Commercial Aquaculture Feed Production (Floating Feeds)

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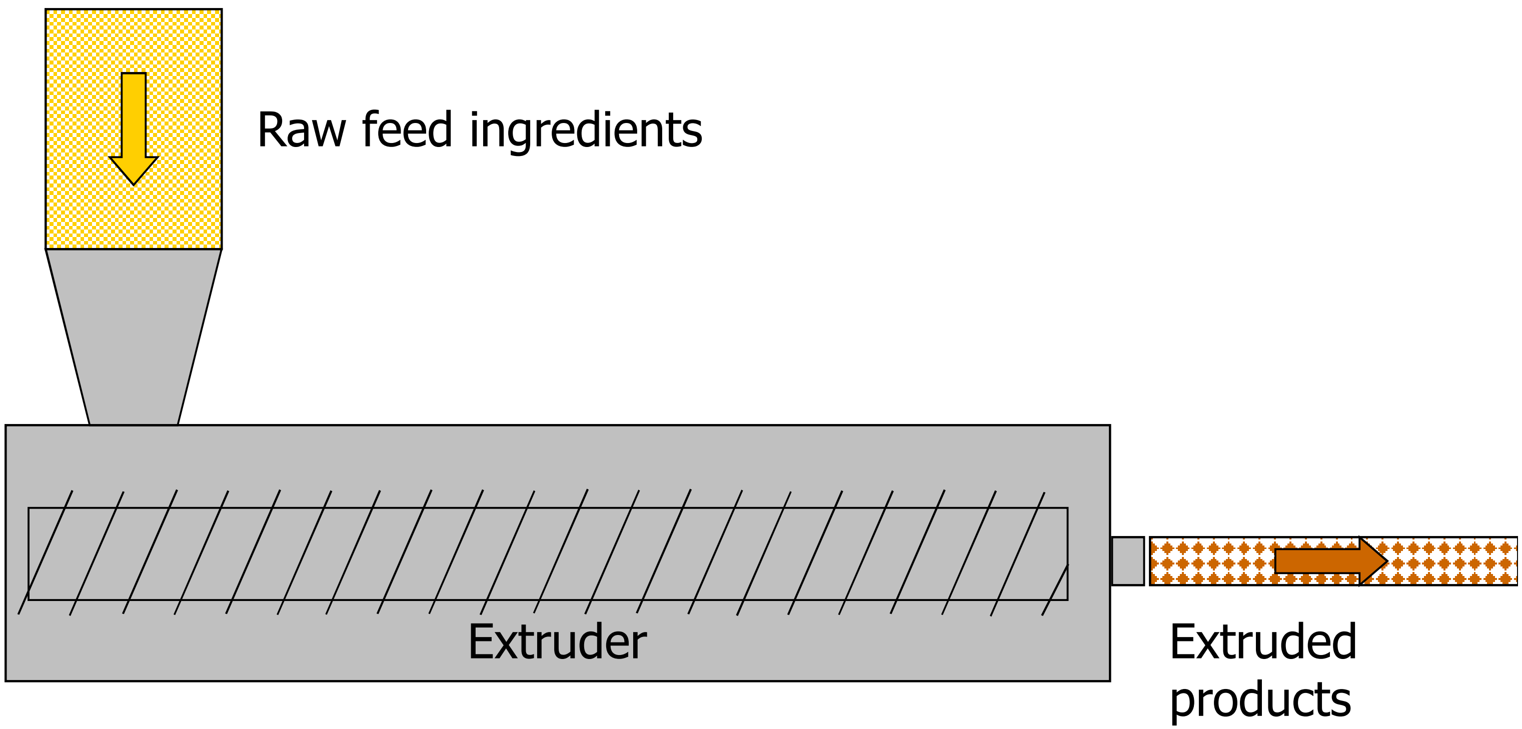
Presentation Outline

