Conditioning, Pelleting, and Cooling

Charles Stark
Peter Ferket
Pelleting

Benefits to Pelleting

- Improve palatability
- Decrease feed wastage (feeder management)
- Destroys pathogens/microorganisms
- Reduce ingredient segregation
- Improves flowability
- Increases formulation flexibility
  - Alternative ingredients
  - Higher fat levels
## Pellets vs. Mash

### Advantages

<table>
<thead>
<tr>
<th>Pellet</th>
<th>Mash</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Grain particle size (&lt;600 um)</td>
<td>- Grain particle size (&gt;700 um)</td>
</tr>
<tr>
<td>- High inclusion of alternative ingredients</td>
<td>- Grain based formula</td>
</tr>
<tr>
<td>- Variable inclusion of alternative ingredients</td>
<td>- Lower manufacturing cost</td>
</tr>
<tr>
<td>- Higher inclusion of fat</td>
<td></td>
</tr>
<tr>
<td>- Improved flowability</td>
<td></td>
</tr>
<tr>
<td>- Less dust</td>
<td></td>
</tr>
<tr>
<td>- Improved F/G</td>
<td></td>
</tr>
</tbody>
</table>
Factors Influencing Pellet Quality

- Formulation: 40%*
- Conditioning: 20%**
- Particle Size: 20%**
- Die Specification: 15%**
- Cooling: 5%**
- Throughput: ??%**

*Nutritionist, **Feed Mill

Modified Behnke, 1994
FORMULATION
Ingredient Characteristics that Affect Pelleting

- Protein content
- Fat/oil content
- Fiber content
- Ingredient Variability
- Abrasiveness: the more abrasive, the more difficult it is to pellet
Feed Processing Research
Effect of Protein & Temperature on Pellet Quality – Coarse Feed

Linear effect protein (P<.08)
Temperature (P<.05)

561 microns

PDI, %

CP 15%  CP 20%  CP 25%

70 C  85 C

Stark, 1994
Feed Processing Research
Effect of Fat Type on Pellet Quality – Exp 1

<table>
<thead>
<tr>
<th>Fat Type</th>
<th>Control</th>
<th>1.50%</th>
<th>3.00%</th>
<th>6.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry Fat</td>
<td>100</td>
<td>95</td>
<td>90</td>
<td>85</td>
</tr>
<tr>
<td>Soy Oil</td>
<td>95</td>
<td>90</td>
<td>85</td>
<td>80</td>
</tr>
<tr>
<td>Choice White Grease</td>
<td>90</td>
<td>85</td>
<td>80</td>
<td>75</td>
</tr>
<tr>
<td>Tallow</td>
<td>90</td>
<td>85</td>
<td>80</td>
<td>75</td>
</tr>
</tbody>
</table>

*Fat x Level interaction (P<.05)*

Stark, 1994
Effect of Fat Addition on Pelleting Production Characteristics

*(Richardson and Day, 1976)*

| Fat Addition, % | Pelleting Production Characteristics |
|-----------------|--------------------------------——-|
|                 | Mixer | PPLA | Fines, % | Prod. Rate, tph | Energy Cons., kWh/t |
| 1.0             | 4.7   | 18.0 | 11.6     | 11.0            |
| 2.0             | 3.7   | 22.0 | 12.1     | 9.7             |
| 3.0             | 2.7   | 29.2 | 13.2     | 8.7             |
| 4.0             | 1.7   | 31.6 | 13.2     | 7.9             |
| 5.3             | .3    | 50.8 | -        | -               |
MAJOR FACTORS AFFECTING PRODUCTION RATE

Phosphate Source
## Comparison of Particle Sizes

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Avg Part. Size, µm</th>
<th>Sgw</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defluorinated Phos.</td>
<td>649</td>
<td>2.01</td>
<td>Medium</td>
</tr>
<tr>
<td>Dical Phos</td>
<td>756</td>
<td>1.34</td>
<td>Very Soft</td>
</tr>
<tr>
<td>Limestone</td>
<td>651</td>
<td>1.90</td>
<td>Soft</td>
</tr>
<tr>
<td>Sand</td>
<td>431</td>
<td>1.50</td>
<td>Hard</td>
</tr>
</tbody>
</table>

Courtesy of Dr. Keith Behnke
Ingredient Variability

Does ingredient source matter?...Yes

Crops
- Weather
- Soil type
- Maturity at harvest
- Fertilizer
- Irrigation

Co-products
- Raw grains
- Dryer designs, speeds & temperature
- Fermentation process & thoroughness

