Standardisation of test method for salt spreader: Air flow experiments

**Report 7: Effect of crosswind on salt distribution**

by

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**Summary**

The purpose of this activity was to determine the difference in spreading patterns behind a stationary and a moving salt spreader during calm and at crosswind of 4 - 5 m/s. A slow driving speed of 2.6 km/h was selected for the moving spreader to ensure that the air movements created by the tractor and hopper was minimal.

For the stationary spreader the salt weight distribution curve was symmetrical during calm. The curve was fairly unaffected by the crosswind, but was displaced 1.5 to 2.0 m in the downwind direction.

During calm the salt weight peak of the distribution curve behind the moving spreader was lower and the distribution curve wider than behind the stationary spreader. Exposed to the cross wind the distribution curve for the moving spreader also moved in the downwind direction as for the stationary spreader, but was not symmetrical. Behind the moving spreader the crosswind created a distinct maximum peak of the deposited salt 3.5m downwind of the center line, the reason being that small salt particles were more sensitive to crosswind than large particles.

**Experimental design**

The spreader had two contra-rotating spreader discs at 40 cm above floor. They were fed Rock salt from a hopper via two conveyor belts. A test area of seize 12 by 6 m with concrete floor was divided into 1 by 1m test squares on which the deposited total weight and the distribution on particle size were to be determined.

The layout of the experimental area is shown in **figure 1**. The area was divided into five bands behind a reference line and six rows on each side of a center line. The position of each test square was identified by the distance from the center line and the distance behind the reference line. The intersection between the center line and the reference line will be referred to as the reference point where the spreader was placed when it was in its stationary position.

![Figure 1](image-url)

**Figure 1.** Layout of experimental area with a bank of 4 axial fans to the right.
The experiment was a two by two factorial design with spreader stationary or moving during calm or exposed to crosswind. The experiments will be referred to as test 1 through 4 as specified in table 1.

<table>
<thead>
<tr>
<th>Test</th>
<th>Spreader</th>
<th>Crosswind</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stationary</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Stationary</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Moving</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>Moving</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 1. The two by two experimental design.

The crosswind was created by a bank of four axial fans on one side of the test area. Looking from the experimental area towards the fan bank a view of the lay-out is shown in figure 2.

Figure 2. View of the experimental area with the spreader stationary at the reference point.

**Test 1. Salt weight distribution from stationary spreader at no wind**

The salt spreader was placed at the reference point. The spreader discs were run for 30 seconds at a salt setting of 40 (Range 0 to 140). A picture of the resulting salt distribution is shown in figure 3. There is a concentration of deposited salt within 1 m from the reference point and a semicircular concentration arc close to 3 m from the center.

Figure 3. Salt distribution from the stationary spreader at no crosswind.
The salt was collected manually from each test square as shown in figure 4. The salt was saved in numbered buckets for weighing and possible later determination of salt particle size distribution as described in appendix A.

![Figure 4. Manual collection of salt deposited on each test square.](image)

The amount of deposited salt as percent of the total amount collected on the test area is shown in figure 5 as a function of the distance behind the reference line and the distance from the center line. 33% of the total salt weight was collected in the band 3.5 m behind the reference line. Near to the center line most salt was collected 3.5 to 4.5 m behind the reference line. Further away from the center line the maximum was lower and found closer to the reference line.

![Figure 5. Salt weight behind spreader as percent of the total weight for test 1.](image)

The sidewise distribution is shown in figure 6 for each band. The salt weight per test square is calculated as the proportion of the weight on the test square to the total weight collected on the whole test area.

The sum for bands A to E is nearly symmetrical around the center line with a maximum of 18% slightly skewed to row +0.5. For the bands A closest and E farthest from the reference line the distribution is symmetrical at a low level. The effect of the two spreader discs is clearly visible for the distribution at distances of 1.5 to 3.5 m from the reference line. The skew distribution is primarily seen in band D.
Figure 6. Sidewise variation in salt weight as percent of the total weight for test 1.