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

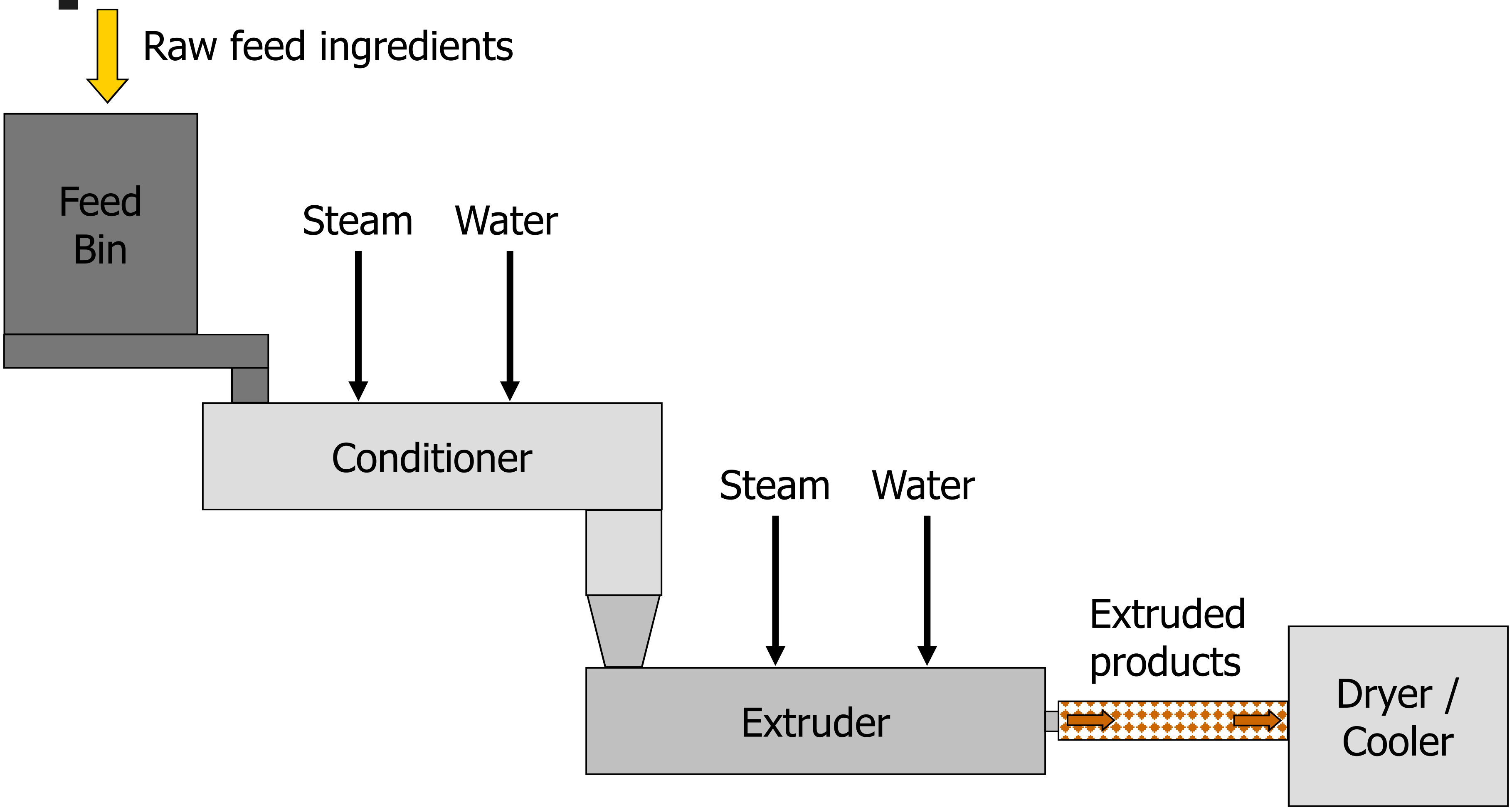
Goals of Extrusion Processing

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