Courtesy of Dr. Keith Behnke
Ingredients that Reduce Pellet Quality

- Fats and oils > 1.5% of the feed mix
- Meat and Bone meal, poultry by-product meal, meat meals
- Distillers Dried Grains with solubles
## Effect of Process Factors on Pellet Durability

<table>
<thead>
<tr>
<th>Process Factor</th>
<th>% PDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>70</td>
</tr>
<tr>
<td>Increase temperature 5°C</td>
<td>75.1</td>
</tr>
<tr>
<td>Increase temperature 10°C</td>
<td>79.4</td>
</tr>
<tr>
<td>Reduce fat by 0.5%</td>
<td>75.0</td>
</tr>
<tr>
<td>Add 1.5% calcium lignosulfonate</td>
<td>82.5</td>
</tr>
<tr>
<td>Decrease production rate by 20%</td>
<td>71.3</td>
</tr>
<tr>
<td>Add 10% wheat</td>
<td>75.4</td>
</tr>
</tbody>
</table>

Source: Dr. T.S. Winowiski
CONDITIONING
Purpose of Feed Mash Conditioning

- Raises the mash moisture and temperature cook
- Activates natural adhesives found in ingredients
- Softens the feed particles for increased surface binding during compression
- Increases pellet die lubrication
- Destroys micro-organisms and deactivates some anti-nutritional factors
Factors that Affect Steam Conditioning

- Mash particle size
  - Surface area increases geometrically as particle size decreases

- Retention time
  - 30 to 90 seconds for optimum pellet quality
  - 5 to 20 seconds is more typical in the industry

- Pick (Paddle) Angle
  - Retention time decreases as forward angle increases.

- Shaft speed

- Water Addition
  - Optimum conditioning at 16-17.5% moisture, with 4-5% moisture added by the conditioner
Factors that Affect Particle Bonding in Pellets

- Heat transfer
- Moisture or water content of the feed ingredient or feed mash
- Chemical composition (ingredient composition)
- Structure of the feed ingredients
- Compressive pressure
Conditioning Principles

Conditioning requires:

- Time
  - Conditioner Length
  - Conditioner Speed
  - Conditioner Pick Set Up

- Moisture
  - Steam
  - Water

- Heat
  - Steam
Particle Bonding During Pelleting
Conditioning Targets

- **Moisture & Temperature**
  - Target 17-18% moisture
  - Target 180 – 200 F temperature
  - 1% moisture increase per 20-25 F temperature
  - **Examples:**
    - **Winter** 40 F to 190 F
      - 150 F delta = 6% moisture
      - 12% to 18%
    - **Summer** 90 F to 190 F
      - 100 F delta = 4% moisture
      - 12% to 16%
## Conditioning

<table>
<thead>
<tr>
<th>Response Criteria</th>
<th>No Conditioning</th>
<th>Steam Conditioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditioning temp, °F</td>
<td>82</td>
<td>176</td>
</tr>
<tr>
<td>Energy consumption, kWh/t</td>
<td>30.7</td>
<td>11.9</td>
</tr>
<tr>
<td>Pfost durability, %</td>
<td>80.3</td>
<td>96.0</td>
</tr>
<tr>
<td>Maltose equiv., mg/g</td>
<td>52.2</td>
<td>37.1</td>
</tr>
</tbody>
</table>

(Skoch et al., 1983)
# Starch Gelatinization and Pelleting

*(Skoch et al., 1981)*

<table>
<thead>
<tr>
<th>Cond. Temperature</th>
<th>Meal</th>
<th>Cond. Meal</th>
<th>Cool Pellet</th>
<th>Durability(^a), %</th>
</tr>
</thead>
<tbody>
<tr>
<td>70° F</td>
<td>29.9</td>
<td>31.7</td>
<td>66.3</td>
<td>69.5</td>
</tr>
<tr>
<td>149° F</td>
<td>30.2</td>
<td>30.0</td>
<td>55.5</td>
<td>90.6</td>
</tr>
<tr>
<td>172° F</td>
<td>31.2</td>
<td>27.7</td>
<td>46.1</td>
<td>93.8</td>
</tr>
</tbody>
</table>

\(^a\)Pfost durability.
Extruder Pre-conditioner
Effect of Temperature on Pellet Quality

Pellet Durability Index (PDI), %

Unpublished
Extended Conditioning
(Hygieniser)

