Ice control Technology with 20% brine on highways

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Contents

<u>1. INTRODUCTION</u>

The purpose of using a saturated saline solution (20%) for ice clearing is to decrease the use of salt (NaCl), but at the same time maintain or increase the level of passability and safety.
In this experiment focus is put on the possibility to decrease the use of salt by way of changing the form of spreading.

<u>2. ABSTRACT</u>

In county of Funen, the use of saturated brine (20%) for combating icy roads in situations of frost, ice formation on wet lanes, glaze, and snow has been successful. In the winter of 1998-99, systematic measuring of residual salt from spreading of brine as well as pre-wetted salt was made (reference). A total of 1800 spots were measured for residual salt.

The test results show that saturated brine is spread more evenly across the road. Diagram 1 also shows that a larger amount of salt from the brine is still present on the road 2 hours after the spreading, compared to the use of pre-wetted salt.

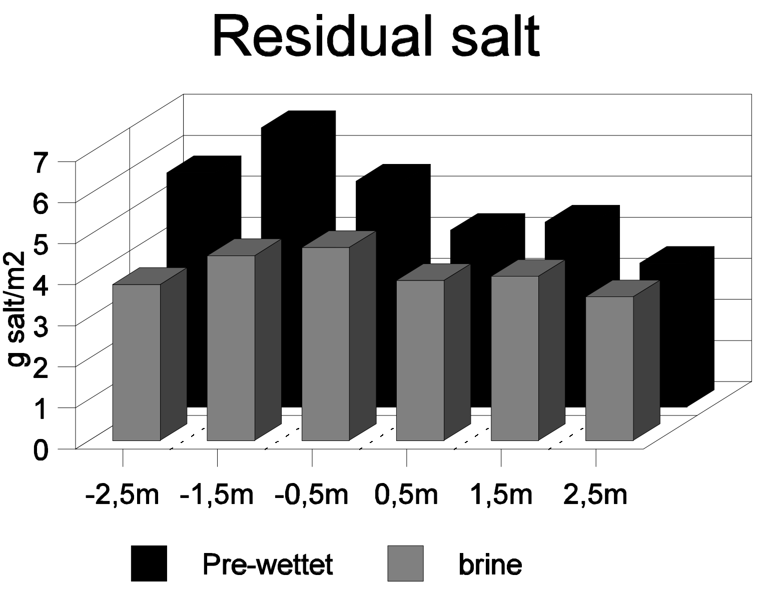


Diagram 1.Cross distribution 2 hours after spreading.
It must be noticed that there has been spread 7.6 g NaCl/m^2 as pre-wetted salt and 4.6 g NaCl/m^2 as brine.

The more even distribution is obtained even though the truck spreading brine is driving with a speed of 70 km/h.

Several statistical analyses have been carried out from the 1800 test results and the following main results have been obtained:

The residual salt measurements give a useable picture of the amounts of residual salt on the carriageway.

That relatively more of the salt from the brine than the pre-wetted salt, is active on the carriageway, is statistically strongly significant, and thereby proven.

About 90% of the salt from the brine are active on the carriageway, but only 60-65% when it comes to the pre-wetted salt.

High traffic intensity has a crucial influence on the degradation of the residual salt.

The following formulas has been obtained

Residual salt (brine) = -0.012% * TI + 88%.

Residual salt (pre-wetted salt) = -0.011% * TI + 64%.

Where TI indicates the number of passing cars.

In practice, spreading of saturated brine works immediately if there is frost or ice on the road, while dry or pre-wetted salt takes time to work.

Likewise it has been shown in practice that saturated brine works in glaze- and snow situations, but in these situations 20 ml (4.6 g/m² NaCl) normally isn't enough.

In county of Funen a very simple mixture of salt and water is made in a 280 m³ container, where it is ensured at the same time that a stratification won't arise in the mixture. Stratification, where freshwater lies above the saltwater, is the most dangerous situation when using saturated brine. If it isn't actively ensured that a stratification don't arise, at some time spreading of freshwater will occur, with a catastrophic result.

