us to investigate this questionable experiment.

As you see on both figures (3-4), the results give an advantage for brine, comparing a dosage of 4,6 g NaCl/m^2 for brine with a dosage of 7,6 g NaCl/m^2 for Pre-wetted method.

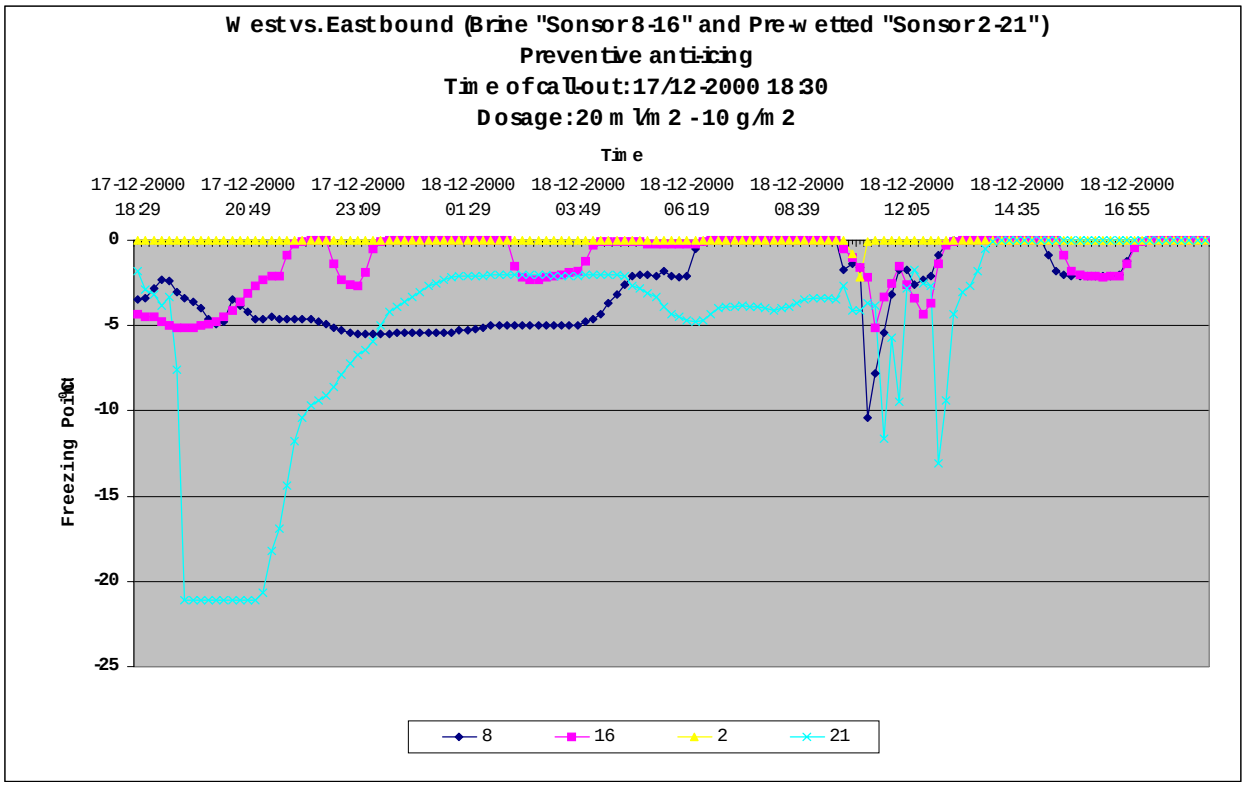


Figure 4 Comparison of freezing point compare for both methods at each bound and respectively for fast lane

Although, the project is still in analysing phase, therefore we are only contributing with our consideration for now.

8.1 Further consideration

8.1.1 Salt amount and date adjustment

The real and exact salt amount has been set in.

At "normal" call-out situations the use of dosage at the westerly lanes is brine 20 ml/m², replying to 4,6 gr. Nacl/m² and at the easterly lane is: Pre-wetted 10 g/m², replying to 7,6 gr. Nacl/m².

At any "hard" call-out situations the use of dosage at the westerly lanes is brine 40 ml/m², replying to 9,2 gr. Nacl/m² and at the easterly lane is: Pre-wetted 15 g/m², replying to 11,4 gr. Nacl/m².

Variable call-outs and dosages are well defined and are used as benchmark for every time of spreading.

8.1.2 Considerations about cross-sectional measurement

The supposition, that the statistical variable Y (distance to axe of road) is normally stributed with equal spreading. The assumption make it probable, that we can apply with average value of these 24 cross-sectional measurements answer to a illustration of residual salt amount in cross section.

The variations that suspend between these single cross-sectional measurements can be caused by:

1. The variation of traffic intensity between these 4 lanes.
2. Systematic deviation in consequence of spreading distribution.
3. Systematic deviation in consequence of direction of motion with spreader.
4. The wind affection crosses the motorway.
5. The road gradient
6. The variation between the two measuring points with 60 m distance.
7. The variation of relative humidity as a function of road temperature.

"At the 1. phase there are no interest for the definite analysis to get exposed the exposition of these above-mentioned variations, therefore we can probability operate the measuring data of these 24 sensor to determine the differences between the two spreading methods".

The dimensions for each single are stated answer to the relative dimensions. There has been calculated average values and standard deviation for each single chosen parameter of these 24 sensors.

8.1.3 Layout of traffic intensity

Base on typical definition of traffic density, the traffic density initially refers to a qualitative statistics variable with 3 level, as Weak, light and heavy.

In this particular project, traffic density is only dependent from the point of spreaders has pass the test field, in consequence of the traffic intensity intended for a day. Therefore, splitting to 3 fixed levels doing subsequent models less strong.

Consequently in this particular case, we introduce the concept of traffic intensity ”TI” and define that as an integral action coefficient of function of traffic load.

9. References (in Danish):

1. Spreading of salt on highways. County of Funen 1999/2000, J. Kr. Fonnesbech and Knud Bjørn Prahl.

2. Analyses of residual salt measurements, December 1999, Henrik Spliid, Denmark.

3. Introductory thoughts of the dependence on the residual salt from the measured traffic and climate parameters. Marts 2000, Thomas Glue, Denmark.

4. Dependence on the residual salt from the traffic. Marts 2000, Thomas Glue, Denmark.

If you want these 4 reports together with a Corel Quattro Pro 8 file, which include all the measured data, please e-mail jkf@vej.fyns-amt.dk. The data is made available in the hope that others can use it in their endeavour to make even better models for degradation of residual salt.

5. Salt spreading. Aarhus Airport, June the 20 to 23, 2000. Freddy Knudsen and Kim Niels Sørensen. Road Directory, Denmark, and County’s of Denmark. ISBN: 87-7923-154-3.