

A PROCESSING ANALYSIS OF DIFFERENT SALT TYPES IN DE-ICING APPLICATIONS

Christine Bauer-Vasko, Helmut Flachberger

Institute for Mineral Processing, Department Mineral Resources and Petroleum Engineering, University of Leoben

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1 Abstract

The use of sodium chloride in de-icing applications has become more accepted than using gritting material. Therefore, the differences between the three main types of salts – rock, sea and evaporated salts – should be analysed from a processing point of view. In order to compare the salt types, the moisture content, the particle size distribution, the percentage of insoluble residue, the flowability and the chemical composition of the three types of salt have been determined.

The results showed no significant difference in the moisture content, but the evaporated salts displayed the most uniform and narrow particle size distribution. In addition the evaporated salts contained the lowest amount of insoluble residue next to sea salt. The flowability was measured with a testing device at the Institute for Mineral Processing and the simple determination of the slope angle. The evaporated salt sample showed the best results, even though it was possible to improve the results of the rock salts to a similar result by classifying the salt to a particle size between 0.2 and 0.8 mm. The analysis of the chemical composition of the three salt types showed that the evaporated salts contained the highest sodium chloride and the lowest sulphate content. The potassium, calcium, magnesium and bromide contents were highest for sea salts and well-balanced in rock and evaporated salts.

2 Tasks

With wintry road conditions, two main types of material may be used to increase the safety conditions on streets: material increasing the friction and chemical material which dissolves the ice. This dissolving or de-icing material is mainly sodium chloride, namely rock, sea or evaporated salt. Those different types of salt have different physical and chemical properties. The aim of this paper was to analyse those differences, concerning in

particular the moisture content, the particle size distribution, the insoluble residues, the flowability and the chemical composition of the salt samples.

3 Testing procedure

The samples of the road salts were sub-sampled and photographed to record the first impression of the samples (see figure 1).

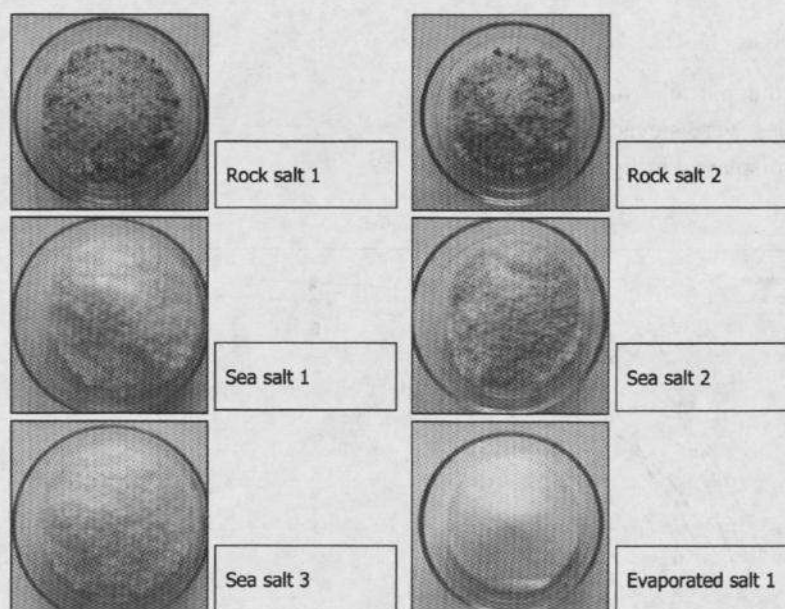


Figure 1: Photographs of selected subsamples

Differences in colour (white to greyish-brown), particle sizes (small to coarse) and moisture content (exhibited by a bad flowability) were observed during the first handling of the samples.

The samples were weighed and dried in a laboratory dryer at 105 °C until mass stability was achieved. After the drying, the samples were weighed again to calculate the moisture content of the sample. The results are given in table 1

3.1 Sample characteristics

	<i>Moisture Content</i>
	<i>[%]</i>
rock salt 1	0.04
rock salt 2	0.06
rock salt 3	0.05
rock salt 4	0.10
rock salt 5	0.10
rock salt 6	1.84
sea salt 1	2.43
sea salt 2	0.26
sea salt 3	0.39
sea salt 4	0.37
sea salt 5	5.23
sea salt 6	0.94
sea salt 7	0.30
evaporated salt 1	0.00
evaporated salt 2	0.05
evaporated salt 3	0.01
evaporated salt 4	1.76
evaporated salt 5	0.01

Table 1: Moisture content of the samples

To determine the particle size distributions, the dried samples were sieved on lab screens. The results are displayed in figure 2.