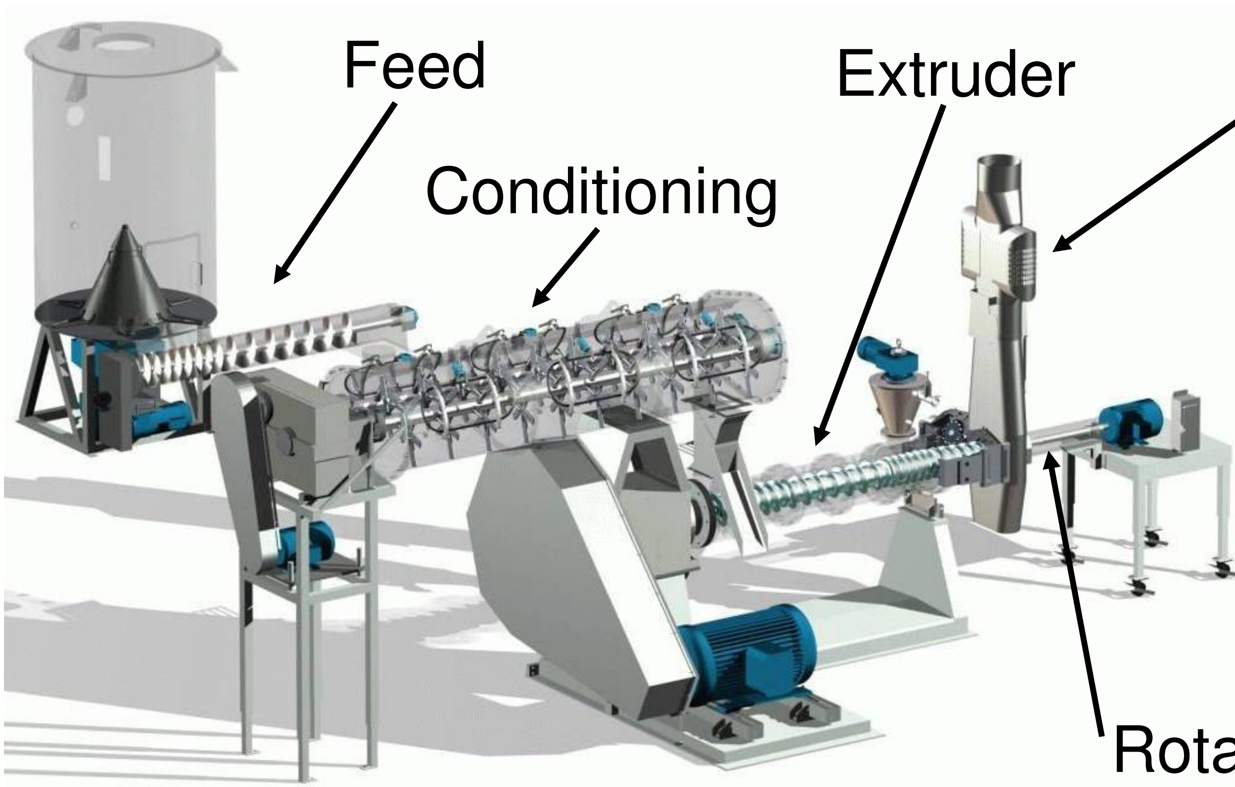
Basic Principles



Basic Principles

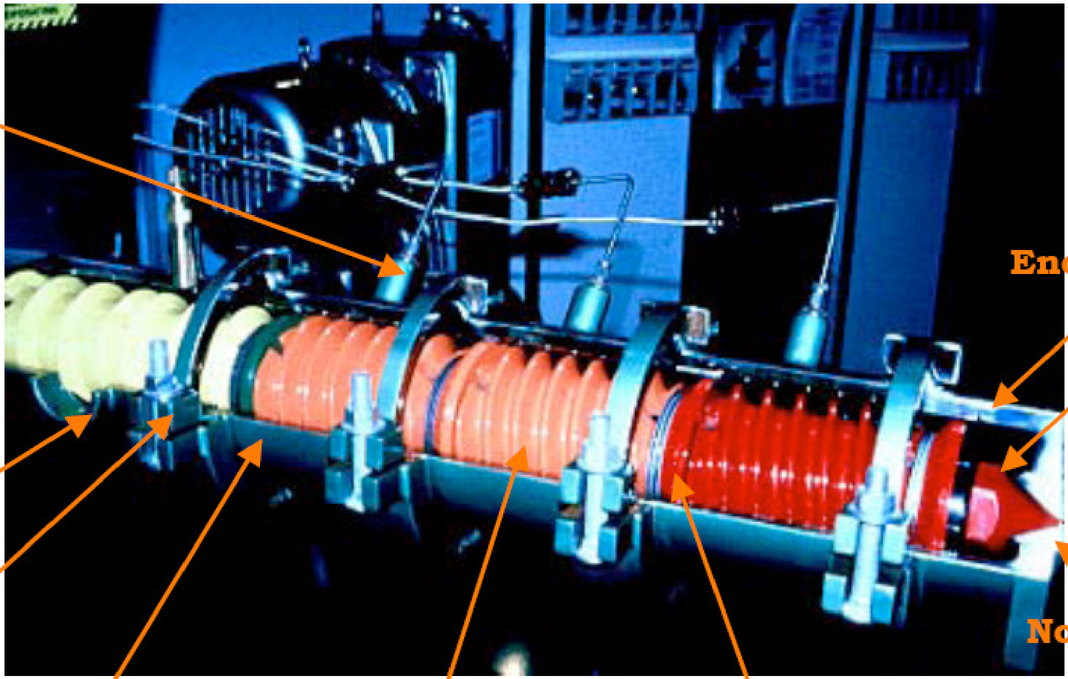


Basic Principles



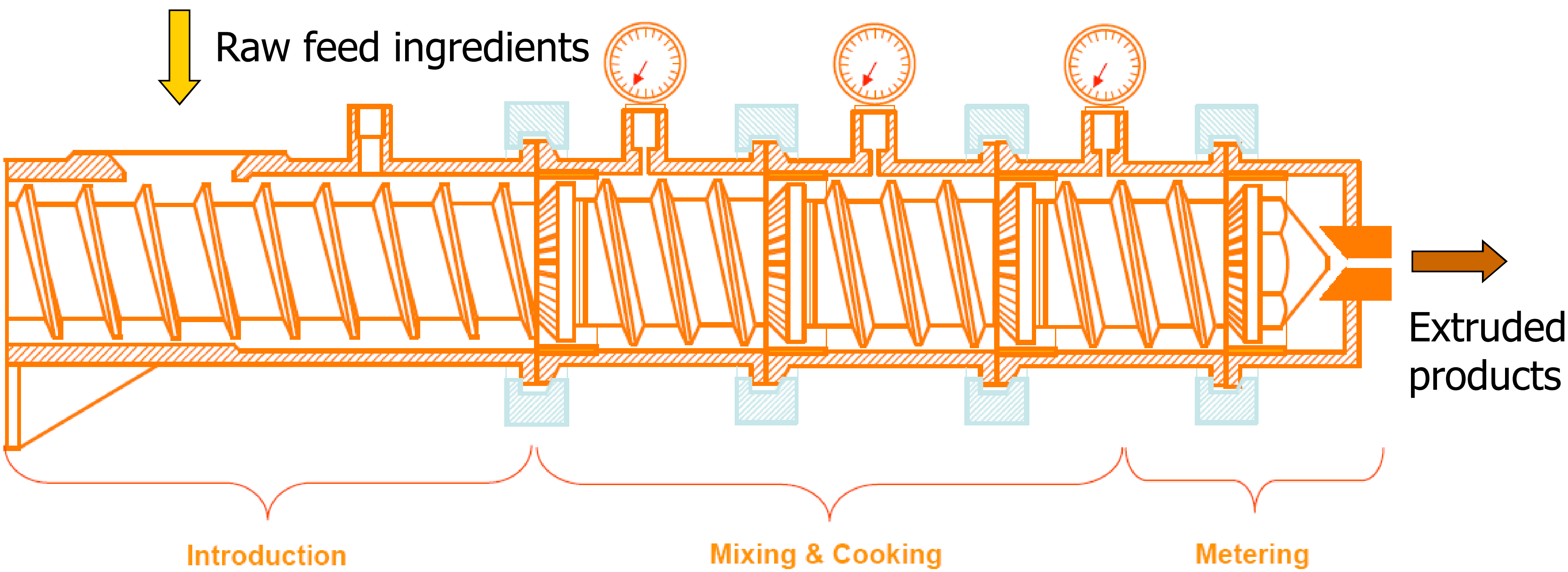
Wenger

Basic Principles