Crosswind velocities
The four fans used to create crosswind were previously used in a wind tunnel (Strøm & Takai, 2011) as shown in figure 7. The cross section of the wind tunnel was 2.8 by 2.8 m and the average velocity measured at full speed was 5 m/s. The airflow rate could thus be estimated at 2.8x2.8x5x3600=140.000 m$^3$/h or 36.000 m$^3$/h per fan.

Figure 7. The four fans when installed in the wind tunnel

The supply velocity at the outlet surface of one of the fans in the spreading hall was determined using a TSI VelocityCalc Air Velocity Meter model 9555 Series. As shown in figure 8 the velocity varied from a peak of 7.8 m/s near the edge to a low of 0.9 m/s at the center.

By integrating the air velocities across the face of the fan the airflow rate may be estimated to be 35.000 m$^3$/h per fan. This is close to that found in the wind tunnel. Averaged over the fan face area the wind velocity in the core of the air jet from the fan bank may thus be expected to be around 5 m/s.
The wind velocities in the test area were determined with the same TSI Velocity meter as used for fan velocity measurements mentioned above. The velocity sensor was placed at different heights above selected test squares as shown in figure 9. At each measuring point velocity data were collected and saved every 5 seconds for 1 minute, and the mean value of the 12 measurements calculated.

The spreader disc height above floor was 40 cm as previously mentioned. The velocity measurements were therefore primarily focused on heights 20 and 40 cm where the wind was expected primarily to influence the spreading patterns of the salt particles. A few supplementary measurements were collected at heights 10 and 80 cm, however, in order to get a better picture of the wind profile created by the fan bank.

Measurements in all test squares between +5.5 and -5.5 m from the center line were taken at height 40 cm above floor in band C, figure 10. Systematic measurements were also taken at heights 20 and 40 cm in every second row test squares spaced 2 m apart sideways from 5.5 to -3.5 m on both sides of the center line.
Variation in the wind speed across the C band is shown in figure 11. At height 40 cm it is seen that the wind velocity was 5.8 m/s nearest to the fan bank decreasing fairly linearly to 4 m/s at the other side of the test area. At height 20 and 10 cm above the floor the wind velocity was closely following the velocities at height 40 cm except close to the fan bank, where the velocity was lower.

The variation of wind velocity with distance from the reference line is shown in figure 12. The high wind velocity at height 40 cm in band C at -3.5 m from the reference line is seen to be extreme at the center of the experimental area and is quickly falling to an average value at other distances.
The variation of wind velocity with distance from the center line is shown in figure 13. The wind was between 4 and 5 m/s at distances up to 3.5 m from the reference line. The wind was slowest at a distance of 4.5 m behind the reference line.

The average wind velocity in the experimental area at height 40 cm was 4.5 m/s and at height 20 cm slightly lower at 4.3 m/s, table 2. In band C the average velocity was 0.3 to 0.4 m/s higher than the average.

<table>
<thead>
<tr>
<th>Height cm</th>
<th>Avg m/s Test area Band C</th>
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<tbody>
<tr>
<td>40</td>
<td>4,5 4,9</td>
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<tr>
<td>20</td>
<td>4,3 4,6</td>
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</tbody>
</table>

Table 2. Average wind velocity in the experimental area.

The variation of the wind velocity with height in band C is shown in figure 14 at distances -3.5, 0.0 and +3.5 m from the center line. It is seen that the velocity is fairly constant with heights up to 40 cm above floor except for the high wind velocity at height 40cm in band C noticed above in figure 12.
Wind velocities at 80 cm are lower than at heights 10 to 40 cm, but these are not expected to influence the salt distribution.

Figure 14. Average wind profile for band C at distances -3.5, 0.0 and +3.5 from the center line.

**Test 2. Salt weight distribution from stationary spreader exposed to the crosswind**

With the spreader at the reference point, the fans were switched on and the spreader run for 30 seconds with the same settings as used previously for the no wind situation. This resulted in a concentration of deposited salt ca. 1 m from the reference point as in test 1. The concentration arc close to 3 m from the center became however more elliptic with salt concentrated on the downwind side. There was nearly no salt deposited upwind more than 2.5m from the center line as shown in figure 15.