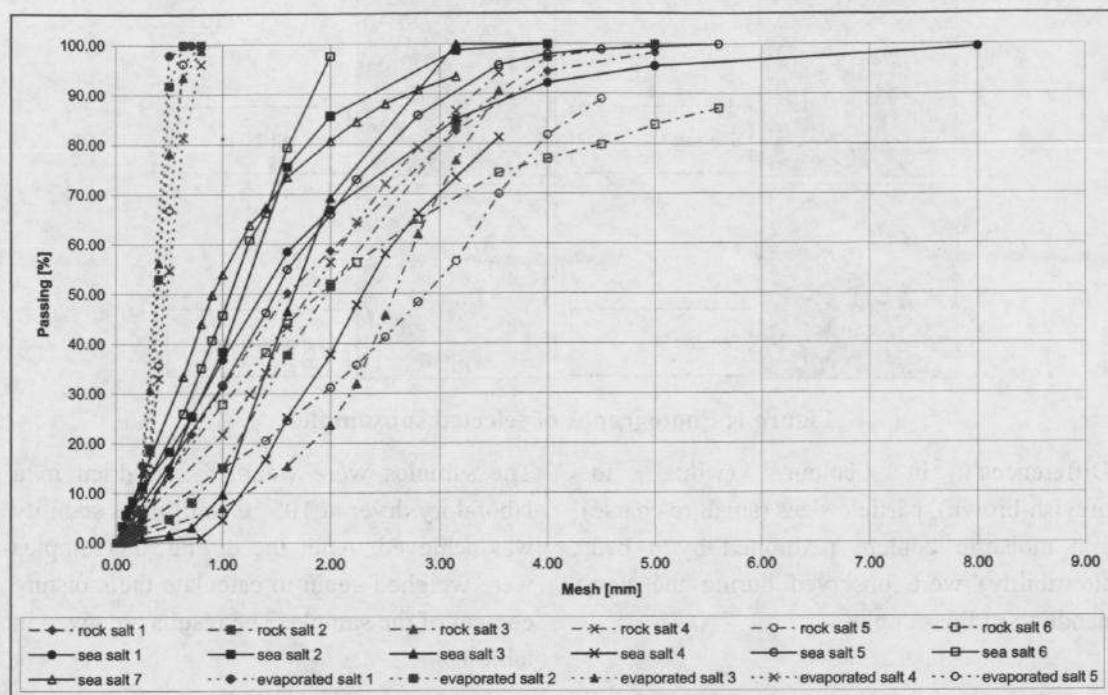


Figure 2: Particle size distributions of the samples.

3.2 Insoluble Residues

The percentage of insoluble residues, e.g. the material, which will not dissolve on the roads, is a very important specification for de-icing salts, as it defines how much material will remain on the streets and may contribute to the formation of respirable dust.

In order to measure this number, filters were dried in the dryer for more than twelve hours at 60 °C. After that, one filter (value A) and a sample of the salt (value B) were weighed. The salt sample was dissolved in about 400 ml of deionised water for at least ten minutes on a

magnetic stirrer. Then the brine was filtered through a membrane filter and the residues were washed with another 500 ml of deionised water. The filter was dried together with the insoluble residues in the dryer at 60 °C for more than twelve hours and weighed afterwards (value C).

The percentage of the insoluble residues is calculated as the ratio between the mass of the insoluble residues after the dryer and the mass of the salt sample before the dissolution test, as seen in formula 1.

$$\% - \text{residue} = \frac{(\text{value C} - \text{value A}) \times 100}{\text{value B}}$$

Formula 1

This test has been carried out with selected salt samples only. The results are given in

table 2. Photographs of the residues on the filters are displayed in figure 3.

	<i>Insoluble Residue</i>
	<i>[%]</i>
rock salt 1	3.74
rock salt 2	2.48
rock salt 3	0.49
rock salt 4	0.62
rock salt 5	3.39
rock salt 6	0.31
sea salt 1	0.07
sea salt 2	0.80
sea salt 3	0.03
sea salt 4	0.02
sea salt 5	0.98
sea salt 6	0.05
sea salt 7	< 0.1
evaporated salt 1	0.00
evaporated salt 2	0.00
evaporated salt 3	0.05
evaporated salt 4	0.00
evaporated salt 5	0.01

