Agglomeration process engineering approach to evaluate the ability of different technologies to agglomerate food powder.


To cite this version:

Ines Hafsa, Sandra Mandato, Charleyne Lafond, Serge Mejean, Anne Dolivet, et al.. Agglomeration process engineering approach to evaluate the ability of different technologies to agglomerate food powder.. 5. International Symposium on Spray Dried Dairy Products, Jun 2012, Saint Malo, France. 2012. hal-01209387

HAL Id: hal-01209387
https://hal.archives-ouvertes.fr/hal-01209387

Submitted on 3 Jun 2020

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Agglomeration process engineering approach to evaluate the ability of different technologies to agglomerate food powder

HAFSA Ines (1), MANDATO Sandra (1), LAFOND Charline (1)
MEJEAN Serge (2), SCHUCK Pierre (2), JEANTET Romain (2), KIM Su Jin (3), CHEVALLIER Sylvie (3)
LE BAIL Alain (3), RUIZ Thierry (1), and CUQ Bernard (1)

(1) UMR IATE, Montpellier.
(2) UMR STLO, Rennes.
(3) UMR GEPEA, Nantes.
Summary

1. Product context
   - Food powders
   - Food powders **agglomeration**

2. Scientific contexts
   - Grains elaboration - Growth and drying
   - Elaboration **mechanisms**
   - Reactive food powders

3. Materials and Methods
   - Raw materials
   - Agglomeration **processes**
   - Product characterization

4. Results
   - Agglomeration yields
   - Agglomerates **characterization**

5. Conclusion
1. Product context

Context - Food Powders

- **Granulated sugar**
- **Table salt**
- **Cocoa**
- **Wheat flour**

Food powders

Food powders functionalities

- **Natural** powders (*flours*, *salt*, etc.)
- **Transformed** and formulated powders (*instant coffee*, *dried milk*)

- **Structuring** (*thickness*, *gelling agent*, etc.)
- **Organoleptic qualities** (*flavours*, *colouring agent*, *additives*, etc.)
- **Nutritional composition** (*vitamins*, *minerals*, etc.)
1. Product context

**Context - Food Powders Agglomeration**

**Agglomerated food powders**

- Couscous grains
- Instant coffee
- Food flavours
- Infant formula

**Agglomeration**

Process where fine particles are bound together into larger granules

**Processes**

- Spray drying
- Fluidized bed
- Low shear mixer
- High shear mixer

**Objectives**

- Dust free powders
- Particle design *(size, shape, porosity)*
- Flow properties
- Solubility
- Heat and mass transfer
- etc.
Summary

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4. **Results**
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   - Agglomerates characterization

5. **Conclusion**
Grains elaboration - Growth & Drying

2. Scientific contexts

Primary particles → Sticky particles → Wet grains → Consolidated grains → Stable grains

Wetting → Nucleation → Growth → Coalescence → Consolidation → Attrition → Drying → Shrinkage

Energy → Water
2. Scientific contexts

**Growth & Drying – Reactive food powders**

- **Primary particles** → **Sticky particles** → **Wet grains** → **Consolidated grains** → **Stable grains**
  - **Wetting** → **Nucleation** → **Growth & Coalescence** → **Consolidation & Attrition** → **Drying & Shrinkage**

**Mechanisms**

- **Dispersion** → **Coating**
- **Droplets** → **Nucleation**
- **Collision/Friction** → **Breakage** → **Shrinkage**

**Food powders**

- **Adhesion (capillary force)**
  - **Viscous force & Plasticization**
  - **Mass transfer, soluble, Glass transition**
- **Heat & mass transfers**
  - **Glass transition**
Spray drying/ Fluidized bed: Semolina is agglomerated when tap water is sprayed under a flow of hot air.

[Hydration + Growth + Reaction + Drying]
2. Scientific contexts

Decoupled approach

Mechanical energy

Primary particles → Sticky particles → Wet grains → Consolidated grains → Stable grains

Thermal energy

Energy → Water → Energy

Horizontal/Vertical low shear mixer:
Spraying water on the semolina and mixing using a blade

[Hydration + Growth]

Air dryer:
Water removing with shrinkage

[Drying]
Decoupled approach

**Mechanical energy**
- Primary particles
- Sticky particles
- Wet grains

**Thermal energy**
- Energy
- Water
- Consolidated grains
- Stable grains

2. Scientific contexts

**Horizontal/Vertical low shear mixer**: Spraying water on the semolina and mixing using a blade

[Hydration + Growth]

**Steam cooking**: Starch gelatinization and reticulation

[Reaction]

**Air dryer**: Water removing with shrinkage

[Drying]
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**Coupled approach**

**Raw Materials**: Durum wheat semolina - Industrial couscous samples (1 & 2)

**Pneumatical energy – Thermal energy**

**Spray dryer** *MSD 20, GEA- Niro (Bionov, Rennes)*

- 0.63 mm diameter nozzle/ Spraying rate = 61 L/h
- Two-fluid flat spray nozzle/ Spraying rate = 11 L/h
- Air temperatures: $T^\circ_{\text{inlet}} = 107^\circ C$/$T^\circ_{\text{outlet}} = 38^\circ C$
- Semolina flow rate = 30 Kg/h

