Commercial Aquaculture Feed Production (Floating Feeds)

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Presentation Outline

- Goals of extrusion processing
- Basic principles
- Types of extruders
- Common extrusion conditions
- Key variables
- Basic theory
- Competing effects during extrusion
- Extrusion challenges
Goals of Extrusion Processing

- Cooking
  - Starch gelatinization
  - Deactivate anti-nutritional factors
- Sterilization
  - Pathogens
- Expansion
  - Floating aquafeeds
- Texturization
  - Porous structure
- Product shaping
  - Pellets
Basic Principles

Raw feed ingredients

Extruder

Extruded products
Basic Principles

Raw feed ingredients

Feed Bin

Steam Water

Conditioner

Steam Water

Extruder

Extruded products

Dryer / Cooler
Basic Principles

- Feed
- Conditioning
- Extruder
- Pneumatic Transfer
- Rotating Cutter

Wenger
Basic Principles
Basic Principles

Raw feed ingredients

Extruded products

- Introduction
- Mixing & Cooking
- Metering

InstaPro
Basic Principles

Product Flow inside Extruder Barrel
Longitudinal Fluting allows Back Flow

Steamlock acts as Flow Control Valve

InstaPro
Basic Principles

Raw feed ingredients → HTST PROCESS

Temperature
Pressure

Extruded products

15sec - 20sec

InstaPro

Temperature
Atmospheric pressure

Raw feed ingredients

Extruded products

HTST PROCESS

Raw feed ingredients

Extruded products
Basic Principles

- Temperature distributions
Basic Principles

- Temperature distributions
Basic Principles

- Pressure distributions
Basic Principles

\[ V_1 = \frac{mRT_1}{P_1} \]
\[ V_2 = \frac{mRT_2}{P_2} \]
\[ P_1 V_1 = P_2 V_2 \]
\[ V_2 = \frac{P_1}{P_2} V_1 \]
Basic Principles

- Die exit
Basic Principles

- Die – for shaping
Types of Extruders

- Single screw
Types of Extruders

- Twin screw
  - Co-rotating
  - Counter-rotating
Types of Extruders

- Laboratory-scale
Types of Extruders

- Pilot scale
Types of Extruders

- Commercial scale
Types of Extruders

- Continuous, single element screws
Types of Extruders

- Multiple element screws
Common Extrusion Conditions

- **Autogenous**
  - No external heat provided; “cold” extrusion
  - All heat is generated by friction

- **Isothermal**
  - Barrel maintained at constant temperature
  - External jackets around barrel

- **Polytropic**
  - Most systems
  - External heat + frictional heat + external cooling
Common Extrusion Conditions

- **Moisture of dough**
  - Low: < 20%
  - Medium: 20 – 30%
  - High: > 30%

- **Shear / screw speed**
  - Low: < 20 1/s (< 191 rpm)
  - Medium: 20 – 100 1/s (191 – 955 rpm)
  - High: > 100 1/s (> 955 rpm)
Producing Quality Aquafeeds

- Several key variables
  - Raw ingredients
  - Processing conditions
  - Final products
  +
- Theoretical considerations
Key Variables

- Raw Ingredient Properties
  - Composition
    - Protein, lipid, fiber, starch, ash, AA profile, FA profile, etc.
  - Particle size distribution
  - Moisture content
  - Water activity
  - Color (Hunter $L-a-b$)
Key Variables

- Extrusion Processing Conditions
  - Geometry, size, shape
  - Temperature distribution
  - Die pressure
  - Dough density in the die
  - Specific mechanical energy (SME)
  - Feed input rate
  - Water input rate (conditioner + extruder)
  - Steam input rate (conditioner + extruder)
  - Extrudate discharge rate (throughput)
Key Variables

- Extruded Product Properties
  - Composition changes
    - Protein, lipid, fiber, starch, ash, AA profile, FA profile
    - Digestibility changes
  - Moisture content
  - Water activity
  - Color (Hunter $L-a-b$) changes
  - Product diameter
  - Product expansion (CSEI, LEI, VEI)
  - Unit density / porosity
  - Bulk density
  - Pellet durability
  - Water absorption
  - Water solubility
  - Water stability
  - Floatability / sinking velocity
Basic Theory

Raw feed ingredients

Metering Zone
Shearing due to friction
Feed Zone

Extruded products
Basic Theory

- Melting – starch gelatinization
  - Break down intermolecular bonds of starch molecules in the presence of water and heat
    - Allows hydrogen bonding sites (the hydroxyl hydrogen and oxygen) to engage more water
    - Crystalline chains begin to separate into an amorphous form
    - Granules swell and then burst
  - Gelatinization temperature of starch
    - Depends on type, amount of water, pH, concentration of salt, sugar, fat and protein
    - Generally > 90 °C
Basic Theory