Table 2: Results of the percentages of the insoluble residues

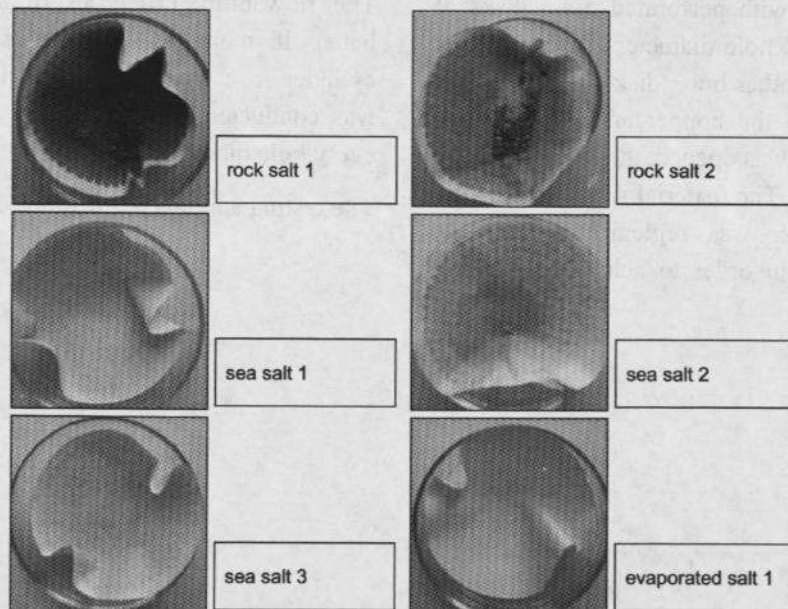


Figure 3: Photographs of the insoluble residues of selected salt samples on the filters

3.3 Flowability

A variety of test procedures are known to enable the measurement of the flowability of powdery material. Two procedures were used to determine the flowability of the road salts:

For the first procedure, a testing device was constructed to measure flow rate (1); a very simple procedure was then carried out to measure the angle of the slope (2).

By the use of these two procedures it is not possible to derive absolute numbers of flowability, but it is possible to compare

various powdery materials analysed by the same procedure. Only selected salt samples were used to determine the flowability.

(1) The first procedure allows the calculation of the flow rate and the FROUDE-number by a defined cylinder with a defined opening.

(2) In the second procedure, the slope angle was measured.

In order to define the flow rate and the FROUDE-number, the bulk density of the samples had to be measured. Therefore, the samples were poured into a cylinder to measure the mass and the volume of the bulk material. After vibrating the cylinder on a vibration table, the volume was measured and the densities were calculated.

The results of the bulk densities are outlined in table 3.

	evaporated salt 1	sea salt 1	sea salt 2	sea salt 3	rock salt 1	rock salt 2
	[g/cm ³]	[g/cm ³]	[g/cm ³]	[g/cm ³]	[g/cm ³]	[g/cm ³]
<i>loose bulk density</i>	1.20	1.11	0.94	0.97	1.20	1.12
<i>vibrated bulk density</i>	1.41	1.34	1.25	1.19	1.43	1.33

Table 3: Loose and vibrated bulk densities of selected salt samples

The testing device consisted of a plastic feed hopper and a glass cylinder, which was closed at the bottom with perforated brass disks of various defined hole diameters. The hole was barred with another brass disk and the sample was filled into the hopper and the cylinder. When the hole was opened, the salt poured out of the cylinder. The material which flowed out of the cylinder was replenished from the hopper above in order to achieve a uniform

flow. Then a sample was taken measuring the time span and the mass of the flowing material. The flowability properties of a sample are better if more material flows out of the cylinder in a smaller time span. The testing was conducted twice with every sample and every hole diameter.

The testing appliance is displayed in figure 4.