To summarise, the use of saturated brine has produced such good results that I expect that county Funen, within the next 10 years will divert to the sole use of this method of ice clearing. At the same time I expect the most used dose to be 20 ml/m² or less, but in special cases it should be necessary to use a 40 ml/m² dose.

3. BACKGROUND

3.1 Gravelling

In Denmark gravelling has been abandoned on larger roads several years ago. Gravelling isn't effective. The gravel or the soil in the shoulder is expensive to remove afterwards as contaminated soil. When gravelling, a large amount of salt is used in the gravel to prevent freezing anyway.

3.2 Dry salt

Dry salt is only used in a limited amount on larger roads in Denmark, usually only in snow conditions. For preventive spreading dry salt is useless. It is blown of the road before having any effect on the road conditions. Formerly 40 g/m^2 of dry salt was spread at a time. The speed of the spreading vehicle must be low to avoid turbulence, which instantly will blow off the salt from the road.

3.3 Pre-wetted salt

Pre-wetted salt has replaced dry salt in Denmark. The salt is mixed with saturated brine immediately before being spread at the spreading disc. In this way the salt is wet and will quickly bind to the road. Usually 10 g/m^2 will be spread - that is 7 g of dry salt and 3 g of brine - a total of 7.6 g/m^2 of NaCl. The speed of the spreading vehicle can be raised compared to dry salt spreading, but the speed must be lower than the legal speed limit for trucks.

3.4 Saturated brine

Saturated brine is some places used in combi spreaders. In combi spreaders it is possible to use either brine or pre-wetted salt. It is generally accepted in Denmark that by spreading brine the dose of salt can be further decreased. In the test here described, the use of 20 ml/m^2 corresponding to 4.6 g NaCl/m^2 has been consistent. Additionally liquid spreaders without the option of spreading pre-wetted salt, has been used in the test. The speed of the spreading vehicle can be raiset to the speed limit for trucks (70 km/hour).

3.5 Snow clearing

Snow clearing will only be mentioned briefly. Preventive spreading of salt before snow is attempted using pre- wetted salt and brine. While snowing, the snow is removed mechanically by snowploughs. After snowing has stopped, 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. With saturated brine, we have only been able to use a dose of 20 ml/m^2. If this hasn't been enough, an extra round has been driven after end of snowing.

3.6 Previous experiments

It is known that other tests has shown the residual amount of salt after 1000 vehicle passings, after spreading of dry salt, pre-wetted salt and saturated brine respectively. This 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.

3.7 Salt consumption

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/m^2 traffic area per year.
At one normal preventive pre-wetted salt spreading, 7.6 g/m^2 NaCl is spread.
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.

3.8 Substitutes for NaCl.

The use of NaCl is dominating in ice clearing in Denmark, because of the relatively low price and its efficiency. Further more it’s an advantage that NaCl is well known by everybody as salt. Therefore it is not regarded as being poisonous.
These advantages make it difficult for an alternative to NaCl to make it into the market. If a change in the spreading system can lower the used amount, then the more expensive CMA (calcium magnesium acetate) could be a realistic alternative.

4. SATURATED BRINE.

4.1 Prejudices.

Despite the knowledge of spreading of saturated brine results in a relative high amount of residual salt on the carriageway, the use has not become generally accepted. This is supposedly because of some prejudices against the use of brine. In the following I will go through some of these prejudices.

4.1.1 "*Frozen water is ice and therefore slippery*".

The obvious truth in this headline makes spreading of brine psychologically unattractive.

"Frozen water is the very thing that causes problems on slippery roads"!

"The addition of water requires even more salt to make sure that the concentration of salt is sufficient to maintain the water in a liquid state, even though the temperature is below zero degree Celsius"!

A more detailed study of the phase diagram of brine shows that the amount of added water is insignificant during normal conditions of salt spreading. Only at really low temperatures the extra water is of importance, and at this circumstances, further examinations is required, to clarify how to avoid slippery roads, when using prewetted salt as well as brine.

