Extrusion Applications -

Optimal Design and Quality Management of Aquafeed

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Aquafeed Workshop Mexico 2018 - An Aquafeed.com technical workshop
Key Aquafeed Design Features

1. Buoyancy
2. Water Stability
3. Non-Polluting
4. Shelf Life
1. Buoyancy (Sinking or Floating)

➢ The Cost:
   • Uneaten Feed
     • Reduced Feed Efficiency
     • Water Pollution
   • Bag Fill
     • Consumer Perception

➢ Pellet Design:
   • Bulk Density Targets:

<table>
<thead>
<tr>
<th>Feed characteristics</th>
<th>Sea water - 20°C (3% salinity)</th>
<th>Fresh water - 20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast-sinking</td>
<td>&gt; 640 g/l</td>
<td>&gt; 600 g/l</td>
</tr>
<tr>
<td>Slow-sinking</td>
<td>580-600 g/l</td>
<td>540-560 g/l</td>
</tr>
<tr>
<td>Neutral buoyancy</td>
<td>520-540 g/l</td>
<td>480-500 g/l</td>
</tr>
<tr>
<td>floating</td>
<td>&lt; 480 g/l</td>
<td>&lt; 440 g/l</td>
</tr>
</tbody>
</table>
1. Keys to Controlling Bulk Density

1. Understand how Extrusion regulates Expansion:
   A. Expansion is the result of the Phase Change of Water
      • Liquid to Vapor

   ![Diagram showing the process of liquid water becoming water vapor through extrusion]
   - Barrel Pressure: > 21 Bar / 300 psi
   - Melt Temperature: >100° C
   - Boiling Point: >214° C
   - Die Opening
   - Water Vapor
   - Pellet Temperature: <85° C
   - Ambient Pressure
1. Keys to Controlling Bulk Density

B. *Water Vapor Pressure* is the driving force of expansion.

![Diagram showing vapor pressure of water versus temperature.]

**Typical Range:** 15-70 psi
1. Keys to Controlling Bulk Density

C. The “Degree of Expansion” is controlled by:
   ➢ *Visco-Elastic Properties of the Melt*
   ➢ *Viscosity* – the resistance to flow
     • Low melt viscosities = Greater expansion levels
     • High melt viscosities = Lower expansion levels

D. **Melt Viscosity** is controlled by:
   ➢ Time
   ➢ Temperature
   ➢ Moisture
   ➢ Raw Material

Typical Expansion Ratios:
- Sinking Feed: 1.10 – 1.25
- Floating Feed: 1.60 – 1.75
1. *Strategies* for Controlling Bulk Density

1. **Monitor, Control, and Repeat the Critical Parameters**
   - **Retention Time** (Dry Mix Rate)
   - **Temperature** (Steam Flow Rate + SME)
   - **Moisture** (Water + Steam Flow Rate)

2. **Specific Mechanical Energy, SME**
   - Best reported on a Total Mass Flow Basis
   - Factors affecting consumed Motor Power
     - Die Open Area
     - Pressure Ring Size
     - Screw Speed
     - Throttling Valve Position
     - Total Mass Flow Rate

3. **Formulation:**
   - **Starch Levels:**
     - Sinking Feeds: 8-10% Starch
     - Floating Feeds: 12-18% Starch
       - (20% for <1mm Ø)

**SME Calculation Example:**

- 315 kW Motor @ 90% power = 284 kW
- Total Mass Flow Rate of 10 Mtph
  - **SME on a TMF basis = 28.4 kW-hr/Mt**

**Notes:**
- Power is not the same as Current.
- A Power Meter is required to accurately determine the power consumption.
- A Motor’s power capacity decreases linearly, as its’ rpm drops below its’ base speed.
1. *Strategies for Controlling Bulk Density*

4. **Sinking Feeds** = *Preventing Expansion*

A. **Density Control Systems:** (two types)

1. **Barrel Vent**
   - Ambient Venting
   - Forced Venting (Vacuum)
   - Removes steam to lower the melt temperature

2. **Pressure Chamber**
   - Pellets exit the die and enter a Pressure Chamber
   - Elevates the boiling point to lower the Vapor Pressure Force.