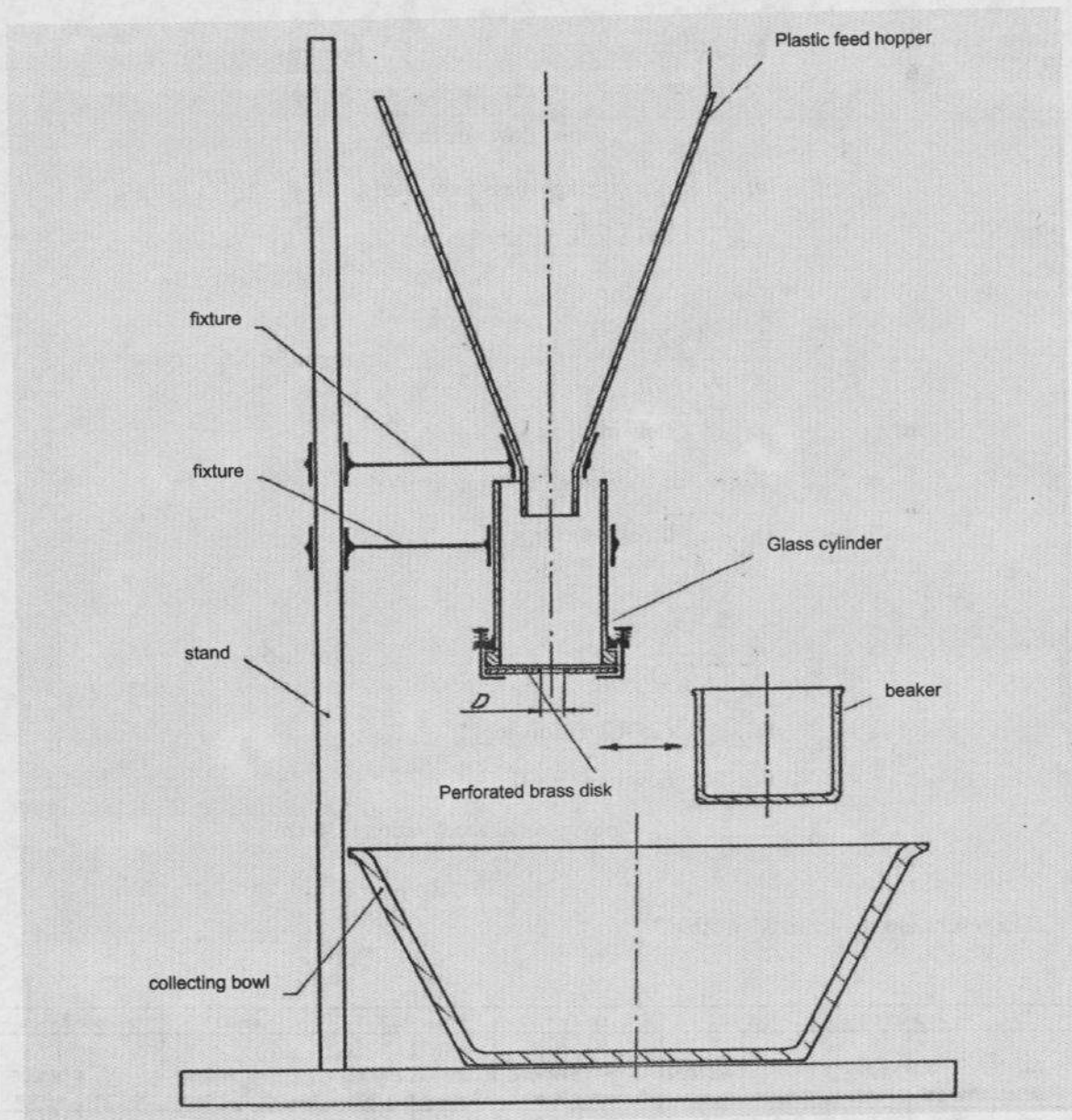


Figure 4: Draft of the testing appliance for the measurement of the flow rate and the FROUDE-number

The calculation was accomplished using the following equations (formulae 2 to 5):

$$\dot{m} = \frac{m}{t}$$

Formula 2

\dot{m} ... mass flow rate [g/s]

m... mass, which flowed out of the cylinder [g]

t... flowing time span [s]

$$\dot{V} = \frac{\overline{\dot{m}}}{\rho_{loose}} \quad \text{Formula 3}$$

\dot{V} ... volume flow rate [cm³/s]

$\overline{\dot{m}}$... average mass flow rate [g/s]

ρ_{loose} ... loose bulk density [g/cm³]

$$v = \frac{4 \times \dot{V}}{D^2 \times \pi} \quad \text{Formula 4}$$

v ... flow rate [cm/s]

\dot{V} ... volume flow rate [cm³/s]

D ... hole diameter [cm]

$$F = \frac{v^2}{g \times D} \quad \text{Formula 5}$$

F ... FROUDE-number [1]

v ... flow rate [cm/s]

g ... gravitational acceleration [918 cm/s²]

The results are summarized in table 3.

	rock salt 1		rock salt 2		sea salt 1		sea salt 2		sea salt 3		evaporated salt 1	
hole diameter	flow rate	FROUDE-number	flow rate	FROUDE-number	flow rate	FROUDE-number	flow rate	FROUDE-number	flow rate	FROUDE-number	flow rate	FROUDE-number
[cm]	[cm/s]	[1]	[cm/s]	[1]	[cm/s]	[1]	[cm/s]	[1]	[cm/s]	[1]	[cm/s]	[1]
3	31.91	0.35	29.49	0.30	-	-	-	-	27.28	0.25	35.10	0.42
2.5	28.02	0.32	25.62	0.27	-	-	-	-	23.96	0.23	35.53	0.51
2	22.69	0.26	19.69	0.20	-	-	-	-	19.63	0.20	33.62	0.58
1.5	16.99	0.20	13.62	0.13	-	-	-	-	14.86	0.15	27.05	0.50
1	-	-	-	-	-	-	-	-	-	-	20.21	0.42
0.75	-	-	-	-	-	-	-	-	-	-	16.71	0.38
0.5	-	-	-	-	-	-	-	-	-	-	12.52	0.32