4.1.2 "*Brine can only be evenly spread using a bar with nozzles, therefore the brine can only be added on the traffic lane covered by the spreading vehicle or by blocking the traffic by using a bar covering several lanes".*

This was our first experience too, but successively we have constructed nozzles, mounted on the side of the spreading vehicle, pointing backwards. In this way brine is spread by the bar on the lane covered by the spreading vehicle and by the nozzles on the adjacent lanes. The spreading has been done with an absolutely satisfactory distribution.

4.1.3 "*A carriageway with brine can suddenly become slippery*!"

No! I am sure the postulat is a result of stratification. The postulate may have risen from experiences with accidental spreading of freshwater. If by accident there has been added freshwater to the brine tank, the result will be a very stable stratification. Consequently freshwater will be spread at a given time. This stratification is mentioned in the section about the mixing of the brine. A sufficient mixing of the solution will prevent a successive stratification until more freshwater or salt is added.

4.2 Spreading technique

The basis idea has been to create a spreading technique that ensures a uniform spreading on 3 traffic lanes – i.e. a 10.5 meter 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 (c. 3.5 meters). Spreading of brine on the two adjacent lanes is obtained by sidenozzles pointing backwards. To prevent atomisation of the jets from the sidenozzles, they have been optimised to spread a continuos thick jet that results in larger drops. Furthermore the nozzles are adjusted so the speed of the jet is the same as the speed of the wind along the vehicle. This diminishes the influence of the wind. The driving speed while spreading is 70 km/h as this is the legal speed for truck driving in Denmark. Because of the variations on the speed that the driver is actually driving, future spreading nozzles will have to be dimensioned for correct spreading at up till 80 km/h driving speed.

On the prototypes of brine spreading equipment that Funen County has used up until now the options of regulation have been limited. There can only be spread 20 ml/m² and either all or none of the sidenozzles on the one side of the vehicle can be used. On the other hand this has resulted in very simple and cheap spreading equipment. The driving speed is measured with radar and from this the amount to spread is adjusted. This results in an accurate spreading dose.

<u>4.3 Mixing of brine</u>

Brine has a higher density than freshwater. This can lead to a very stable stratification, if saltwater and freshwater is brought together without controlled mixing. It is the same situation if two portions of brine with different concentrations are brought together.

<u>4.3.1 Tests on stratification</u>

To examine the stability of the stratification we constructed a small pilot plant. The plant consists of a 6-litre container with the possibility to create circulation and pump water in and out of the container. The pump capacity is c. 0.1 litre/min (6 litre/h). This means that the "mean retention time" of water in the container is about 1 hour. The container was added 3 litre of saturated brine which amounts to 8 cm in the tank and then 3 litre of freshwater. To visualise the experiment the brine was dyed blue.

Test data:
1999-08-22 13:10. Inlet and outlet of water is in the bottom of the container.

Time	cm of brine	
13:10	8.0	
14:05	8.5	
15:20	9.0	Mean = 0.4 cm/h
16:20	9.4	
17:20	9.8	
20:50	11.3	

1999-08-22, at 20:53.Chanching the inlet to the top of the container (through the freshwater.

20:53	11.3	
20:59	8.5	
21:03	7.8	Mean = 0.4 cm/min
21:07	5.0	
21:10	4.3	

During the test the outlet of water was in the bottom of the container from the brine layer. For 8 hours the brine was lead into the bottom of the container to ensure maximum circulation. This resulted in movement of the borderline between salt- and freshwater by 0.4 cm/h.

After 8 hours the set up was changed to pumping the brine from the bottom into the top of the container (brine into freshwater). This resulted in movement of the borderline by 0.4 cm/min. The test shows that the mixing is 60 times faster when adding the relative high-density brine into the low density freshwater. Of cource the result has to be the same if the low density freshwater has been adding in the bottom into the relative high density brine.

In a real size mixing plant the stratification is even more stable. The reason is that the test pump was placed in the bottom of the container (in the brine layer). The pump has caused some turbulence resulting in a significant higher mixing in the beginning of the test.

4.3.2 Practical construction of a mixing plant.

Funen County has constructed a mixing plant with a 280-m³ container, where the outlet is from the surface and in the mixing phase the brine is recirculated to the bottom of the container. Recirculation continues till the surface level has a salt concentration of 20%. Theoretically the stratification may not be completely avoided, but the result is that brine used for spreading has a salt concentration of at least 20%. In practise it has been shown that no stratification occur.