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![Graph of Vapor Pressure of Water vs Temperature](image)

- **VAPOR PRESSURE OF WATER**
- **PRESSURE, PSI**
- **TEMPERATURE, °C**

- **Lowers the Vapor Pressure Force**
Key Aquafeed Design Features

1. Buoyancy
2. Water Stability
3. Non-Polluting
4. Shelf Life

Aquafeed

FAMSUN
Integrated Solution Provider
2. Water Stability

- A measure of the pellets ability to hold up in water for a specific time period without breaking down and without the loss of solids.
- Often expressed as % Water Stability by determining the grams of solids retained in pellet form and divided by the initial pellet weight.

➢ Requirements vary by species
  - Shrimp are slow eaters
    - 50% eaten in first 30 minutes
    - 100% eaten after 2.5 hours
  - Floating: > 1 hour
  - Shrimp: 4-8 hours
  - Turtle: Up to 24 hours
2. Keys to Improving Water Stability

A. Functional Properties of Protein may provide Excellent Water Stability

1. Raw or “Functional” Proteins
   - They thicken into a paste or gel and are excellent binders.
   - Have an affinity to water.
     - Wheat Flour
     - Vital Wheat Gluten
     - Blood Meal, Spray Dried
     - Fish Meal, Spray Dried
     - Chicken Liver, Spray Dried

2. Denatured or Non-Functional Protein
   - Fully Denatured Proteins offer no help in improving Water Stability
   - They are extensively cooked, making them insoluble in water and unable to create a gel or paste.
     - Poultry Meal, Drum Dried
     - Fish Meal, Drum Dried
     - Feather Meal
     - Corn Gluten Meal, Wet Milled

Li and Lee, 1996, “Effect of Extrusion Temp...on wheat protein”
2. Keys to Improving Water Stability

B. Understand the Physico-Chemical Changes of Starch

Starch Cooked in Excess Water

1. Raw Starch Granules
   Insoluble in Cold Water

2. Heated, Hydrated and Swollen Granules

3. Gelatinized Starch
   (ruptured granule)
   Soluble in Cold Water

Extruded Starch with High Shear and Low Moisture*

4. Degradation or Chain Scission
   (caused by shear)

5. Dextrin
   (short chain starch molecules)
   Extremely Soluble in Cold Water

* Hagenimana et al., 2006 – WSI is a function of both the severity of the screw profile and process temperature.
* Harper 1992 – Severe extrusion conditions, such as low moisture and high temperature, can cause extensive dextrinization of starch, resulting in an increased formation of water soluble products.
2. Keys to Improving Water Stability

C. Extruded Starch Pasta versus Corn Snacks

<table>
<thead>
<tr>
<th>Extrusion Parameters</th>
<th>Extruded Starch Pasta</th>
<th>Extruded Corn Snacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preconditioning Time, min:</td>
<td>&gt; 3</td>
<td>0</td>
</tr>
<tr>
<td>Melt Moisture, %:</td>
<td>30-33%</td>
<td>10-13%</td>
</tr>
<tr>
<td>Melt Temperature, °C:</td>
<td>100 - 110</td>
<td>150-160</td>
</tr>
<tr>
<td>SME, kWh/t:</td>
<td>10-12</td>
<td>85-90</td>
</tr>
<tr>
<td>Water Stability:</td>
<td><strong>Excellent</strong></td>
<td><strong>Poor</strong></td>
</tr>
<tr>
<td></td>
<td>(93% after 20 min. in boiling water)</td>
<td>(0% after 5 minutes in 40 °C water)</td>
</tr>
<tr>
<td>Starch Response:</td>
<td><img src="image1" alt="Starch Response" /></td>
<td><img src="image2" alt="Starch Response" /></td>
</tr>
</tbody>
</table>

Water Stability Test of a Corn Based Snack:
- 100% Starch
- 40° C Water

Time, Minutes: 0 1 3 5
2. Keys to Improving Water Stability

D. Aqua Feed Water Stability Test

- **“Rapid” Water Stability Test Method**
  1. Soak Pellets in 25 °C water for 50 min
  2. Drop from 1m height onto a concrete floor
  3. The Pellets cannot splinter or break open