- Starch gelatinization
Basic Theory

- Flow – viscosity
Basic Theory

- Flow – viscosity

\[ \tau = \eta (-\dot{\gamma}) \]
Basic Theory

- Flow – viscosity
Basic Theory

- Flow rate (material throughput)

\[ Q = Q_d^\text{drag} + Q_p^\text{pressure} \]

\[ Q = \frac{m}{\rho} \]
Basic Theory

- Energy consumption

\[ E_{\text{total}} = E_{\text{mech}} + q + m_s \lambda \]  

(J)
Basic Theory

- Energy consumption

\[ E_{\text{mech}} = p \left( \frac{(\mu ND)^2 L}{\sin \theta} \right) \left( \mu \frac{W}{H} \right) \left( \cos^2 \theta + 4 \sin^2 \theta + \mu \frac{\rho}{\delta} \right) + p \left( \frac{\pi ND WH}{2} \right) (\Delta P \cos \theta) \]

\[ E_{\text{mech}} = \mu (\pi ND)^2 WL \left( \cos^2 \theta + 4 \sin^2 \theta + 3a \cos^2 \theta \right) \]

\[ H \sin \theta \]

\[ SME = \frac{E_{\text{mech}}}{m} \]

(J/kg)
Typical extruder power consumption curve. Mean power consumption was determined by averaging the net consumption (i.e., excluding that due to friction) from the beginning to the end of the trial.
Competing Effects during Extrusion

- As screw speed ↑
  - Viscosity ↓
    - Shear thinning (pseudoplastic)
  - SME ↑ at same T
    - Energy to turn screw greater than decrease in torque
- Expansion ↑
  - T increases due to increased friction
- Mass flow rate ↑
Competing Effects during Extrusion

- As temperature ↑
  - Viscosity ↓
    - Temperature effects
  - SME ↓ at same screw speed
    - Energy to turn screw decreases
- Expansion ↑
  - Greater water evaporation at die exit
Competing Effects during Extrusion

- Temperature is critical
  - T too low:
    - No cooking; feed particles don’t melt; no pellets form
  - T midrange:
    - Good cooking; starch gelatinization; particles melt and flow; expansion at die; pellet cohesion
  - T too high:
    - Protein denatures; burning; fouling; jamming
Competing Effects during Extrusion

- Amino acids, enzymes, antibiotics, pre/probiotics, vitamins

![Degradation vs. Time](image)

- Red line: $T=70$
- Yellow line: $T=80$
- Blue line: $T=90$
Competing Effects during Extrusion

- As moisture content increases:
  - Viscosity decreases
    - Less resistance to flow
  - SME decreases at same screw speed and temperature
    - Energy to turn screw decreases
  - Pressure drop decreases
  - Expansion decreases
Competing Effects during Extrusion

- Moisture content is critical
  - MC too low:
    - Pellets won’t bind together; no water stability
  - MC midrange:
    - Particles melt and flow well; proteins are plasticized; good binding; pellet cohesion; high water stability
  - MC too high:
    - Not enough cooking; pellets not cohesive; will plug extruder
Competing Effects during Extrusion

- As die diameter $\uparrow$
  - Pressure drop $\downarrow$
    - Less resistance to flow
  - SME $\downarrow$ at same screw speed and temperature
    - Energy to turn screw decreases
- Expansion $\downarrow$
  - Less water evaporation at die exit
Competing Effects during Extrusion

- Ingredient particle size is important
  - Best to mill all ingredients prior to extrusion
    - < 0.5 mm

- Otherwise
  - Stress fractures in pellets
  - Poor pellet durability
  - May plug die
    - Especially fish bones (from fish meal)
Competing Effects during Extrusion

- Ingredients + processing conditions + product quality
Extrusion Challenges

- **Fiber content**
  - Nonreactive with starch or protein
  - Absorbs water from other ingredients
  - Solution: grind all ingredients well; change formulation

- **Oil content**
  - Oil is a lubricant at high levels
    - Screw can’t push dough or build up pressure
  - Solution: coat oil after extrusion

- **Protein content**
  - High protein blends do not expand
    - Do not float well; are not water stable
  - Solution: increase moisture during extrusion; change starch source
Quality Considerations

Some examples of high quality pelleted feeds
Quality Considerations

Some examples of poor quality pelleted feeds
Quality Considerations

Floating feeds

Sinking feeds
Quality Considerations

Low water stability
Small-scale extruder

Extruder input

Extruder power

50 – 250 kg/h/machine; > 1000 in Bangladesh
Farm-Scale Mills

Air-drying extruded pellets
Thank you

Any questions?