Dissolving of the salt takes place directly in the container. In the container there is mounted a forceful propeller mixer that is started, when mixing is required. When freshwater has been filled into the container, salt is added directly in front of the propeller, which prevent an immediate sedimentation. In practise the system functions even though the plant is very simple. Funen County uses vacuum salt for the brine.

4.4 Water for mixing

In the large mixing plant of Funen County ground water is used for Brine. This is because the plant is far from the sea and there is no local lack of ground water. The news medias have of course questioned the use of “drinking water” for brine. During the winter 1999/2000 less than 10.000 m³ of water was used, covering c. 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 that there is up till 3% salinity in the seawater. This plant has been working for 2 years without any problems.

Other means of supplying water is taken into consideration. The used water could be an industrial waste product, containing e.g. $CaCl_2$ or another de-icing chemical.

5. THE TEST PERIODE 1998 - 1999

5.1 Test sections

The tests have been carried out on single carriageway highways with 2 lanes with respectively heavy and light traffic. 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 section and the reference section for the sake of geographical orientation, distance to the coast, type and age of the wearing course and intensity of the traffic

Brine section:	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 section:	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.

5.2 Call for salt spreading.

During the test salt spreading has been following the usual guidelines in County of Funen. In most cases the calls for salt spreading have been made for preventive reasons because of the expectation of slippery roads. Calls for salt spreading is performed centrally on the whole county and are based on the Danish early ice warning system with measuring stations all over the county. The measurements are combined with models and weather forecasts at the Danish Meteorological Institute. Preventive salt spreading is normally performed with 10 g/m² pre-wetted salt (7.6 gram NaCl) or 20 ml/m² brine (4.6 gram NaCl).

5.3 Measurement of residual salt.

Measurements are obtained from 6 spots across the road at the measuring points. The spots are placed ½ m, 1½ m and 2½ m from the centreline of the road. The measurements are repeated 500 m further down the road. Measurements are obtained 2; 5 and 10 hours after spreading of salt/brine. At every new measurement the measurement point is moved 10 meters 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 saltstick (SOBO 20) and the results are given in whole figures as g/m². The results are written in a paper form and later saved in a database.

6. TEST RESULTS

Totally c. 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.

6.1 Inaccuracies

The measuring method involves a wide variation of single results. Just from the readout there is an accuracy of ± ½ g/m^2 at values of residual salt, frequently measured below 5 g/m^2. When analysing results from a cross section (data set) we find a variation between 15 and 50%**.** The following statistical analyses are performed under the assumption that the results from the cross sections 500 meters apart are the same for the sake of the spreading and degradation of salt.

Data from the situations with preventive salt spreading because of expected frost have 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 2 cross section results).
The conclusion according to this is "**that the measurements of residual salt gives a useful picture of the residual amounts on the roadway".**

6.2 Cross distribution of the salt on the road.
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.

The results are presented in diagram 1.

It is obvious that the brine spreader performs the most even distribution across the road. In Funen County this has practically led to 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.