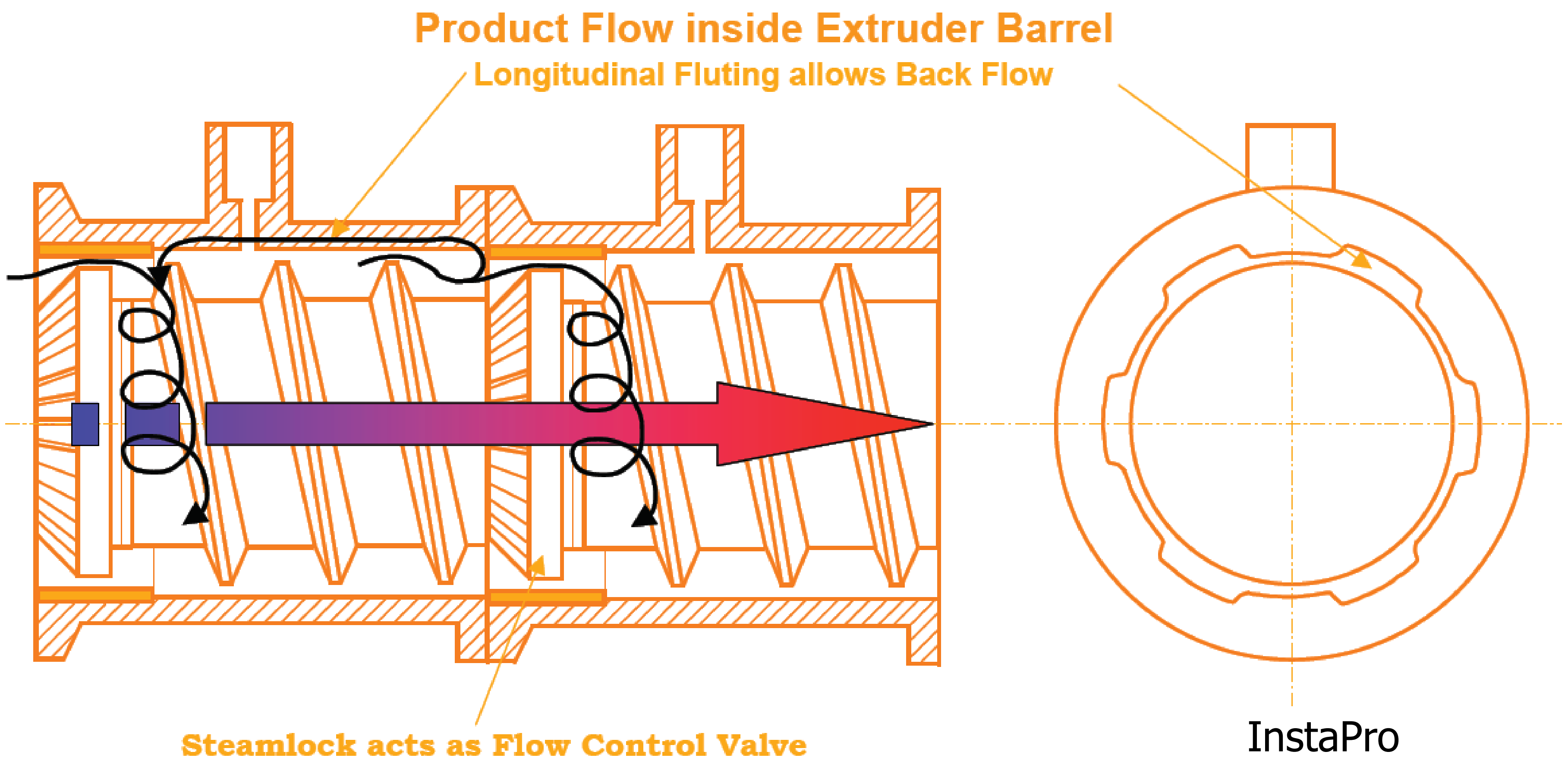
InstaPro

Basic Principles

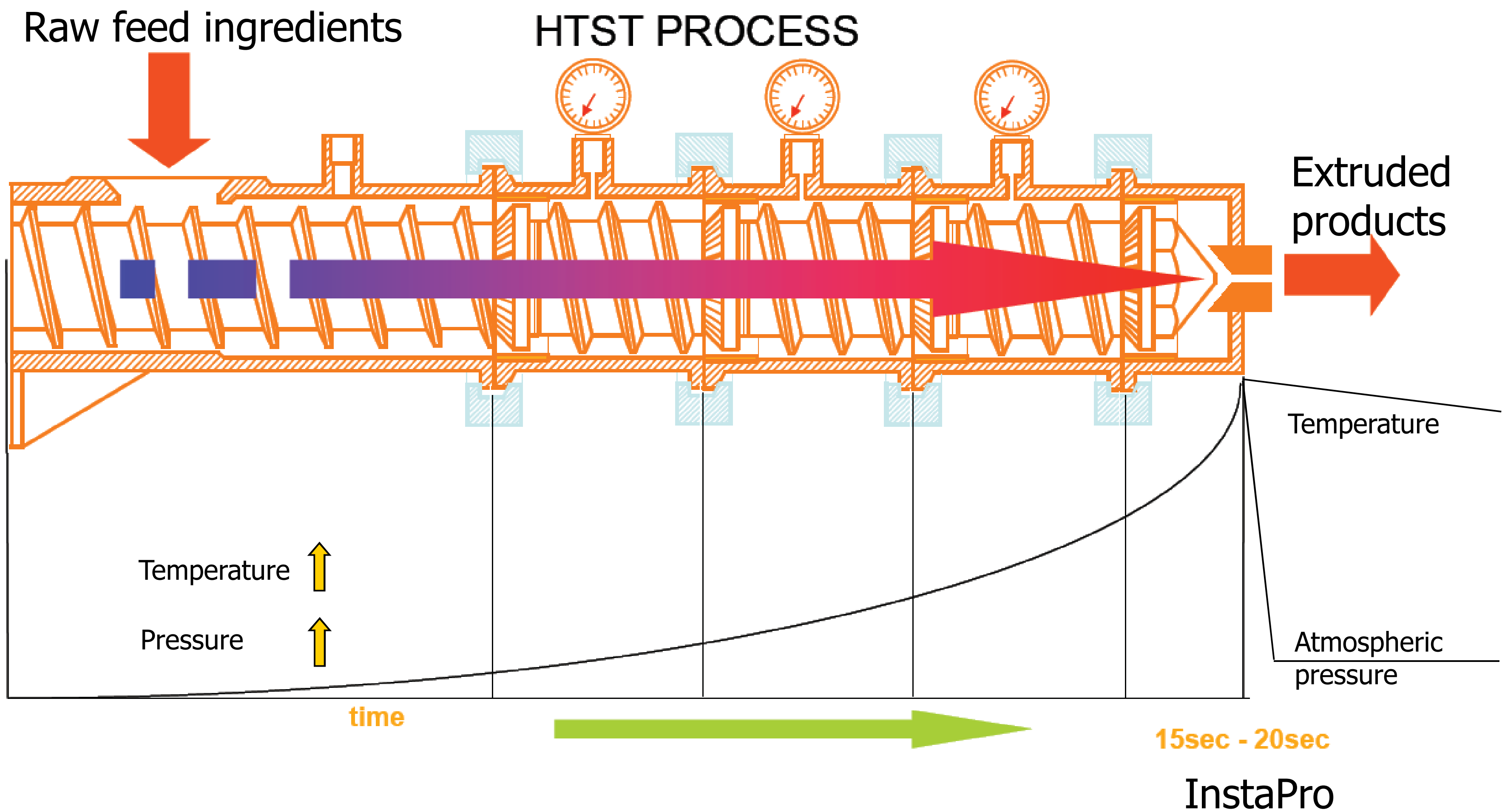


InstaPro

Basic Principles

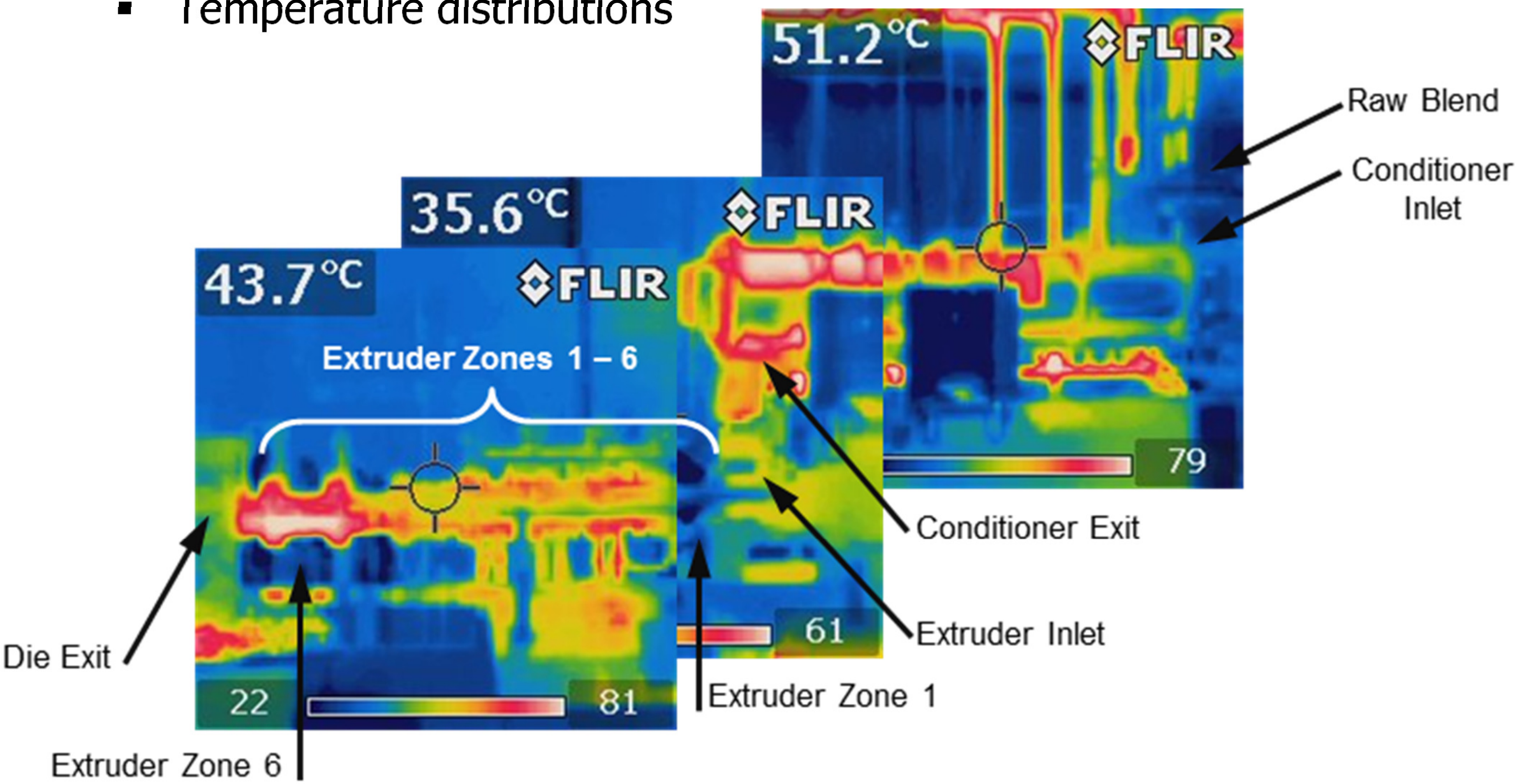


