6. **Design and selection of flow promotion devices**

6.1 Flow additives (glidants and lubricants)
6.2 Size enlargement (agglomeration)
6.3 Flow promotion devices

...
### Measures and Flow Promotion Devices to avoid Bridging and Channeling

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<th>Flow promotion devices</th>
<th>objectives</th>
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<td>Increasing flow channel</td>
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<tr>
<td>Improve flowability of powder</td>
<td>X</td>
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<td>Size enlargement (agglomeration, pelletizing, tableting)</td>
<td>X</td>
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<td>Wall liners and coatings</td>
<td>Slippery paints, wall coatings</td>
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<td>Rigid inserts</td>
<td>Cone, roof, beams, grid, bin</td>
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<td>Continuous aeration (pneumatic bottom or bin)</td>
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<td>Bin cushion, aeration tube, box, whistle</td>
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<td>Gas shocks waves by explosions</td>
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<td>Oscillating devices</td>
<td>External vibrator, rapper, knocker</td>
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<td></td>
<td>Internal vibrating grid or cone</td>
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<td></td>
<td>Soil penetration rocket</td>
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<td></td>
<td>Oscillating bins</td>
</tr>
<tr>
<td>Rotating devices</td>
<td>Flexible arm agitator</td>
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<tr>
<td></td>
<td>Beam, arm, plough, plate agitator</td>
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<tr>
<td></td>
<td>paddle shaft</td>
</tr>
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<td>Feeders with flow promotion function</td>
<td>Arm agitators in convergent or divergent hoppers</td>
</tr>
<tr>
<td></td>
<td>Rotary plough feeder (bunker discharge wagon)</td>
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<tr>
<td></td>
<td>Transverse driven screw feeder</td>
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</table>

(X) partially effective
6.1 Flow additives (glidants and lubricants)

Effect of flow additive on heap formation of a technical herbicide

Herbicide with 0.3% Aerosil

Herbicide with 0.9% Aerosil

Consolidation functions $\sigma_c = f(\sigma_1)$ and time consolidation function of herbicide

Estimation of optimal guest particle size and their content:

Adhesion force

$$F_{H0} = \frac{C_{H,als}}{24} \left[ \frac{d_h}{(d_g + 2 \cdot a_0)^2} + \frac{2 \cdot d_g}{a_0} \right]$$

Guest particle size at $F_{H0,\min}$

$$\frac{dF_{H0}}{d(d_g)} = 0 \rightarrow d_{g,\min} = a_0 \cdot \left( \frac{d_h}{a_0} - 2 \right)$$

Load of guest particle at $F_{H0,\min}$

$$\mu_g = \frac{n_g \cdot m_g}{2 \cdot m_h} = \frac{\pi \cdot \rho_{a \cdot g}}{2 \cdot \rho_{s \cdot h}} \left[ \left( \frac{a_d}{d_h} \right)^{2/3} - 2 \cdot a_d \right]$$
6.2 Agglomeration - Size Enlargement

Operation principles of agglomeration processes:

a) tumble agglomeration (growth or agitation agglomeration)
   pelletizing

A – feed material (for agglomeration), \( \dot{Q} \) heat flow

b) press agglomeration (compaction) in partially open or closed die
   - continuous sheets (ribbon)
   - solid forms (tablets, briquettes)

c) sintering (thermal process)
Tumble Agglomeration (Pelletizing)

1. Balling drum and balling pan
   a) balling drum

![Diagram of balling drum]

   A feed material
   P green pellets
   W water

   b) balling pan

![Diagram of balling pan]
Press Agglomeration

Operation principles of press agglomeration:

a) in a closed die
b) in a open die
c) by roller pressure

A feed
B agglomerate
\(F_p\) compaction or press force
\(F_R\) wall friction force in the die channel

h punch stroke length
l filling level (not compacted)
s thickness of compacted material
k compaction (\(k=l/s\))
\(\beta_1\) half of nip angle

1 punch
2 pressing die
Microprocesses and deformation mechanism at powder press agglomeration (compaction)

- a) Feed of loose packing
- b) Elastic-plastic contact deformation
- c) Pore filling by fine particles
- d) Plastic deformation of particles to create large contact areas
- e) Breakage of edges, particle breakage, pore filling
- f) Plastic deformation of entire tablet

Compaction function of cohesive powder

\[ \sigma_T = f(p) \]

Tablet, briquette or ribbon strength \( \sigma_T \)