Figure 15. Salt distribution from a stationary spreader with crosswind.

Salt deposited in the different test squares is shown in figure 16 as percentage of the total salt collected on the test area. For the two bands farthest from the spreader the distribution is fairly symmetrical at a low level with a maximum at distance 1.5 m from the center line. The effect of the two spreader discs is clearly visible for the distribution at distances of 1.5 and 2.5 m from the reference line, while the distribution in band D is showing only one distinct maximum 0.5 m downstream from the center line.

The sum of salt deposited in rows from band A through F is skewed with a maximum of 18% at a distance of 2.5 m downwind from the center line.
The effect of crosswind for the stationary spreader is shown in figure 17. At no crosswind (test 1) the maximum salt weight in row +0.5 m was 18 %. Exposed to crosswind (test 2) the maximum salt weight moved 2 m in the downwind direction. For the rest of the curve the displacement was 1.5 to 2 m in the downwind direction.

Test 3. Salt weight distribution behind a moving spreader at no wind
In order to determine the salt distribution behind a moving spreader the tractor with spreader was started some 10 m from the reference line and driven at slow, constant speed for a distance of 40 m passing the experimental area on its way, figure 18. The time for the run was 57 sec. which converts to a driving speed of 0.726 m/s or 2.6 km/h.
The slow driving speed was selected to provide sufficient salt deposits per test square and to secure that large scale turbulence created by the tractor was avoided (Strøm, 2012).

The salt was primarily collected from all test squares in band C. To check how constant the distribution was in the driving direction control samples were also collected in test square A-0.5 and E-0.5, figure 19.

The variation in salt load for the control samples is shown in table 3. Using the salt load in band C as the reference it is seen that the load varied from 104% to 97% over the 4m covered. This is within a measurement accuracy of ±5%.

<table>
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<th>Distance from center, m</th>
<th>+5.5</th>
<th>+4.5</th>
<th>+3.5</th>
<th>+2.5</th>
<th>+1.5</th>
<th>+0.5</th>
<th>-0.5</th>
<th>-1.5</th>
<th>-2.5</th>
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Table 3. Variation in salt load per control test square -0.5 m from the center line in test 3
The distribution behind the moving spreader is shown in figure 20. It is seen that the salt load was symmetrical with a highest salt load of 15% at the center line declining to nearly nothing ±5.5 m from the center line. There was only minor effect of the two spreader discs.

For comparison the distribution behind the stationary (test 1) and the moving spreader (test 3) at calm is shown in figure 21. With the spreader stationary the salt weight peaks at 18%. Behind the moving spreader under the same condition the salt weight curve peaks at 15%, and the curve is wider as the reduction in salt weight near the center line is distributed further out.

Test 4. Salt weight distribution from a moving spreader exposed to crosswind
The effect of wind on the salt distribution behind a moving spreader was determined in the same way as described above for the moving spreader at calm.

The result is shown in figure 22. The distribution curve is skewed in the downwind direction with a fairly flat maximum of 12 to 13% per row at distances between -1.5 and +2.5 m from the center line. A distinct maximum peak of 17% of the deposited salt appeared 3.5m downwind of the center line. The reason for this peak may be that small salt particles are more sensitive to crosswind than large particles.
Figure 22. Sidewise distribution of salt weight behind the moving spreader at calm (test 3) and at crosswind (test 4).

For comparison the difference in salt distribution behind the stationary spreader (test 2) and the moving spreader (test 4), at crosswind is shown in figure 23. In both cases the peak salt load is nearly the same, but the salt load is lower behind the moving spreader from the center line to 2.5 m downstream with the marked maximum peak 3.5 m downwind. The missing salt load near the center line behind the moving spreader is found further downstream at 4.5 – 5.5 m from the center line.

Figure 23. Sidewise distribution of salt weight at crosswind behind the stationary (test 2) and the moving spreader (test 4).