Basic Principles



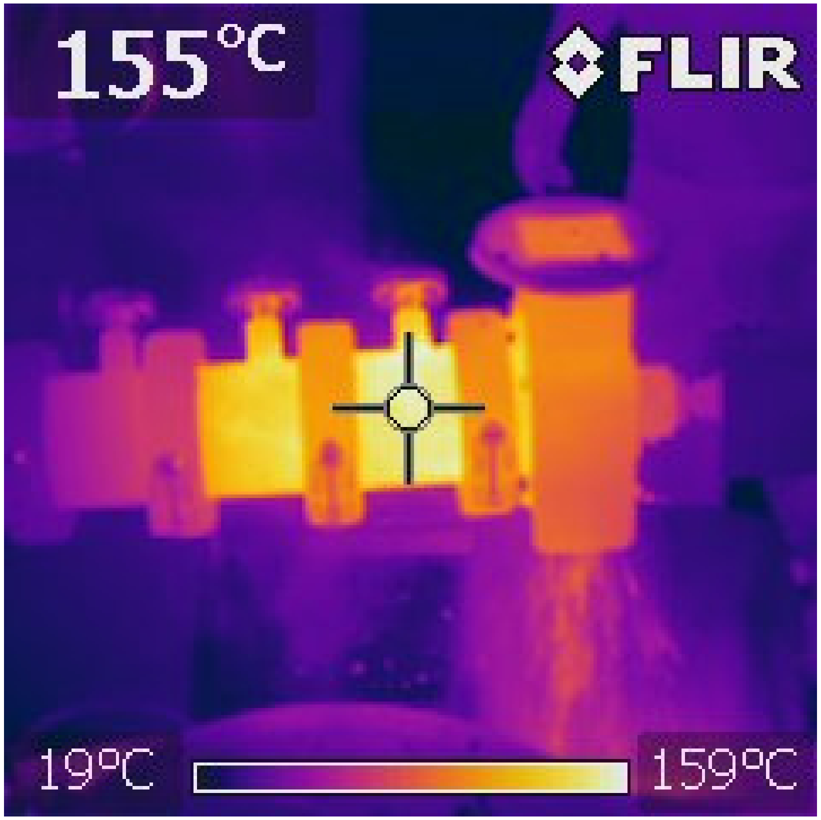
Basic Principles

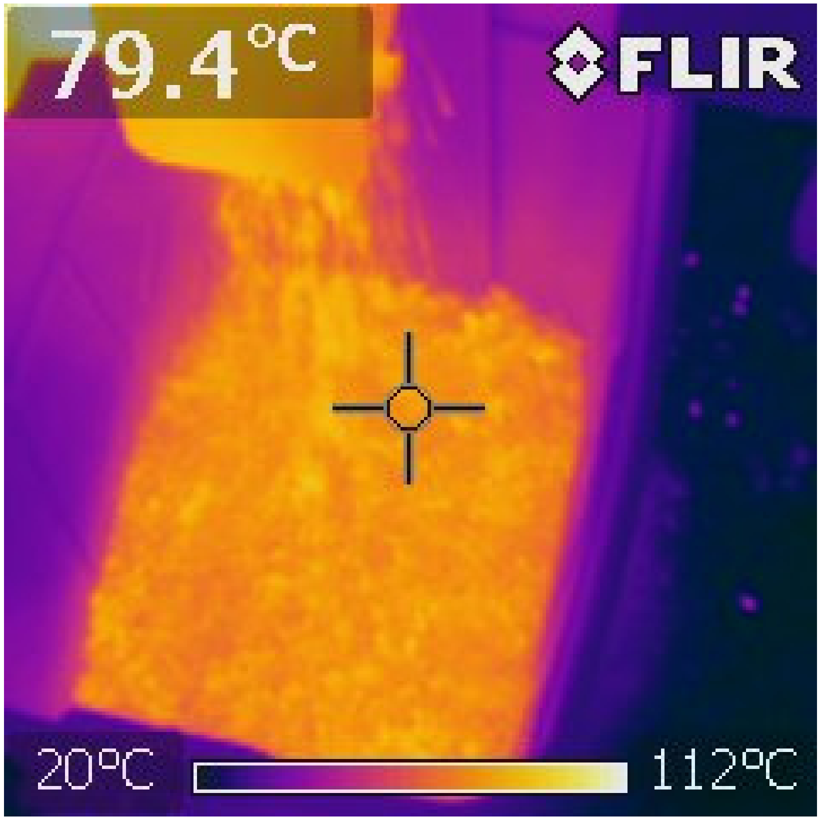
- Temperature distributions



Basic Principles

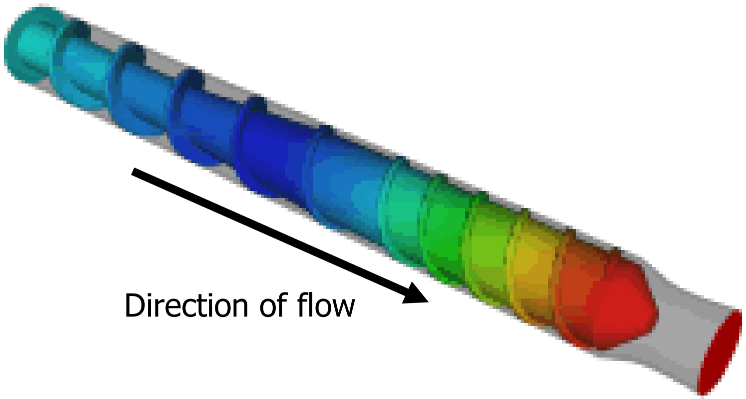