CPM Hygieniser
Extended Conditioning

Buhler

- modular
- hygienizing
  process

- biggest
  flexibility

- highest
  security

- state
  of the art
  pelleting
  technology
Steam Conditioning

- Most common conditioning temperatures
  - 185-195 F, depends on steam quality
- Good steam quality = 97% vapor
  - Increases conditioning temperature by 25 F for every 1% moisture added
- Poor steam quality = 80% vapor
  - Increases conditioning temperature by 20 F for every 1% moisture added
- Steam quality preserved by condensation traps to remove water and impurity
  - Place at low areas every 100 feet in steam line
Effect of Conditioning Temperature on Hot Pellet Temperature

- Increasing the conditioning temperature will decrease the temperature rise through the die during the pelleting process.
- Temperature rise is due to frictional heat between the die and pellet surface.
- Moisture acts as a lubricant in the die hole.

<table>
<thead>
<tr>
<th>Conditioning Temperature</th>
<th>Hot Pellet Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>185 F</td>
<td>192 F</td>
</tr>
<tr>
<td>191 F</td>
<td>194 F</td>
</tr>
<tr>
<td>194 F</td>
<td>195 F</td>
</tr>
<tr>
<td>200 F</td>
<td>199 F</td>
</tr>
</tbody>
</table>
Effect of Low Conditioning Temperature

- Increases die wear
- Requires more energy
- Reduces throughput
- Increases fines
- Increase in hot pellet temperature due to frictional heat between the die and feed/pellet surface
Effect of Temperature on Moisture

![Chart showing the effect of temperature on moisture content]

- **Mash**
- **Cond Mash**
- **Pellet**

Temperature (°C): 185, 190, 195, 200

Moisture (%): 11.1, 11.7, 11.1, 11.9, 11.1, 11.8, 11.1, 11.5
Effect of Moisture on Electrical Consumption

![Bar chart showing kWh/ton vs. Mash Moisture percentage]

- 12.2% Moisture: 5.21 kWh/ton
- 13.1% Moisture: 5.25 kWh/ton
- 14% Moisture: 5.19 kWh/ton
- 14.7% Moisture: 5.14 kWh/ton
- 15.1% Moisture: 5.09 kWh/ton
Effect of Moisture on Pellet Quality

![Bar chart showing the effect of mash moisture on PDI percentage. The chart indicates that as mash moisture increases from 12.2% to 15.1%, PDI percentage increases from 77.6% to 88.6%.]
PELLET MILLS
Pellet Mill

Single Pass Conditioner

Double Pass Conditioner

Triple Pass Conditioner
Multi-port Steam & Liquid Addition
Hygieniser
Pellet Mill Types

Belt Drive

Gear Drive
Gear Drive Pellet Mill

http://www.cpmroskamp.com/pelletmill/products/pelletmills/
Pellet Mill

Pellet Die & Rolls

Pellet Mill Video
Remote Roll Linear Adjustment

Linear Adjustment Video
Corrugated Rolls
Pellet Die

Die Hole Specifications

Diameter

Counterbore

Effective Thickness

One Step Relief

Two Step Relief

$L/D = \frac{\text{Length}}{\text{Hole Diameter}}$

$L/D = 8$

Length

$1\,\frac{1}{4}''$

$10/64''$
Types of Pellet Die Configurations

Die hole specification
Inlet:
1. Normal
2. Deep
3. Flat
4. Well type

Relief:
5. Cylindrical
6. Conical
7. Stepped

- Standard Die
- Standard Relieved Die
- Outside Rows Relieved Die
- Variable Relief Die
Pellet Die Wear

- “Honey comb” pattern of die wear is most common
- Causes of excessive die wear:
  - Improper roller adjustment
  - Uneven feed distribution
  - Trash metal and stones
- Consequence of die wear
  - Reduced pellet mill throughput
  - Increased power usage/ton
  - Reduced pellet quality
Die Specifications

- **Die Materials**
  - High Chrome
  - Alloy Dies

- **Die Diameter**
  - 1/8” to 3/4” (range cube)

- **Die Thickness**
  - 1” to 3” effective thickness

- **Die Relief**
  - Straight Bore
  - Two-step relief
  - Taper relief
Production Rate

Die Thickness

Kg/hr

Throughput

500 1000 1500
Pellet Mill Efficiency

Linear ($P<0.01$)

<table>
<thead>
<tr>
<th>Die Thickness</th>
<th>kg/hpr</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>98</td>
</tr>
<tr>
<td>35</td>
<td>96</td>
</tr>
<tr>
<td>44</td>
<td>90</td>
</tr>
</tbody>
</table>

Linear ($P<0.01$)