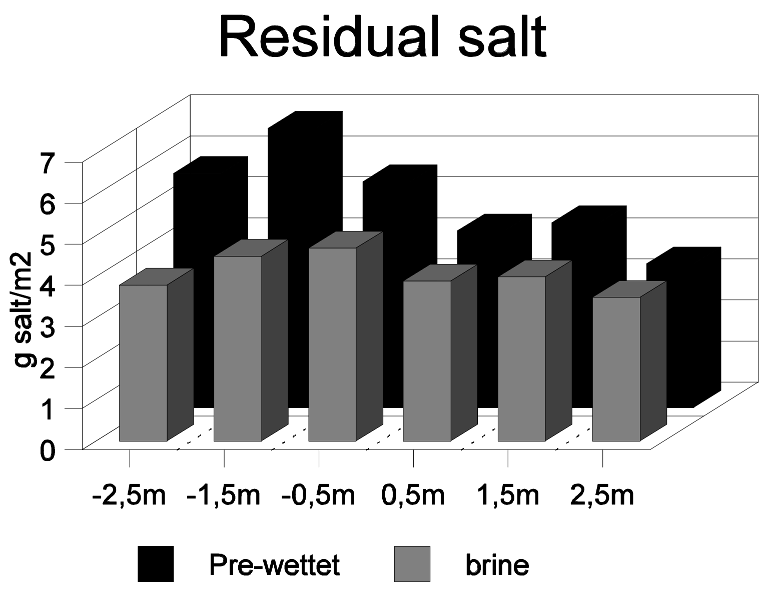


Diagram 1. Cross distribution 2 hours after spreading. It's emphasised that the amount of spread out NaCl is 7.6 g/m² for pre-wetted salt and 4.6 g/m² for brine.

From the mean values of residual salt 2 hours after spreading, it is evident that brine leaves 89% residual salt, while pre-wetted salt only leaves 66%. That is to say, when using brine the necessary amount of NaCl can be reduced by approximately 26% [(89-66)/89*100%].

6.3 Models
The following models and diagrams are based on the mean value of the 12 saltstick measurements that have been obtained at the same time at each measure location.

The data are collected in sets, including all values belonging to the same spread incident. The models include data from the preventive actions against slippery roads, but not against snow or glaze.

6.3.1 Model for degradation of salt, primarily as a function of time [2].

The model 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.

	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	0,68	0,54	0,38	0,54	0,40	0,25

Table 1. Relative amount of residual salt as a function of time and traffic. Only observations from the preventive actions against slippery roads, but not against snow or glaze.

The analysis shows statistical significance for the mean value of the relative residual salt is higher for brine than pre-wetted salt. The difference between the relative residual salt of the to methods amounts to 0.17 + 0.05 g/m^2 (95% interval of confi-dence).

This result is supported by another analysis on the same. It showed a strong signifi-cance (>99%) that the difference between the 2 methods is not coincidental, and that brine spreading results in a generally higher relative residual salt amount on the roads [3].

The table shows that pre-wetted salt spreading apparently is most influenced by traffic. At low traffic counts the relative loss of salt at 2 hours is “21%” higher than by brine spreading. At high traffic counts the difference is “30%”. If the figures are interpreted directly it means that at high traffic counts the amount of NaCl spread as brine can be reduced by 36% and still the residual amount of salt after 2 hours is at the same level as for pre-wetted salt.

The difference between the 2 methods is at the same level or even bigger after 10 hours, namely 40%. From these figures it may be assumed that the degradation of salt by both methods follows the same pattern after 2 hours. This is supported by the observation that pre-wetted salt after 2 hours has been dissolved and become a “brine”. The analysis of variance does not show that these figures are statistical significant. Another model [4] that includes the variation of traffic during the day will later show the same tendency in a statistical significant way.

6.3.2 Degradation of brine on the carriageway [1].

If a linear or exponential regression analysis is carried out compared to time, the following curves and equations will be obtained.

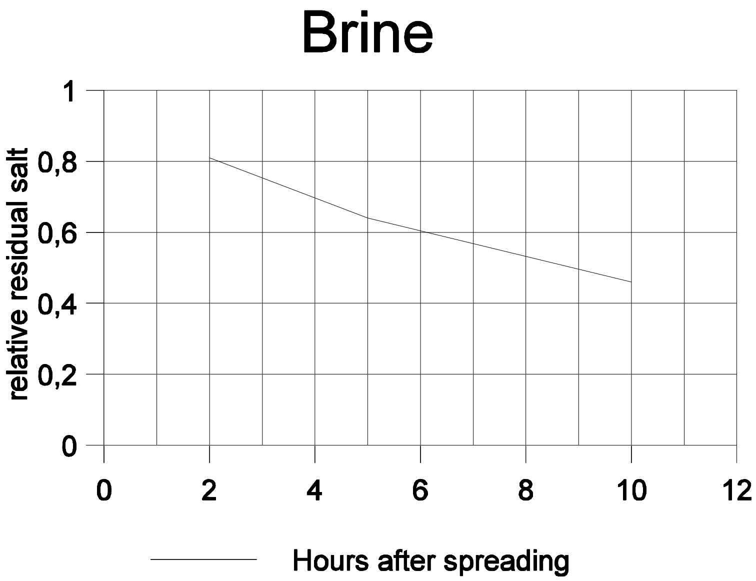


Figure 1 Regression curves for brine on road no. 206.