Table 3: Calculated flow rates and FROUDE-numbers of the salt samples; ["-" indicates that the samples did not flow out of the cylinder at all or that no uniform flow could be achieved]

In comparison to the results of the evaporated salt sample, the rock salt samples and one sea salt sample showed only reduced flowability, and two of the three sea salt samples did not flow out of the cylinder at all. In order to improve the flowability of the rock and sea

salts, the rock salts were classified to a size range of 0.2 to 0.8 mm (comparable to the evaporated salts) and the sea salts were dried in the dryer at 105 °C. These results are outlined in table 4. All results are summarized and displayed in figures 5 and 6.

	rock salt 1		rock salt 2		sea salt 1		sea salt 2	
	0.2/0.8 mm		0.2/0.8 mm		dried		dried	
hole diameter	flow rate	FROUDE-number	flow rate	FROUDE-number	flow rate	FROUDE-number	flow rate	FROUDE-number
[cm]	[cm/s]	[1]	[cm/s]	[1]	[cm/s]	[1]	[cm/s]	[1]
3	34.06	0.39	35.16	0.42	30.28	0.31	32.79	0.37
2.5	37.65	0.58	29.02	0.34	29.76	0.36	32.54	0.43
2	29.98	0.46	28.03	0.40	23.27	0.28	25.25	0.33
1.5	24.44	0.41	23.13	0.36	18.24	0.23	-	-
1	17.23	0.30	16.25	0.27	-	-	-	-
0.75	14.27	0.28	13.54	0.25	-	-	-	-
0.5	10.32	0.22	9.73	0.19	-	-	-	-

Table 4: Calculated flow rates and FROUDE-numbers of the dried and classified salt samples.