- Temperature distributions

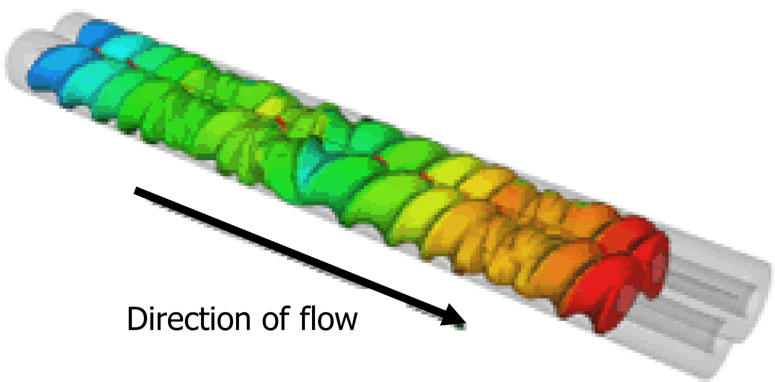




Basic Principles

- Pressure distributions

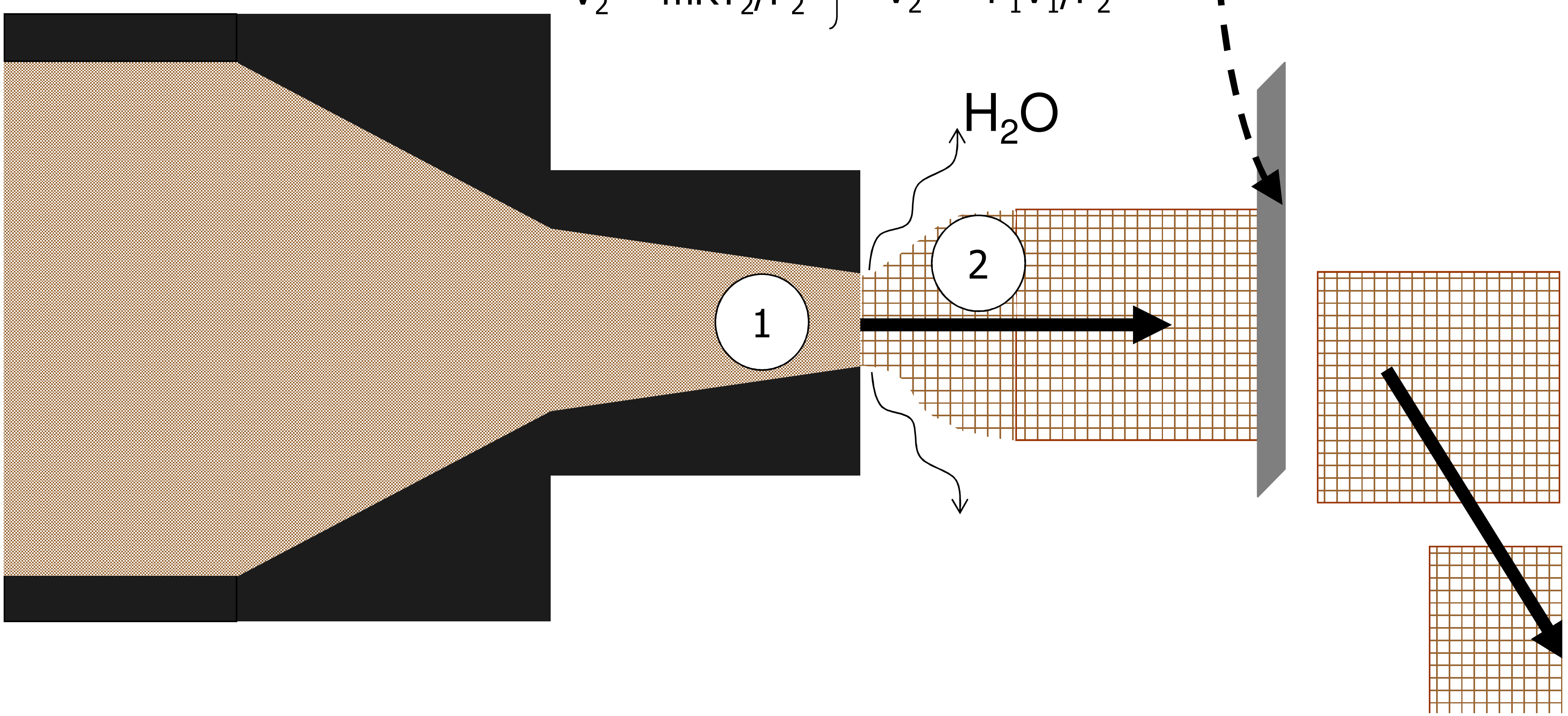




Basic Principles

