Size Enlargement,

Agglomeration

7. Particle formulation by agglomeration,
   7.1 Fundamental agglomeration principles
   7.2 Agglomerate strength
   7.3 Pelletizing of moist powder
   7.4 Press agglomeration
      7.4.1 Powder compression and compaction behaviour
      7.4.2 Briquetting and tabletting
      7.4.3 Roller press
**Processes or unit operations of mechanical process engineering according to RUMPF**

<table>
<thead>
<tr>
<th>without change of particle size</th>
<th>separation</th>
<th>combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>mechanical separation (filters, separators, screens, sifters)</td>
<td>powder mixing and blending</td>
<td>particle size analysis</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>with change of particle size</th>
<th>size reduction (crushing and grinding)</th>
<th>size enlargement (agglomeration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>transport and storage of bulk materials</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Agglomeration - Size Enlargement

7.1 Fundamental agglomeration principles:

a) tumble agglomeration (growth or agitation agglomeration)
   pelletizing

b) press agglomeration (compaction)
   • continuous sheets
   • solid forms (tablets, briquettes)

c) sintering (thermal process)

A – feed material (for agglomeration), \( \dot{Q} \) heat flow
Different Types of Pellets and Granulates

Cellets
Pelletizing
Pharma

Micropellet < 500 µm
Coating
Pharma

Micropellet < 500 µm
(Cross-Section)
Coating
Pharma

Instant-Tee
Agglomeration
Food

Aromas
Encapsulating
Food

Sweetener
Agglomeration
Food

Amino acid
Coating
Feeding stuff

Polymer
Agglomeration
Fine chemistry

Detergent component
Spraying granulation
Fine chemistry

Quelle: www.glatt.de
7.2 Tensile Strength of Agglomerates

Approximation of the theoretical tensile strength of agglomerates versus primary particle size, porosity $\varepsilon = 0.35$ (according to RUMPF)
Compressive strength of agglomerates

(according to RUMPF)

- Lignite briquettes
- Ore briquettes
- Green pellets 50 x 50 mm
- Pellets 25 mm diameter
- Dried with 2 - 3% of salt
- Green
- Dried
- Calcinated pellets of 25 mm diameter
- Green pellets 20 mm diam.
- Dried pellets 20 mm diam.
7.3 Tumble Agglomeration (Pelletizing)

Species of the genus *Scarabaeus*, which occur throughout Southern Europe and Northern Africa, are fairly typical of the ‘dung - rolling’ scarabs:

Scarabaeus sacer  
(actual size 25 – 30 mm long)

adult beetle rolling its ball of dung  
to a suitable place for burial

Scarabaeus sacer, nature’s “pelletizer”
7.3 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]
Models of pellet nucleation and pellet formation mechanism

a) Pellet nucleation mechanism

b) Embedding of small feed particles at the surface of wet agglomerates (acc. to Pietsch, Aufbereitungstechnik 7 (1966) 177-191)
Balling pan pelletizer

Inclined pan pelletizer

1. pan
2. pan drive
3. water supply
4. bottom share
5. device for changing the pan angle of inclination (tilt angle to the horizontal)
Figure shows conditions to determine the critical rotation speed of pan

\[ n_{\text{crit}} = \frac{1}{\pi} \sqrt{\frac{g \sin \beta}{2D}} \]

\( n_{\text{crit}} \)  critical number of revolutions

\( \beta \)  pan bottom angle of inclination (tilt angle to the horizontal)

\( \Phi_b \)  dynamic angle of repose of the material to be granulated

\( \omega \)  angular velocity

\( D \)  pan diameter

\( g \)  gravitational acceleration

\( m \)  mass in the pan
Movement of the charge in a pelletizing pan at different rotational speeds

Qualitative relationship between moisture, residence time or throughput and average pellet size for balling pan
Deep dish or pan pelletizer

1 disc
2 screw conveyor
3 water supply

A feed
P green product
Different material flow patterns during revolution of balling drums

- Material is sliding, rotational speed too slow
- Material is rolling, rotational speed is optimal, 8 – 14 rpm, 6 – 10° drum angle
- Material is cataracting, rotational speed too fast
Flow sheets for pelletizing systems

a) with balling drums

1 mixer
2 balling drum or pan
3 screen
4 mill

A feed
Z additives
P green pellets
7.4 Press Agglomeration

Operation principles of press agglomeration:

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

A feed
B agglomerate
F<sub>p</sub> compaction or press force
F<sub>R</sub> 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)
β<sub>1</sub> half of nip angle

1 punch
2 pressing die
Isentropic Powder Compression

Adiabatic gas compression:
\[
\frac{dV}{dp} = \frac{1}{\kappa_{ad} \cdot p}
\]

Isentropic powder compression:
\[
\int_{\rho_{b,0}}^{\rho_b} \frac{d\rho_b}{\rho_b} = n \cdot \int_0^{\sigma_{M,st}} \frac{d\sigma_{M,st}}{\sigma_{M,st} + \sigma_0}
\]