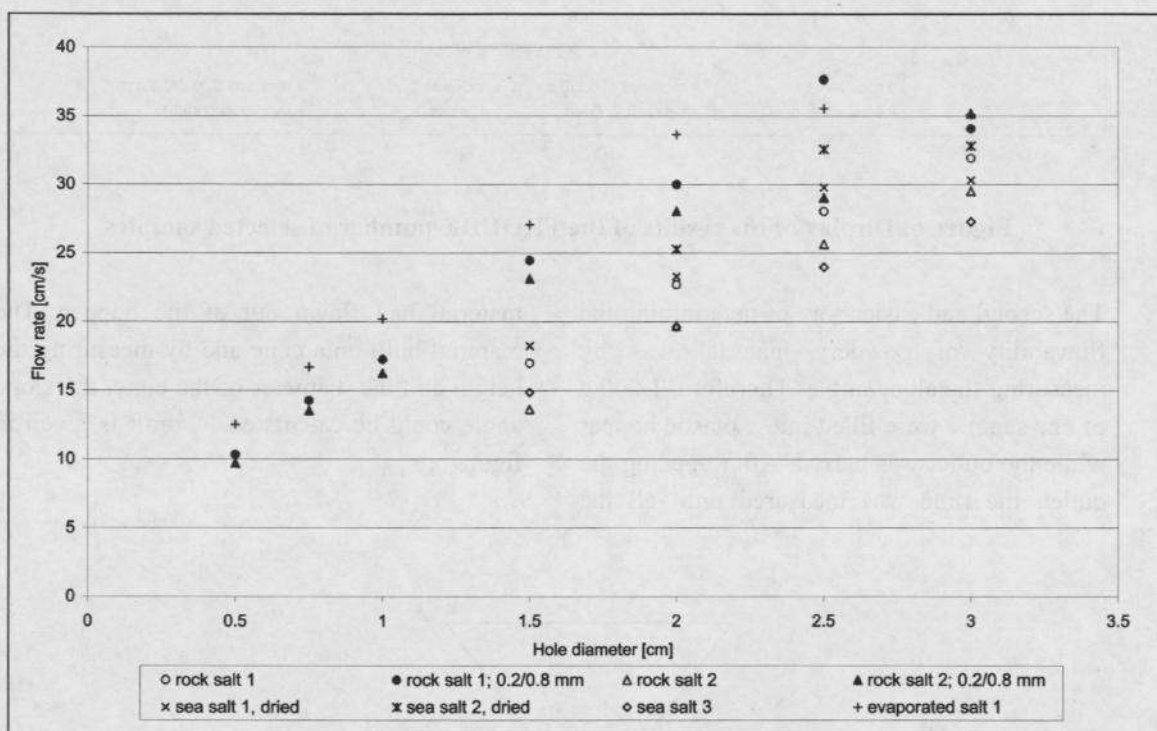


Figure 5: Display of the results of the flow rate of selected samples

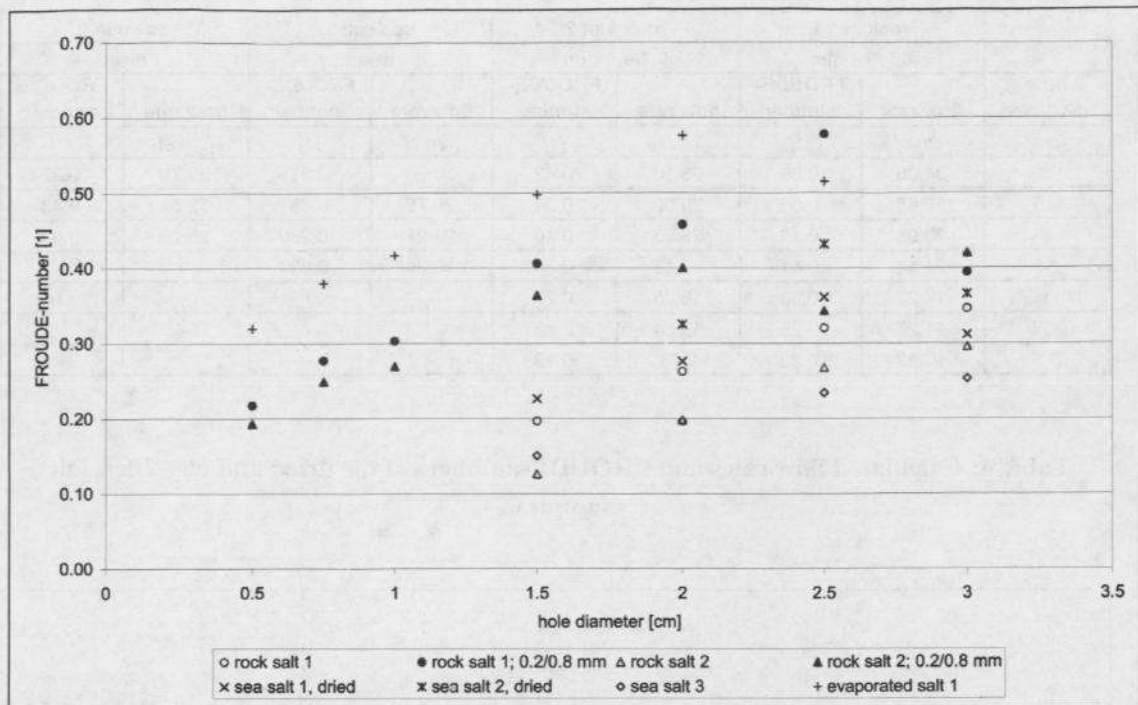


Figure 6: Display of the results of the FROUDE-number of selected samples

The second and easier way of determining the flowability of powdery material was by measuring the slope angle. Therefore, 1,000 g of one sample were filled into a plastic hopper, while the outlet was barred. After opening the outlet, the time was measured until all the

material had flown out of the hopper. The material built up a cone and by measuring the height and the diameter of the cone, the slope angle could be calculated. A draft is given in figure 6.

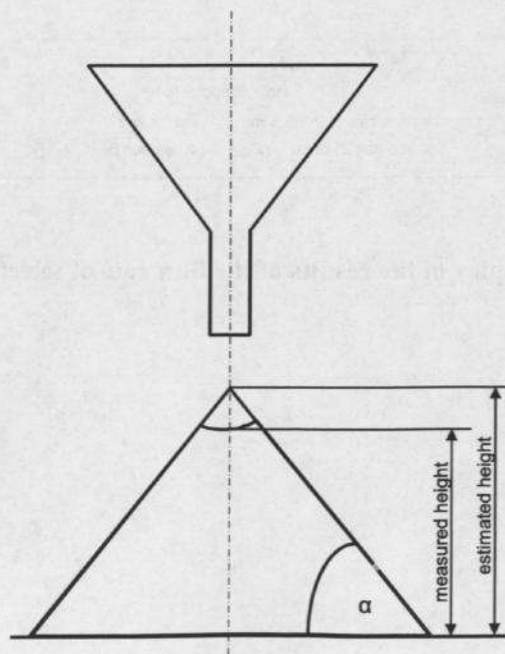


Figure 6: Draft of the testing procedure to determine the slope angle

The last part of the material, which flowed out of the hopper, caved the cone top in. Therefore it was necessary to measure not only the true height of the cone, but also to estimate one as

if the cone had not caved in. This procedure was done three times and the average slope angle was calculated (see table 5).