<table>
<thead>
<tr>
<th>No</th>
<th>Parameters</th>
<th>Test #1</th>
<th>Test #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dry Mix Rate, tph:</td>
<td>7.5</td>
<td>9.8</td>
</tr>
<tr>
<td>2</td>
<td>SME, kW-hr/T:</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>Extrusion Moisture:</td>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>4</td>
<td>Water Stability Test:</td>
<td><strong>FAIL</strong></td>
<td><strong>PASS</strong></td>
</tr>
<tr>
<td>5</td>
<td><strong>Starch Source:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cassava:</td>
<td>14.5 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rice:</td>
<td>12.2%</td>
<td></td>
</tr>
</tbody>
</table>
2. Keys to Improving Water Stability

E. Impact of Starch Content on Water Stability

➢ Tilapia feed (protein 30%, starch 8%, fat 4.5%)
➢ Water Stability can be Excellent, even with Low Starch.

Tilapia feed (soaking for 2 hours).

Has elasticity and sponginess.
2. Strategies for Improving Water Stability

A. **Use Functional Protein**

B. **Avoid creating Dextrin**
   (degrading the starch chains)
   - Increase Preconditioning Time
   - Minimize Shear
     - Use less aggressive screw profiles
     - Reduce SME
   - Increase the Extrusion Moisture

C. **Monitor, Control, and Repeat the Critical Parameters**
   - **Retention Time** (Dry Mix Rate)
   - **Temperature** (Steam Flow Rate + SME)
   - **Moisture** (Water + Steam Flow Rate)

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**Raw Protein**
- Functional
- Mixture of soluble or insoluble protein, depending on source.
- Hydrophobic molecules are bound within folds of the chains.

Li and Lee, 1996, “Effect of Extrusion Temp...on wheat protein”

**Degraded Chains of Starch – Dextrin**
Key Aquafeed Design Features

1. Buoyancy
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3. Non-Polluting
4. Shelf Life
3. Non-Polluting

➢ Preventing feed residue or pellet secretions from spoiling the aquatic environment.

➢ **The Cost:**
  ➢ Fewer fines mean cleaner ponds, lower fatality rates, less undesirable bacteria, increased conversion rates, higher production yields, improved digestibility, and reduced feed cost.

➢ **Pellet Design Elements:**
  – High Pellet Durability
  – High Water Stability
  – Contains minimal Fines
  – No leaching of nutrients
3. Keys to Avoiding Water Pollution

1. **Know the Contamination Sources**
   - **Ingredient Particles**
     - Coarse particle size
   - **Broken Pellets and Fines**
     - Due to low mechanical durability
   - **Dissolved Pellets**
     - Due to low water stability
   - **Leaching**
     - Fat
     - Water soluble ingredients

2. **What is Mechanical Durability?**
   - **Resistance to External Forces**
     - Attrition
     - Impact
     - Shear
     - Compression

Example of Fat Leaching: Large particles are potential pollutants.
3. Strategies to Avoid Water Pollution

A. Fine Grinding

- Impact of Particle Size
  - Large Particles easily detach from the pellet during shipping and handling.
  - Small Particles are less likely to separate from the pellets.

A cavity created by a detached particle.

Famsun Pulverizer
3. Strategies to Avoid Water Pollution

B. How to Improve Mechanical Durability
   – Use some Functional Protein
   – Observe Minimum Starch Levels
   – Optimize Starch Gelatinization Levels
     • Fine grinding
   – Extensive Preconditioning
   – Keep internal fat level below 8%

C. Material Handling
   – Delicate conveyors – Bucket Elevators
   – Short drops into bins
   – Use of “Let Downs” (slide system)
3. Strategies to Avoid Water Pollution

D. Product Screening

➢ Polishes the Pellet
  ▪ Removes rugged edges

➢ Removes Fines and Broken Pellets

1. After Drying
2. After Cooling
3. Before Packaging

After Extrusion (rough surface)  After Coating and Screening (smooth surface)
Key Aquafeed Design Features

1. Buoyancy
2. Water Stability
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4. Shelf Life
4. Shelf Life - Preventing Mold Growth

- **Shelf Life:** is the length of time a product remains fit for consumption, resulting from the proliferation of microorganism or chemical breakdown of ingredients (e.g., rancidity).