Compressibility index of powders, semi-empirical estimation

<table>
<thead>
<tr>
<th>index n</th>
<th>evaluation</th>
<th>examples</th>
<th>flowability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 0.01</td>
<td>incompressible</td>
<td>gravel</td>
<td>free flowing</td>
</tr>
<tr>
<td>0.01 – 0.05</td>
<td>low compressibility</td>
<td>fine sand</td>
<td></td>
</tr>
<tr>
<td>0.05 - 0.1</td>
<td>compressible</td>
<td>dry powder</td>
<td>cohesive</td>
</tr>
<tr>
<td>0.1 - 1</td>
<td>very compressible</td>
<td>moist powder</td>
<td>very cohesive</td>
</tr>
</tbody>
</table>
Powder Compression

\[ W_{m,b} = \frac{n}{1 - n} \cdot \frac{\sigma_0}{\rho_{b,0}} \cdot \left[ (1 + \frac{p}{\sigma_0})^{1-n} - 1 \right] \]

\[ \rho_b = \rho_{b,0} \cdot \left( 1 + \frac{p}{\sigma_0} \right)^n \]

\[ \frac{d\rho_b}{dp} = n \cdot \frac{\rho_b}{p + \sigma_0} \]

Bulk density \( \rho_b \)

Isostatic tensile strength \(-\sigma_0\)

Average pressure \( p \)

Specific compression work \( W_{m,b} \)
Compression and Preshear Work

\[ W_{m,b,\text{pre}} = \frac{s_{\text{pre}} \cdot \sin 2\varphi_{st}}{2 \cdot h_{Sz}} \cdot \frac{\sigma_0}{\rho_{b,0}} \left( 1 + \frac{\sigma_{M,\text{st}}}{\sigma_0} \right)^{1-n} \]

\[ W_{m,b} = \frac{n}{1 - n} \cdot \frac{\sigma_0}{\rho_{b,0}} \cdot \left[ \left( 1 + \frac{\sigma_{M,\text{st}}}{\sigma_0} \right)^{1-n} - 1 \right] \]
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

**Tablet, briquette or ribbon strength** $\sigma_T$

$$\sigma_T = f(p)$$

For hopper design

$$\sigma_T = a_1 \cdot \sigma_1 + \sigma_{c0}$$
Density in cylindrical compacts

panels a) – g):
pressure of isobars given in MPa

panel h):
agglomerate density of isodensity lines in % of pure solid density (according to ORR)
Punch - and - Die - Presses

a) Reciprocating piston and die (excenter) press

1 excenter drive
2 upper punch
3 lower punch
4 rotating table with inwrought dies
5 feed shoe with hopper
A feed
B tablets

b) Rotary tabletting machines
Pelletizing machines

1 cutter     A feed     B briquettes

a) ram extrusion or plunger press
b) screw extruder
c) pelleting machine with flat die and muller-type press rollers
d) pelleting machine with one solid and one hollow roll
e) pelleting machine with two hollow rolls
f) pelleting machine with internal press roll
g) gear-type pelletizer
Compaction mechanism in a ram press

Sequence of events during a briquetting cycle in the ram press

(according to KEGEL and RAMMLER)
Schematic representation of the decrease in elastic recovery and increase of density of a briquette during consecutive press cycles in a ram press.
Ram extrusion press for coal briquetting (ZEMAG, Zeitz, Germany)

1 briquette die
2 ram
3 ram holder
4 press top cap
5 thrust piece
6 coal ejector channel
7 slipping dog
8 connecting rod
Vacuum Ram Press

product Breitenbach
type VAS 56b
cylinder-dia. 560 mm
press force: max. 500 kN
drive: 240 kW
Roller press machines

Types of roller press machines:

a) roller compacting machine  b) roller briquetting machine  c) ring roller press
Compaction zones and angles of a roller press

\( \alpha_o \)  feed angle of roller

\( \alpha_E \)  grip angle of roller (angle of compaction)

\( \alpha_g \)  nip angle or neutral angle (sign of friction forces changes)

\( \alpha > \alpha_g \)  velocity lag of compacted (compressed) powder compared to roller tip speed \( v_b < v_u = \omega D/2 = \pi n D \)

\( \alpha < \alpha_g \)  velocity advance of compacted material sheet (ribbon) compared to roller tip speed \( v_b > v_u \)

\( \alpha_V \)  angle of elastic release (recovery) zone after passing the minimum roller gap, the ribbon (compacted sheet) gets thicker \( s_2 > s_1 \) than the roller gap for roller angle \( \alpha = 0 \) to \( -\alpha_V \)
Feeder design for roller press machines (KÖPPERN, Hattingen, Germany)

a) gravity feeder with adjustable tongue (or plate)

b) screw feeder for filling and pre-compaction
Roller press (KÖPPERN, Hattingen, Germany)

1. rollers with replaceable rings or sleeves as pressing tools
2. roller core with integral journals
3. hydraulic cylinder
4. hydraulic reservoir
5. hydraulic pump
6. automatic grease lubrication