For hopper design

\[ \sigma_T = a_1 \cdot \sigma_1 + \sigma_{c,0} \]
### 6.3 Flow promotion devices

**Lining of Bins**

Material data of ultrahigh-molecular weight polyethylene

1. *Werkstoffdaten von ultrahochmolekularem Niederdruckpolyäthylen (UHMW – PE solidur 1000)*

<table>
<thead>
<tr>
<th>Eigenschaften</th>
<th>Einheit</th>
<th>Prüfmethoden</th>
<th>mines solidur 1000</th>
<th>solidur 1000</th>
<th>solidur 1000</th>
<th>solidur Reg.conf.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dichte</td>
<td>g/cm³</td>
<td>DIN 53479</td>
<td>0.94</td>
<td>0.96</td>
<td>0.95</td>
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<tr>
<td>Molekulargewicht</td>
<td>Millionen g/mol</td>
<td>viskosimetrisch</td>
<td>ca. 4.5</td>
<td>ca. 4.5</td>
<td>ca. 4.5</td>
<td></td>
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<tr>
<td>mechanische Eigenschaften</td>
<td></td>
<td>DIN 53456</td>
<td>22</td>
<td>22</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Zugfestigkeit (Stromspannung)</td>
<td>N/mm²</td>
<td>DIN 53455</td>
<td>22</td>
<td>22</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>RiBfestigkeit +23°</td>
<td>N/mm²</td>
<td>DIN 53455</td>
<td>&gt;350</td>
<td>&gt;350</td>
<td>&gt;420</td>
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<tr>
<td>RiBdehnung +23°</td>
<td>%</td>
<td>DIN 53456</td>
<td>&gt;350</td>
<td>&gt;350</td>
<td>&gt;420</td>
<td></td>
</tr>
<tr>
<td>Torsionssteifheit +23°</td>
<td>N/mm²</td>
<td>DIN 53455</td>
<td>250</td>
<td>300</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Torsionssteifheit –40°</td>
<td>N/mm²</td>
<td>DIN 53477</td>
<td>370</td>
<td>400</td>
<td>350</td>
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</tr>
<tr>
<td>Kugeldruckhärte 30 Sekunden</td>
<td>N/mm²</td>
<td>DIN 53456</td>
<td>38</td>
<td>40</td>
<td>42</td>
<td></td>
</tr>
</tbody>
</table>

2. *Befestigung fastening*

- Rounded edge profiles promote mass flow
- No bulging bolts or edges!
Rigid Hopper Inserts

a) before

b) Plate insert

\[ \Theta_G \text{ hopper angle limit of the flow zone} \]

b_{\text{min}}

\[ b_{\text{min, wedge}} \]

\[ b_{\text{min, con}} \]

c) Cone insert

d) Bin insert ("Bininsert")

\[ 2 \cdot \Theta_G, \text{ con} \]

\[ \Theta_G, \text{ wedge} \]
Pneumatic Flow Promotion Devices

a) Fluidisation of whole bin

b) Aeration bottom

c) Aeration box

d) Bin wall cushion

e) Porous aeration tube

f) Aeration whistle

g) Movable air lance

h) Air cannon
Air Pressure Shock Device (Air Cannon)

Arrangement of air cannons:

- channelling
- piping (ratholing)
- bridging
- in hopper
- in shaft
Vibrating discharge aids

a) Unbalanced motor at hopper wall (dashed lines: wall oscillations at high-frequency excitation $f > 100$ Hz)

b) Silo with flexible connected vibrating hopper and conical deflector ($\Delta x < 4$ mm, $f < 25$ Hz)

Additional options for convex deflector and/or oscillating inserts (rods, cages, screens, flexible grids):

c) Matcon-Bules® as “valve” with lowered cone (left) and with lifted and vibrating cone by pneumatic excitation as discharge aid (right)

Arrangement of Discharge Aids at Time Consolidations

1. Minimum discharge width versus storage time at rest

\[ b_{\text{min}}(t) = b_{\text{min},0} + b_\infty \left[ 1 - \exp\left( -\frac{t}{t_{63}} \right) \right] \]

- no bridging for \( t < t_1 \)
- no bridging for \( t = 0 \)
- bridging for \( t > t_1 \)

2. Outlet design

- a) no discharge aid necessary
- b) discharge aid necessary for \( t > t_1 \)
- c) discharge aid necessary for \( t > 0 \)
- d) discharge aid necessary for \( t > 0 \)
- e) discharge aid always necessary