**Basic salt particle sizes**
The salt used for the experiments was Rock salt. The behavior of the salt during spreading was expected to depend on particle size, the small particles being more influenced by crosswind than large particles.
Before, during and after the tests a sample of the salt was taken for determination particle distribution. Before the two experiments with stationary spreader started the sample was taken at point A at the top of the salt hopper. Before, between and after the two experiments with moving spreader the sample taken was a mixture of the salt on the two conveyers at the point where the salt dropped to the spreader discs, figure 22.

Figure 22. A sample of the salt was taken at point A the top of the hopper and at points B on the salt conveyers.

The result of the fractioning of the basic salt is shown in figure 23. There is a noticeable difference between the sample 1 and the samples 2, 3 and 4. Sample 1 is seen to contain a larger weight portion of small particles and less large particles than the other three samples. The particle size distribution in the three other samples is in fair agreement with each other. Sample 2 contains slightly more small particles than sample 3, while sample 4 is an average of the two.

Figure 23. The weight of the basic salt particles collected on the different sieves
Measured particle seize distribution
Determination of the particle size distribution was resource intensive. It was therefore decided to focus on the size distribution in band C for which samples was available for all four tests.

The result is shown in figure 24, where the size distribution for the base salt is also shown for comparison. It is seen that the size distribution from test 1 is similar to sample 1 and that that the size distribution from the tests 3 and 4 is similar to samples 2 - 4. The size distribution for test 2 is somewhere in between sample 1 and samples 2 - 4.

![Figure 24. The weight distribution for different particle sizes of basic salt and salt collected in band C on the floor in the four tests](image)

The two different particle distribution curves found for the base salt may thus not be explained by how the samples were taken. It is more probable that salt with a different salt particle distribution was added before test 2 and that a mixture of the two was used in test 2.

In order to simplify the comparison between the particle distributions salt particle size is divided into only three size groups below: small particles less than 1 mm, medium particles between 1 and 2.8 mm, and large particles larger than 2.8 mm. The composition of the salt using these groups is shown in chronological sequence in figure 25. It is clearly seen that the particle size distribution in the salt collected in test 2 deviates from the rest having a low content of small particles and a large content of medium particles.

The effect of wind on the particle distribution is therefore only valid for the moving spreader in test 3 and 4, having the same basic salt particle distribution. The effect of wind on the particle in tests 1 and 2 is not discussed further.
Effect of crosswind on particle size distribution behind a moving spreader

In figure 26 is shown the sidewise weight distribution on particle size behind the moving spreader at calm. There is only seen a minor effect of the two spreader discs on the distribution for the medium size particles with a nearly flat level of 5% at ±2.5 m from the center line. For the two other particle sizes and for the total weight the distribution is symmetrical with a maximum at or within ±0.5 m from the center line.

The small particles are practically not present further than ±3.5 m from the center line. The medium particles are present up to ±4.5 m and the large particles up to ±5.5 m from the center line.

In figure 27 is shown the sidewise size distribution behind the moving spreader at crosswind. The effect of the crosswind is particularly visible for the small particles which have been concentrated between 2.5 and 5.5 m downwind with a remarkable 5% peak 3.5m downwind of the center line. The
distribution curve for the medium sized particle still have a flat level of 5% that have been moved downstream from -2.5 / +2.5 m to -1.5 / +4.5 m relative to the center line. The downwind limit for the large particles moved 2 m from 5.5m to 3.5 m; the maximum value at 0.5m downwind of the center line is increased from 6.5% to 8.4% of the deposited salt.

The net result is that the total weight curve that was symmetrical at no wind has become unsymmetrical. The crosswind has caused a distinct 16.9% peak 3.5m downstream of the center line. The peak is primarily due to the dislocation of the small particles.

![Figure 27. Distribution of size fractions and total salt deposition in band C 2.5 m behind the moving spreader at crosswind.](image)

**Conclusions**

For the stationary spreader the deposited salt was collected for the whole experimental area.

1. At no wind (test 1) the sidewise the distribution of the total salt was nearly symmetrical with a maximum of 18% at the distance +0.5 m from the center line. For the band closest to and farthest behind the reference line the distribution was symmetrical at a low level. The effect of the two spreaders was clearly visible in the bands B and C (1.5 and 2.5 m behind the reference line).