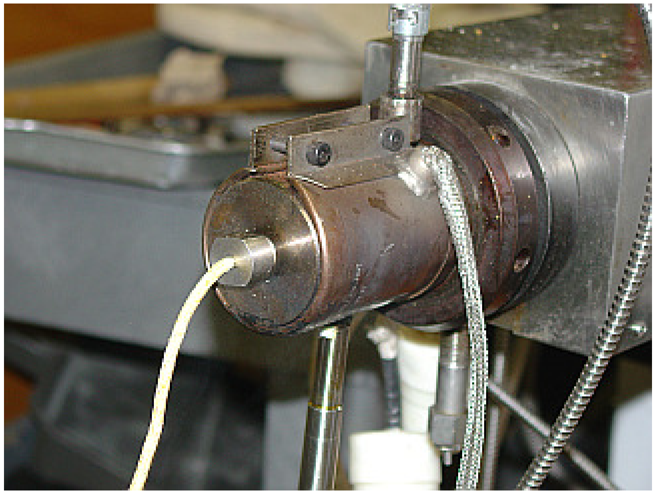
- Die exit

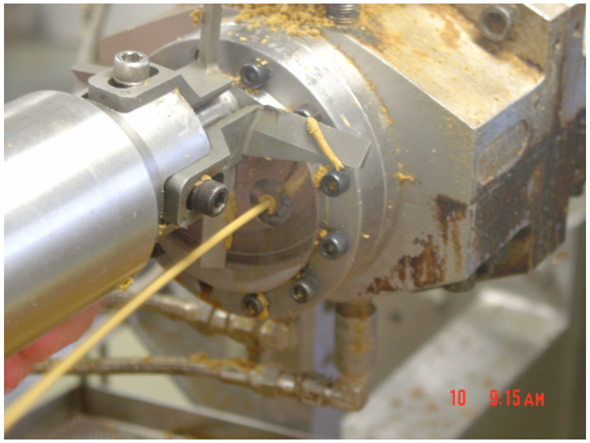
$$V_1 = mRT_1/P_1 \qquad P_1V_1 = P_2V_2$$
$$V_2 = mRT_2/P_2 \qquad V_2 = P_1V_1/P_2$$