- **The Cost:**
  - Spoiled Feed
  - Yield Loss
  - Customer Impression of Quality

- **Pellet Design Elements:**
  - $a_w$ Target: ≤ 0.65
  - Moisture Target: ?

Mold can quickly spoil feed products.
4. Keys to Preventing Mold Growth

A. What is Water Activity, $a_w$?

- Some portion of the water in food is bound to a variety of molecules.
- $a_w$ refers to the un-bound water.
- $a_w$ is not the same as Moisture Content.
- $a_w$ is measured via a Water Activity Meter.
- The relationship between $a_w$ and moisture are plotted on a Moisture Sorption Isotherm
- The results are on a Scale from 0 to 1
  - 0 is perfectly dry and 1 is pure water
4. Keys to Preventing Mold Growth

A. Each species of micro organism (bacteria, yeast, mold) has a minimum $a_w$ value, which growth is no longer possible.
   - A slight change in $a_w$ can change the shelf life from a couple of days to a couple of weeks.
   - To avoid Mold Growth; keep your product’s $a_w \leq 0.65$

<table>
<thead>
<tr>
<th>$a_w$ Range</th>
<th>Example of Organisms Generally Inhibited by the lowest $a_w$ in the range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.95 – 1.00</td>
<td><em>Pseudomonas, Escherichia, Bacillus, Clostridium perfringens, some yeasts</em></td>
</tr>
<tr>
<td>0.91 – 0.95</td>
<td><em>Salmonella, Lactobacillus, some molds and yeasts</em></td>
</tr>
<tr>
<td>0.87 – 0.91</td>
<td>Many yeasts, <em>Micrococcus</em></td>
</tr>
<tr>
<td>0.80 – 0.87</td>
<td>Most molds, <em>Staphylococcus aureus</em></td>
</tr>
<tr>
<td>0.75 – 0.80</td>
<td>Most halophilic bacteria, <em>mycotoxigenic aspergilli</em></td>
</tr>
<tr>
<td>0.65 – 0.75</td>
<td><em>Xerophilic molds (Aspergillus chevalieri, A. candidus, Wallemia sebi), Saccharomyces bisporus</em></td>
</tr>
<tr>
<td>0.40 – 0.65</td>
<td><em>Osmophilic yeasts, few molds</em></td>
</tr>
</tbody>
</table>

4. Keys to Preventing Mold Growth

B. Establishing a Moisture Target

➢ Each Diet or Recipe will have a unique $a_w$ and Moisture relationship.
➢ Process Control, the ability to keep the moisture within a tight range, plays a role in setting your moisture target.

• **Poor Process Control**: (high level of moisture variation over the length of a run)
  • Extrusion mass flow variation, dryer moisture uniformity, etc…
  • Dryer Moisture Uniformity - Side to side variation

![Diet A: 7.5% Moisture Target](image1)

![Diet B: 8.5% Moisture Target](image2)

Water Activity Production Data
4. Keys to Preventing Mold Growth

C. Mold Proliferation Circumstances:

1. **High Moisture Product**
   - Widespread Mold Growth
   - **Cause:** The entire contents of a package were too wet, and the $a_w$ exceeded 0.65.

2. **Inadequate Cooling / Hot Pellets**
   - Small amounts of localized Mold Growth
   - **Cause:** Hot pellets.
   - Hot pellets emit water vapor inside of the package. The vapor condenses on a cool location within the bag.
   - The condensation pools and drips onto the product, causing the $a_w$ in localized areas to exceed 0.65.
   - The moisture may have been below your moisture target.
4. Strategies for Preventing Mold Growth

A. Monitor and Control $a_w$
   - Adjust the Dryer to keep the Water Activity below 0.65.
   - Control the Process – Extrusion Stability and Dryer Uniformity

B. Adequately Cool the Product before Packaging
   - Cool to within 5 to 7° C of Ambient
   - Continually monitor the Kibble Temperature Exiting the Cooler
   - Train the operators of the importance of fully cooling the product
Thank You

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