[Hydration + Growth + Reaction + Drying]

**Fluidized bed** *ProCell 5, Glatt (Bionov, Rennes)*

- Two-fluid flat spray nozzle/ Spraying rate = 5.6 L/h
- Air Temperature : $T^\circ = 80^\circ C$
- Air flow rate : 60 $m^3$/h
- Semolina = 2 Kg

[Hydration + Growth + Reaction + Drying]
3. Materials and Methods

**Decoupled approach**

**Raw Materials**: Durum wheat semolina - Industrial couscous samples (1 & 2)

**Mechanical energy – Thermal energy**

**Horizontal mixer** *Sarcom (Supagro, Montpellier)* – **Air dryer** *Afrem (Supagro, Montpellier)*

- Primary particles
  - Mono-fluid flat spray nozzle/ Hydration = 40% db
  - Blade speed = 60 rpm
  - Semolina = 0.8 Kg

- [Hydration + Growth]

- Stable grains
  - Air temperature: $T = 50^\circ C$
  - Air Humidity: RH = 50%
  - Time = 90min

- [Drying]

**Vertical mixer** *VMI (Supagro, Montpellier)* – **Air dryer** *Afrem (Supagro, Montpellier)*

- Primary particles
  - Mono-fluid flat spray nozzle/ Hydration = 40% db
  - Blade speed = 80 rpm
  - Bowl speed = 9 rpm
  - Semolina = 1.5 Kg

- [Hydration + Growth]

- Stable grains
  - Air temperature: $T = 50^\circ C$
  - Air Humidity: RH = 50%
  - Time = 90min

- [Drying]
3. Materials and Methods

**Decoupled approach**

**Raw Materials** : Durum wheat semolina - Industrial couscous samples (1 & 2)

**Mechanical energy** – Steam cooking – Thermal energy

**Vertical mixer VMI (Supagro, Montpellier)** – Steam cooker – Air dryer Afrem (Supagro, Montpellier)

- **Hydration** = 35%db
  - Semolina = **1.5 Kg**
  - **Hydration + Growth**

- **Temperature** : T= 100°C
  - Pressure: P = 1bar
  - Time = 15min
  - **Reaction**

- **Air temperature** : T= 70°C
  - Air Humidity : RH = 80%
  - Time = 60min
  - **Drying**

**Stable grains**
3. Materials and Methods

Product characterization

- Molecular scale
  - Water content

- Macromolecular scale
  - Starch gelatinization (DSC)

- Microstructural scale
  - External microstructure (SEM)
  - Internal microstructure (XMT)
  - Compactness

- Functional attributes
  - Swelling capacity
  - Cohesion (FT4)
  - Coefficient of friction (FT4)
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4. Results

Results – Agglomeration yield

**Agglomeration yield**

<table>
<thead>
<tr>
<th>Process</th>
<th>Technology</th>
<th>Agglomeration yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coupled process</strong></td>
<td>Spray dryer</td>
<td>15.7</td>
</tr>
<tr>
<td></td>
<td>Fluidized bed</td>
<td>47.6</td>
</tr>
<tr>
<td><strong>Decoupled process</strong></td>
<td>Horizontal mixer - dryer</td>
<td>17.7</td>
</tr>
<tr>
<td></td>
<td>Vertical mixer - dryer</td>
<td>13.7</td>
</tr>
<tr>
<td><strong>Decoupled &amp; reaction process</strong></td>
<td>Vertical mixer - cooker - dryer</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>Industrial 1</td>
<td>?</td>
</tr>
<tr>
<td></td>
<td>Industrial 2</td>
<td>?</td>
</tr>
</tbody>
</table>

- **Agglomerates were obtained** whatever the technology used.
- **It is possible** to produce couscous grains using a spray drying chamber!!!
- **Decoupled & reaction processes** show the lowest agglomeration yield: *The reaction step (steam-cooking) has no effect on the agglomeration yield.*
4. Results

Results – Agglomerates characterization

**Molecular & macromolecular scales**

<table>
<thead>
<tr>
<th>Process</th>
<th>Technology</th>
<th>Water content(%)db</th>
<th>Starch gelatinization (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coupled process</strong></td>
<td>Spray dryer</td>
<td>10.2 (0.1)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>13.8 (1.9)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Fluidized bed</td>
<td>10.2 (0.1)&lt;sup&gt;c,b&lt;/sup&gt;</td>
<td>10.0 (0.9)&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Decoupled process</strong></td>
<td>Horizontal mixer - dryer</td>
<td>9.3 (0.1)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.4 (1.3)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Vertical mixer - dryer</td>
<td>10.0 (0.1)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>14.7 (1.3)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Decoupled &amp; reaction process</strong></td>
<td>Vertical mixer - cooker - dryer</td>
<td>9.4 (0.1)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100 (0.1)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Industrial 1</td>
<td>10.5 (0.1)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>100 (0.1)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Industrial 2</td>
<td>10.8 (0.1)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>100 (0.1)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