	time	estimated height	measured height	diameter	estimated slope angle	measured slope angle	estimated average	measured average
	[sec.]	[cm]	[cm]	[cm]	[°]	[°]	[°]	[°]
rock salt 1	5.08	6.3	5.1	20.55	31.51	26.40	32.49	27.32
	5.36	6.5	5.5	20.7	32.13	27.99		
	3.35	6.8	5.3	20.3	33.82	27.57		
rock salt 2	6.02	6.5	5.6	21	31.76	28.07	32.14	28.18
	5.71	6.6	5.7	20.9	32.28	28.61		
	5.63	6.6	5.5	20.8	32.40	27.87		
sea salt 1	-	-	-	-	-	-	-	-
	-	-	-	-	-	-		
	-	-	-	-	-	-		
sea salt 2	-	8.1	8.1	20.3	38.59	38.59	37.64	36.44
	8.85	8.1	7.1	20.7	38.05	34.45		
	-	7.6	7.6	20.7	36.29	36.29		
sea salt 3	7.69	7.6	6.7	20.85	36.09	32.73	36.05	32.16
	7.78	7.6	6.4	20.8	36.16	31.61		
	7.44	7.6	6.6	21	35.90	32.15		
evaporated salt 1	5.32	-	4.66	21.7	-	23.24	-	22.87
	5.38	-	4.77	22.05	-	23.40		
	5.27	-	4.49	22.25	-	21.98		

Table 5: Calculations of the slope angels

The sea salt 1 did not flow out of the hopper.

3.4 Chemical composition

To determine the chemical composition of the salt types, a sub-sample of each salt was sent to K-UTEC, a testing laboratory in Germany. The composition was analysed for the content

of sodium chloride, sulphate, potassium, calcium, magnesium and bromine. The results are outlined in table 6.

	NaCl-content	SO ₄ ²⁻ -content	K-content	Ca-content	Mg-content	Br-content
	[%]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]
rock salt 1	98.33	2,220	300	800	1500	73.3
rock salt 2	97.26	4,860	100	2400	500	66.6
rock salt 3	99.14	1,841	184	554	67	116.8
rock salt 4	98.47	4,644	686	615	129	0.0
rock salt 5	96.32	904	27	470	17	22.6
rock salt 6	96.79	6,704	438	1074	739	33.7
sea salt 1	97.61	1,690	500	800	1500	213.1
sea salt 2	98.22	8,400	1200	4400	700	163.2
sea salt 3	99.19	3,170	600	800	1500	186.5
sea salt 4	98.82	2,756	345	736	755	142.6
sea salt 5	90.63	13,813	4882	5300	491	80.0
sea salt 6	98.20	3,458	444	411	432	n.t.
sea salt 7	98.82	3,746	519	334	421	n.t.
evaporated salt 1	100.00	741	300	800	n.t.	126.5
evaporated salt 2	99.90	158	254	1	0	92.8
evaporated salt 3	99.35	300	2577	48	26	153.6
evaporated salt 4	99.93	284	25	10	1	13.8
evaporated salt 5	99.81	417	289	118	25	84.2

Table 6: Chemical composition of the salt samples [n.t. ... not traceable]

4 Discussion

The drying of the various salt samples did not give definitive results. No salt type contained continuously high moisture content, even though it may be stated that some of the sea salt varieties tended to have a little higher moisture content than the other two varieties. Rising moisture content increases the danger of agglomeration in storage silos. In the literature, the moisture content is limited to assure the flowability of the salt: The Guidelines and Regulations for Transport Affairs published by the Austrian Federal Ministry for Transport, Innovation and Technology mention a limit of 0.5 %, the Swiss Standard is between 2 and maximum 3 % and the German Research Association for Road and Transport Affairs differentiates between silo and hall storage. When using silo storage, the maximum moisture content is 0.6 %, whereas when stored in halls, the salt may contain up to 2 % moisture. The addition of anti-caking agents may enable an increase in moisture content to 4 %.

The analysis of the particle size distributions demonstrated that all salt samples were between 0 and 8 mm in size. The evaporated salt samples were very uniform and in the smallest size range. This property is related to the production process of the salts. In contrast, rock and sea salts appear to be coarser and less uniform.