<table>
<thead>
<tr>
<th>Throughput</th>
<th>kg/hpr</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>73</td>
</tr>
<tr>
<td>1000</td>
<td>97</td>
</tr>
<tr>
<td>1500</td>
<td>112</td>
</tr>
</tbody>
</table>
Pellet Durability Index

**Die Thickness**
- 29:
- 35:
- 44:

**Throughput**
- 500:
- 1000:
- 1500:
Hot Pellet Temperature

Temperature, °C

Die Thickness
- 29
- 35
- 44

Througput
- 500
- 1000
- 1500
Pellet Mill Monitoring

- Mash
  - Moisture
  - Temperature
- Steam
  - Temperature
  - Pressure
- Motor
  - Amps
- Conditioned Mash
  - Moisture
  - Temperature
- Hot Pellet Temperature
- Conditioner
  - RPM
Pellet Mill Motor Load

hp

College of Agriculture & Life Sciences
Academics • Research • Extension
COOLERS
Cooling and Drying

- Purpose is to remove moisture and heat generated during the conditioning and pelleting process.
- Pellet "shock" can occur if air volume or the temperature or humidity of the cooling air is too low, resulting in stress cracks in the pellets.
- Pellet quality and shelf-life will be reduced if air volume is too low or if the ambient humidity is too high.
Requirements for Drying and Cooling Pellets

Air
- Carries away heat and moisture
  - Works only on the surface

Heat
- Required to remove moisture
  - Heated air expands, lowering the relative humidity, & increases the drying capability of the air

Time
- Required for heat and moisture to migrate to the surface
Heat and Moisture Removal

- Heat and/or Moisture always moves from higher levels to lower levels until equilibrium is achieved.
Pellet Cooler

- **Purpose**
  - Remove moisture after the pelleting process
  - Remove heat after the pelleting process
Moisture Capacity of Air

32° F       70° F       100° F

2 Grains       8 Grains       20 Grains
Psychrometric Charts

[Diagram showing percent saturation curves, adiabatic cooling, mixing, and heating zones with temperature and moisture content axes.]
### Water Holding Capacity of Air

<table>
<thead>
<tr>
<th>Temperature, C</th>
<th>Moisture in Air (kg water/kg dry air)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>0.020</td>
</tr>
<tr>
<td>30</td>
<td>0.028</td>
</tr>
<tr>
<td>40</td>
<td>0.049</td>
</tr>
<tr>
<td>50</td>
<td>0.087</td>
</tr>
<tr>
<td>60</td>
<td>0.150</td>
</tr>
<tr>
<td>135</td>
<td>1.426</td>
</tr>
</tbody>
</table>
Pellet Coolers

Types

- Horizontal Coolers
  - Single Pass
  - Double Pass
- Counter-flow Cooler
  - Round design
  - Square design
Counterflow Cooler
Counterflow Cooler

- **Features**
  - Minimal floor space required
  - Moderately high capacities available
  - Low air requirement
  - Effective at beginning and end of run
  - Lower capital cost than comparable horizontal
  - Mechanically simple

- **Limitations**
  - Not good for small particles
  - Difficult to adapt for heat addition

- **Performance**
  - Lowest air requirement
  - Most effective at drying

Diagram showing the flow of warm, moist product in, cooling zone, and cool, dry product out.
Horizontal Pellet Cooler
Horizontal Cooler – Cross Flow

Warm, Moist product in

Drying Zone

Cool, Dry product out
Factors that affect cooler performance

- Inlet air temperature
  - Cold Air – Low water holding capacity
  - Warm Air – Higher water holding capacity
- Bed depth in the cooler
  - Horizontal – 12 to 15” level across the pans
  - Counterflow – 2/3 to 3/4 full
- Air volume
PELLET QUALITY TESTS
PDI Procedure

Obtain sample → Remove fines → Re-screen and weigh the remaining whole pellets

\[ PDI = \frac{\text{Weight of pellet after tumbling}}{\text{Weight of pellets before tumbling}} \times 100 \]

Weight 500 grams

Tumble sample for 10 minutes

ASAE S269.3

*Add modifiers to the tumbler to model the mills system

Pacheo, 2009
Pellet Quality Test

Modified KSU Method

Pellet Quality Index – PDI Test
Tumble 10 min with 3-5 Hex nuts
Pellet Quality Test

Holmen Tester

- 100 grams whole pellets
- Test time 30-90 seconds
Effect of Pellet Durability Index Based on Sample Weight

Sample Weight, grams

300  400  500  600

85  87  88  89  90

* 3 hex nuts/no fat