The regression curve for road no. 206 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.

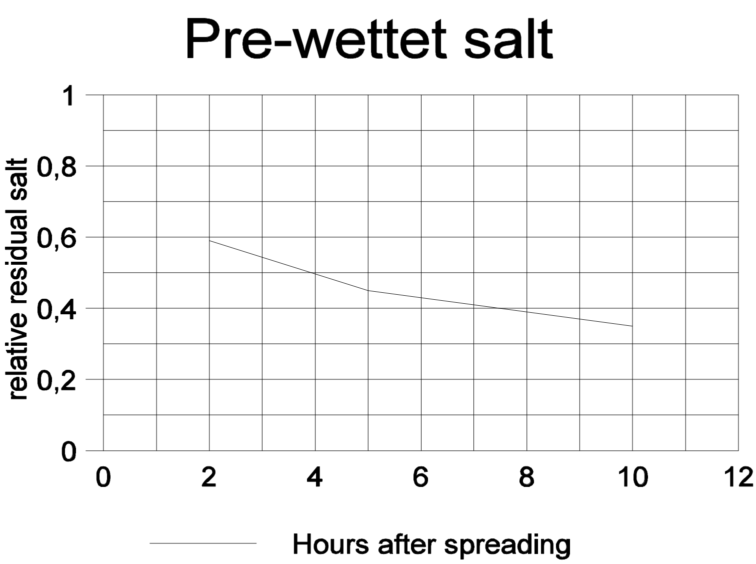


Figure 2 Regression curve for pre-wetted salt on road no. 714

The regression curve for road 714 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.

6.3.3 Salt degradation as a function of the traffic intensity. [4]

In this section the results of the linear regression analyses on importance of the traffic intensities for the residual salt quantity.

The analysis is made separately on each road. From table 2 it becomes evident for the roads nos. 206 and 714, that the traffic intensity (TI) has an effect on the relative residual salt quantity. The degrees of explanation are 16.9 and 18.1% respectively. This makes TI to the best explicative single factor. The TI gives no significant explanation to the residual salt quantities on road nos. 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 interpreted 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.

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

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

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

$$\text{Residual salt in \%} = - 0{,}012\% \times TI + 88\%$$

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

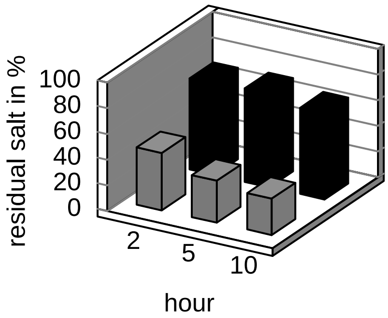
$$\text{Residual salt in \%} = - 0{,}011\% \times TI + 64\%$$

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 and binds to the surface and does any good to the traffic.

7. DIAGRAMS FROM SPECIAL SITUATIONS.

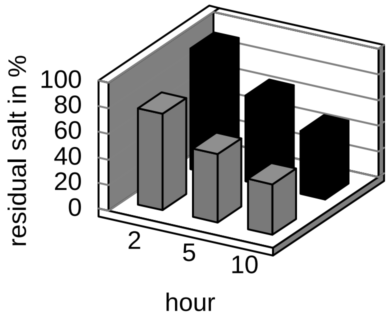
21 november 7:00 a.m.

grey pre-wettet, black brine



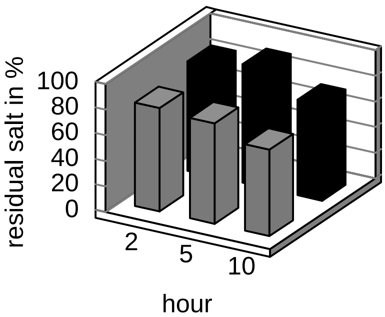
24 november 3:00 a.m.