For the use in winter services the road salts should meet the following requirements regarding particle size distribution: first, a narrow distribution prevents size segregation. Second, the particles should neither be too fine nor too coarse. Very fine particles may lead to agglomeration and wind-blown dispersal off the required point of application; whereas too coarse particles may dissolve the ice more slowly (because of the lower reactive surface) and they may be dispersed too far and off the streets [Badelt, Guidelines and Regulations for Transport Affairs published by the Austrian Federal Ministry for Transport, Innovation and Technology]. In the literature, the particle size distribution is defined by a maximum

percentage per size grades. The Swiss standard mentions a limit of 2 % smaller than 0.15 mm and no particles bigger than 5 mm. The Austrian Guidelines and Regulations for Transport Affairs regulate the particle size distribution to 80 % between 0.16 and 3.15 mm, whereas the proportion smaller than 0.16 mm should be very little. The German Research Association for Road- and Transport Affairs recommends not more than 5 % smaller than 0.16 mm and no particles bigger than 5 mm. Variances up to 2 % are tolerated, but the biggest particle has to be smaller than 8 mm.

The analysis for the insoluble residues demonstrated that the analysed rock salts contained the highest content of insoluble material. The evaporated salt samples were the purest ones.

As mentioned above, the amount of insoluble residues in the road salts is a very important factor. First of all, the insoluble part of the salts does not contribute to the main function, which would be the de-icing of the streets. Since those residues do not dissolve in ice or water, they will remain on the roads. The trouble is that they are usually extremely fine-grained and will therefore account for more respirable dust on the streets. Therefore, the percentage of these residues should be as low as possible [Austrian Guidelines and Regulations for Transport Affairs].

When determining the flowability of the salt samples, the evaporated salt sample exhibited the highest flow rate and FROUDE-number, therefore it may be seen as the best flowing salt, probably because of its uniform and fine particle size distribution and its low moisture content. The flow rate and the FROUDE-number of the rock salts could be improved significantly by classifying the salts to particle sizes of 0.2 to 0.8 mm. By the drying of the two sea salts, the samples started to flow out of the cylinder and flowability could be measured, even though neither the flow rate nor the FROUDE-number can really compete with the results of the evaporated salt sample.

The blockage-free flow of the salt out of storage silos and gritting trucks in winter service is crucial for a smooth operation. If the salt shows a tendency to form agglomerates, anti-caking agents may be added to assure an easy flow. In order to compare different salt types, it is not only important to mention the result of a flowability test, but also the method of measurement.

The analysis of the chemical composition showed significant differences between the types of salt, especially in the content of sodium chloride and sulphate. It is obvious that the evaporated salt types contain the highest amount of sodium chloride and the lowest amount of sulphates. Rock and sea salts are similar to each other, except for "sea salt 5", which contains the lowest amount of sodium chloride and the highest sulphate percentage. The potassium, calcium, magnesium and bromide contents are highest in the sea salts. Rock salts contain more calcium and magnesium than evaporated salt on average, whereas evaporated salt contains more potassium and bromide.

The two most important values are the sodium chloride and sulphate content. The sodium

chloride content determines what percentage of the dispersed salt actually accounts for the dissolution of ice and snow. In comparison to that, the percentage of insoluble residue also includes the amount of other soluble materials which do not contribute to the de-icing of the streets, e.g. gypsum. Therefore, the sodium chloride content is of more importance and is recommended to be minimum 96 % [Swiss Standard, German Research Association for Road- and Transport Affairs].

Another important value is the sulphate content, because water containing sulphates causes a chemical destruction of the concrete surface of the roads. These waters generate alteration and formation of minerals (e.g. ettringite), which results in an increase in volume and therefore a destruction of the concrete. The sulphate content in the water depends on the sulphate content in the dispersed salt, the salt/ice/snow-ratio and the amount of dispersed salt. According to the Austrian Standards Institute, the allowable amount of sulphate in the salts depends on the type of concrete (see table 6).

type of concrete	chemical attack	sulphate content [mg/l]
XA1	low	200 - 600
XA2	medium	600 - 3000
XA3	strong	3000 - 6000

Table 6: Types of concrete and chemical attack

In Austria, concrete XA1 is usually used for road construction. Therefore, the sulphate content should not exceed 200 mg/l. Evaporated salts will never exceed this limit, whereas when using rock or sea salts it is important to control the amount of dispersed salt on the streets because the sulphate content of 200 mg/l may be exceeded if the generated brine becomes concentrated in stagnant puddles.

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