- **No differences in water contents** between the products: all the technologies used are able to remove water.
- **Decoupled & reaction processes** induce the highest **starch gelatinization** values: the reaction step (steam cooking).
## Results – Agglomerates characterization

### Microstructural scale

<table>
<thead>
<tr>
<th>Process</th>
<th>Technology</th>
<th>Compactness</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coupled process</strong></td>
<td>Spray dryer</td>
<td>0.856 (0.017)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Fluidized bed</td>
<td>0.810 (0.003)&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Decoupled process</strong></td>
<td>Horizontal mixer - dryer</td>
<td>0.817 (0.016)&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Vertical mixer - dryer</td>
<td><strong>0.794 (0.005)&lt;sup&gt;a&lt;/sup&gt;</strong></td>
</tr>
<tr>
<td><strong>Decoupled &amp; reaction process</strong></td>
<td>Vertical mixer - cooker - dryer</td>
<td>0.879 (0.021)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Industrial 1</td>
<td>0.866 (0.002)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Industrial 2</td>
<td>0.836 (0.010)&lt;sup&gt;b,c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

- Significant differences in compactness are observed.
- Decoupled & reaction processes induce the highest compactness values: the reaction step (steam cooking) generates a higher microstructural changes.
4. Results

**Results – Agglomerates characterization**

### Microstructural scale (SEM)

- **Spray dryer** *(magnifications X50 and X150)*
- **Vertical mixer - Air dryer** *(magnifications X50 and X150)*

- **Differences** in the **shape and surface** of the grains.
- **Coupled processes** generate agglomerates formed with only large size primary particles: *(segregation effects).*
- **Decoupled processes** generate agglomerates formed with both large particles / small particles.
4. Results

**Results – Agglomerates characterization**

**Microstructural scale (SEM)**

- Decoupled & reaction processes induce **differences in the external surface**: *the reaction step (steam cooking) induce a partly melted semolina particles at the surface with a more regular faces.*
4. Results

Results – Agglomerates characterization

Microstructural scale (XMT)

- Agglomeration processes generate differences in voids distribution within the agglomerates.
### Results – Agglomerates characterization

## Functional attributes

<table>
<thead>
<tr>
<th>Process</th>
<th>Technology</th>
<th>Swelling capacity ml moist product/100g dry product</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coupled process</strong></td>
<td>Spray dryer</td>
<td>241 (1)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Fluidized bed</td>
<td>250 (0)&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Decoupled process</strong></td>
<td>Horizontal mixer - dryer</td>
<td>231 (1)&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Vertical mixer - dryer</td>
<td>234 (1)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Decoupled &amp; reaction process</strong></td>
<td>Vertical mixer - cooker - dryer</td>
<td>345 (0)&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Industrial 1</td>
<td>325 (0)&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Industrial 2</td>
<td>400 (0)&lt;sup&gt;g&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

- **Decoupled & reaction processes** induce the highest swelling capacity values: The reaction step (steam cooking) leads to higher starch gelatinization levels which enhances water absorption and swelling capacity.
### Functional attributes

<table>
<thead>
<tr>
<th>Process</th>
<th>Technology</th>
<th>Coefficient of friction $\mu$ (with standard deviation)</th>
<th>Cohesion $C$ (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coupled process</strong></td>
<td>Spray dryer</td>
<td>0.294 (0.023)&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>0.297 (0.045)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Fluidized bed</td>
<td>0.324 (0.021)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.316 (0.043)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Decoupled process</strong></td>
<td>Horizontal mixer - dryer</td>
<td>0.351 (0.015)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.340 (0.045)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Vertical mixer - dryer</td>
<td>0.268 (0.012)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.266 (0.064)&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Decoupled &amp; reaction process</strong></td>
<td>Vertical mixer - cooker - dryer</td>
<td>0.404 (0.028)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.333 (0.034)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Industrial 1</td>
<td>0.438 (0.006)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.366 (0.012)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Industrial 2</td>
<td>0.469 (0.043)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.389 (0.119)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Semolina</strong></td>
<td></td>
<td>0.600 (0.005)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.191 (0.046)&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

- All the **processes** used reduce the frictional properties but slightly increase the cohesion values compared to native semolina particles.

\[ \tau = \mu \sigma + C \]  

*Equation for Coulomb Law*
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5. Conclusion
- All the investigated **processes** (coupled process, decoupled process, decoupled & reaction process) are **able to agglomerate** food powder to produce grains with different attributes.

- The **type and intensity of the energy** input (thermal energy, mechanical energy and pneumatical energy) affect the internal microstructure of the agglomerates (more or less compactness, differences in the voids distribution).

- The **reaction stage** (steam cooking) induces external and internal microstructure changes, because of the high gelatinization level of the starch granules.

- Semolina is a **reactive food powder** with low water solubility, different agglomeration results are expected with more soluble food powders (i.e milk powders).
Thank you for your attention