grey pre-wettet, black brine



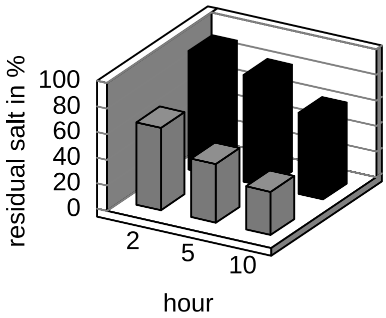
30 november 7:00 p.m.

grey pre-wettet, black brine



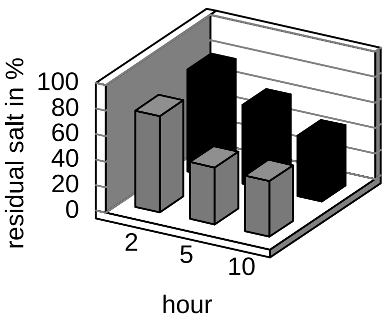
2 december 3:00 a.m.

grey pre-wettet, black brine



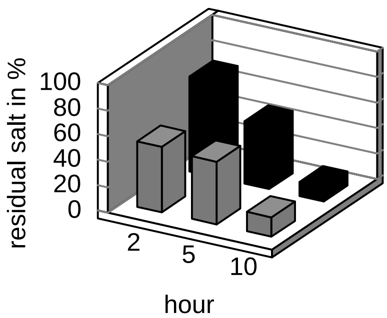
3 december 4:00 a.m.

grey pre-wettet, black brine



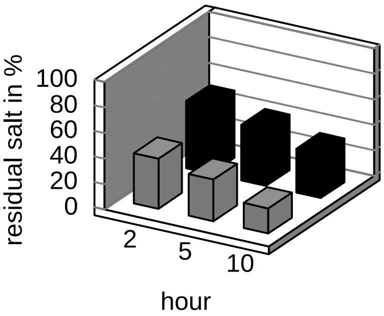
20 december 3:00 a.m.

grey pre-wettet, black brine



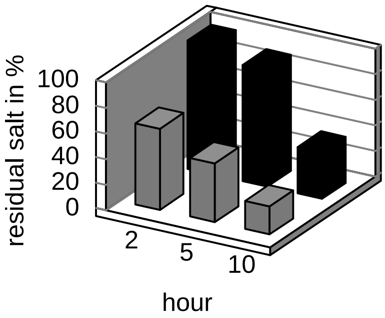
20 december 4:00 p.m.

grey pre-wettet, black brine



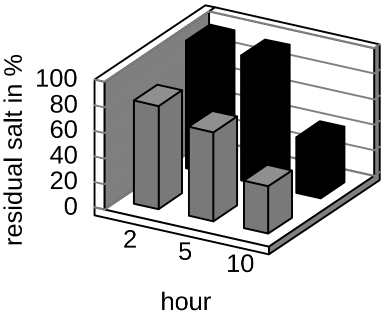
21 december 4:00 a.m.

grey pre-wettet, black brine



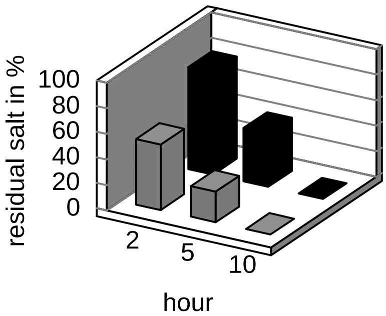
22 december 9:00 a.m.

grey pre-wettet, black brine



29 december 10:00 a.m.

grey pre-wettet, black brine



Only observations from the preventive actions against slippery roads is shown in this diagram.

8. POSTSCRIPT.

Hopefully these experiments can be of help for further development and progress in lowering of the salt consumption while maintaining or increasing the level of passability and safety. For this purpose I invite everybody to come forward with his or her advice, and use the test material that has been obtained anyway.
To contact me, write to e-mail: jkf@vej.fyns-amt.dk

Jens Kr Fonnesbech

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.