2. Crosswind was created by a bank of four axial fans. The average wind speed for the whole experimental area was 4.5 m/s at height 40 cm and 4.3 m/s at height 20 cm.

3. The net result of the crosswind (test 2) was that the distribution curve maintained its shape but moved 1.5 to 2.0 m in the downwind direction.

For the moving spreader the deposited salt weight was collected in band C only.

4. The salt load at no wind (test 3) was symmetrical with the highest salt load of 15% at the center line declining to nearly nothing ±5.5 m from the center line. There was only minor visible effect of the two spreader discs.

5. At no wind the salt weight peak of the distribution curve behind the moving spreader was lower and the distribution curve wider than behind the stationary spreader.

6. The average wind velocities in band C were 4.9 m/s at height 40 cm and 4.6 m/s at height 20 cm, i.e. slightly higher than for the whole experimental area. The wind velocity varied linearly from 5.8 m/s nearest to the fan bank decreasing linearly to 4.0 m/s at the other side of the test area. The average wind velocity at the center line was 4.9 m/s.
7. The net result of the crosswind was to move the distribution curve in the downwind direction with a fairly flat maximum of 12% to 13% per row between -1.5 and +2.5 m from the center line. A distinct maximum peak of 17% appeared 3.5 m downwind from the center line.

The distribution of salt particles was dependent on size groups: small particles less than 1 mm, medium particles between 1 and 2.8 mm, and large particles larger than 2.8 mm.

8. Behind the moving spreader at calm the weight distribution was symmetrical relative to the center line. Small particles were practically not present further than ±3.5 m from the center line, medium particles up to ±4.5 m, and the large particles up to ±5.5 m from the center line.

9. Exposed to crosswind the total weight distribution behind the moving spreader became unsymmetrical with a distinct peak 3.5 m downstream from the center line.

10. The small particles were present from 2.5 m downwind from the center line, the medium particles from 2.5 m, and the large particles 3.5 m upstream from the center line. The distinct peak in the total weight distribution was primarily due to the dislocation of the small particles.

11. The effect of the crosswind was particularly visible for the small particles which were concentrated between 2.5 and 5.5 m downwind with a remarkable 5% peak 3.5 m downwind from the center line. The distribution curve for the medium sized particle moved downstream from -2.5 / +2.5 m to -1.5 / +4.5 m relative to the center line. The upwind limit for the large particles moved from -5.5 m to -3.5 m and was deposited further downstream increasing the maximum value at 0.5 m from 6.5% to 8.4% of the deposited salt.

**Literature**

Jan S. Strøm and Hisamitsu Takai, 2011. Standardisation of test method for salt spreader, Air flow experiments. Report 1: Velocity distribution and stability around a scale model salt spreader, Aarhus University, Engineering Centre Bygholm, Test and Development

Strøm, Jan S. 2012. Standardization of test method for salt spreader: Air flow experiments. Report 9: Visualization of airflow patterns behind a full scale salt truck. Aarhus University, Engineering Centre Bygholm, Test and Development
Appendix A. Determination of particle size distribution
The particle size distribution was determined with a stack of five sieves with opening 4.0 - 2.8 - 2.0 1.0 and 0.5 mm, Figure A1.

Figure A1. Laboratory test sieves from Endecotts Ltd. was used to determine the size of salt.

The salt sample from the spreader was put in the sieve with 4.0 mm openings, and the sieve stack with successive smaller openings was placed on the vibration platform shown in figure A2.

Figure A2. Vibration platform from Pascall Engineering.

The sample was then vibrated for five minutes resulting in six size groups of salt particles, figure A3: More than 4.0 mm - 2.8 to 4.0 mm - 2.0 to 2.8 mm - 1.0 to 2.0 mm - 0.5 to 1.0 mm and less than 0.5 mm.

Figure A3. Distribution of different salt particle size on the laboratory sieves.

Each size group was weighed on a laboratory scale as show in figure A4.

Figure A4. Weighing size fraction of the collected salt.