Basic Principles

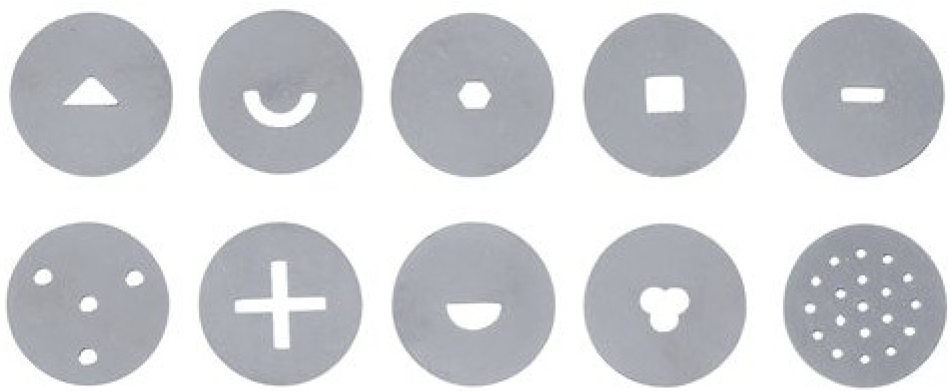
- Die exit





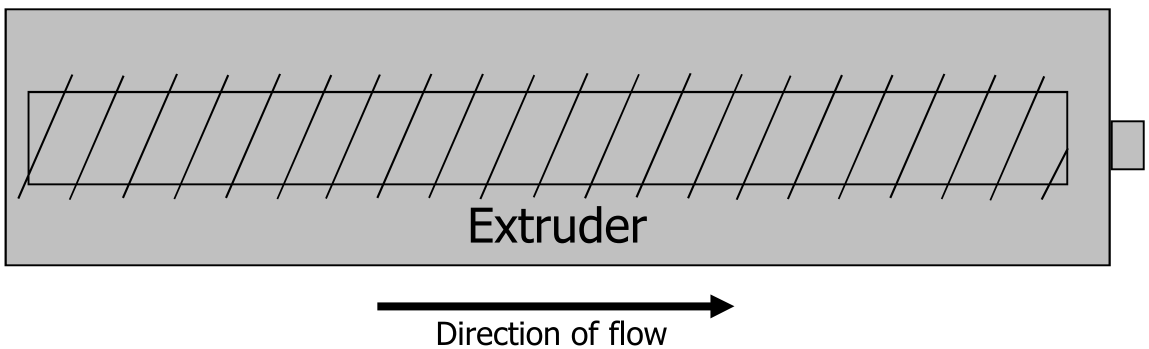
Basic Principles

- Die – for shaping



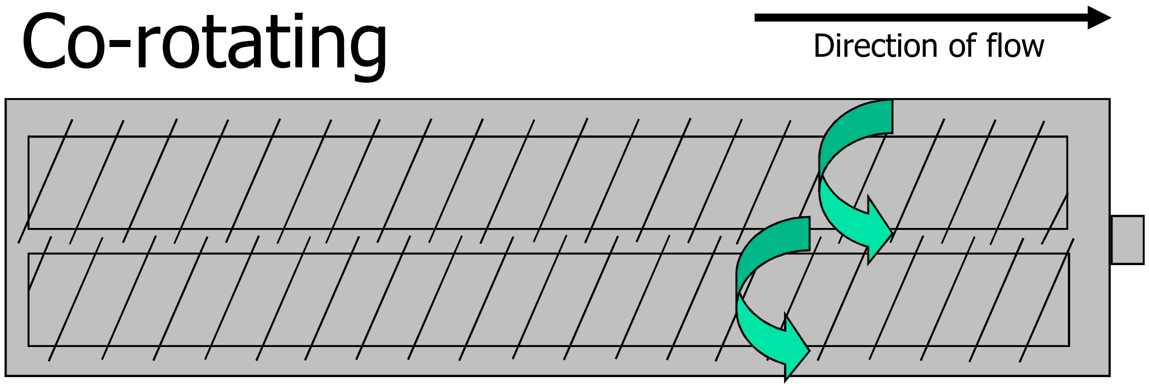
Types of Extruders

- Single screw

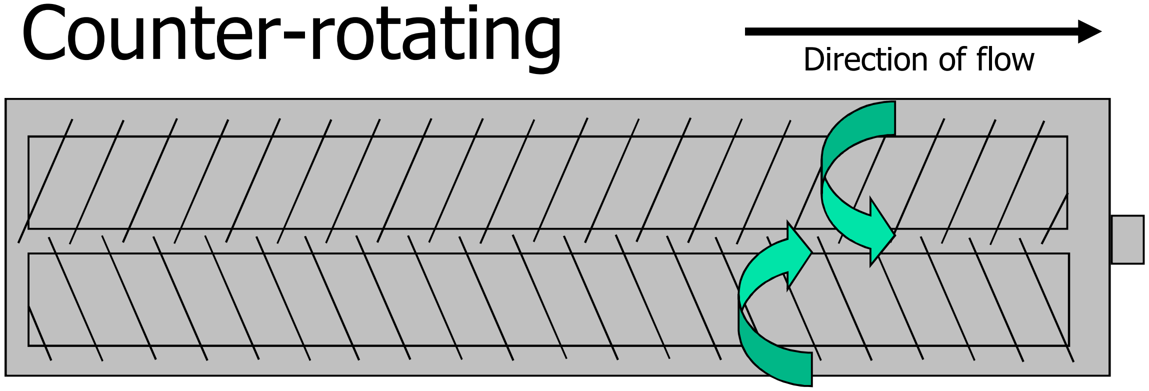


Types of Extruders

- Twin screw
  - Co-rotating

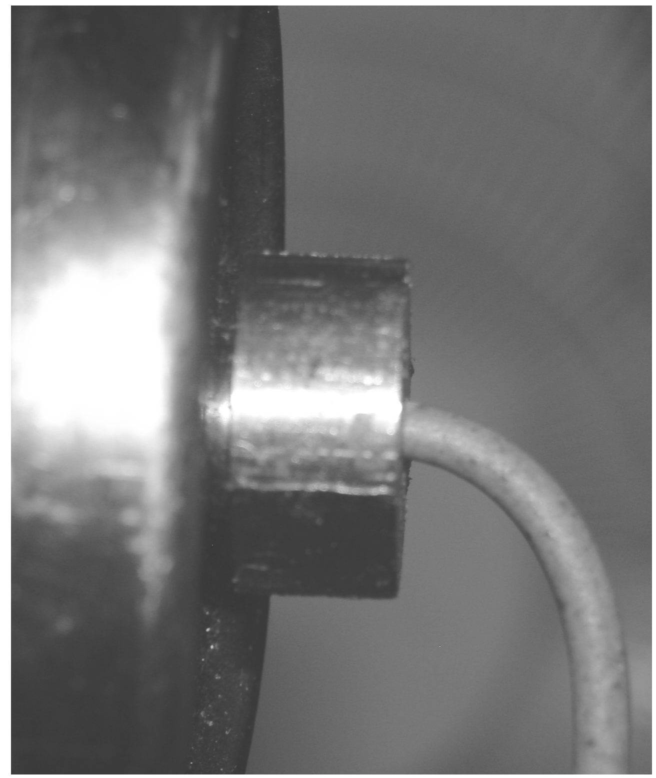


  - Counter-rotating



Types of Extruders

- Laboratory-scale

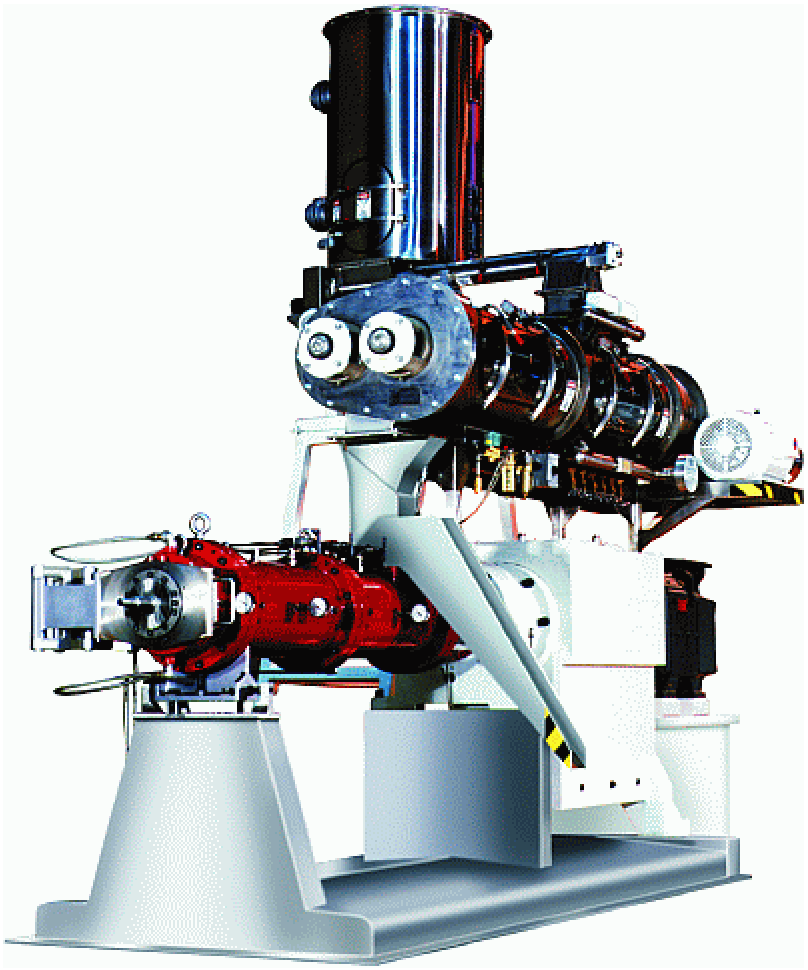


Types of Extruders

- Pilot scale

Types of Extruders

- Commercial scale

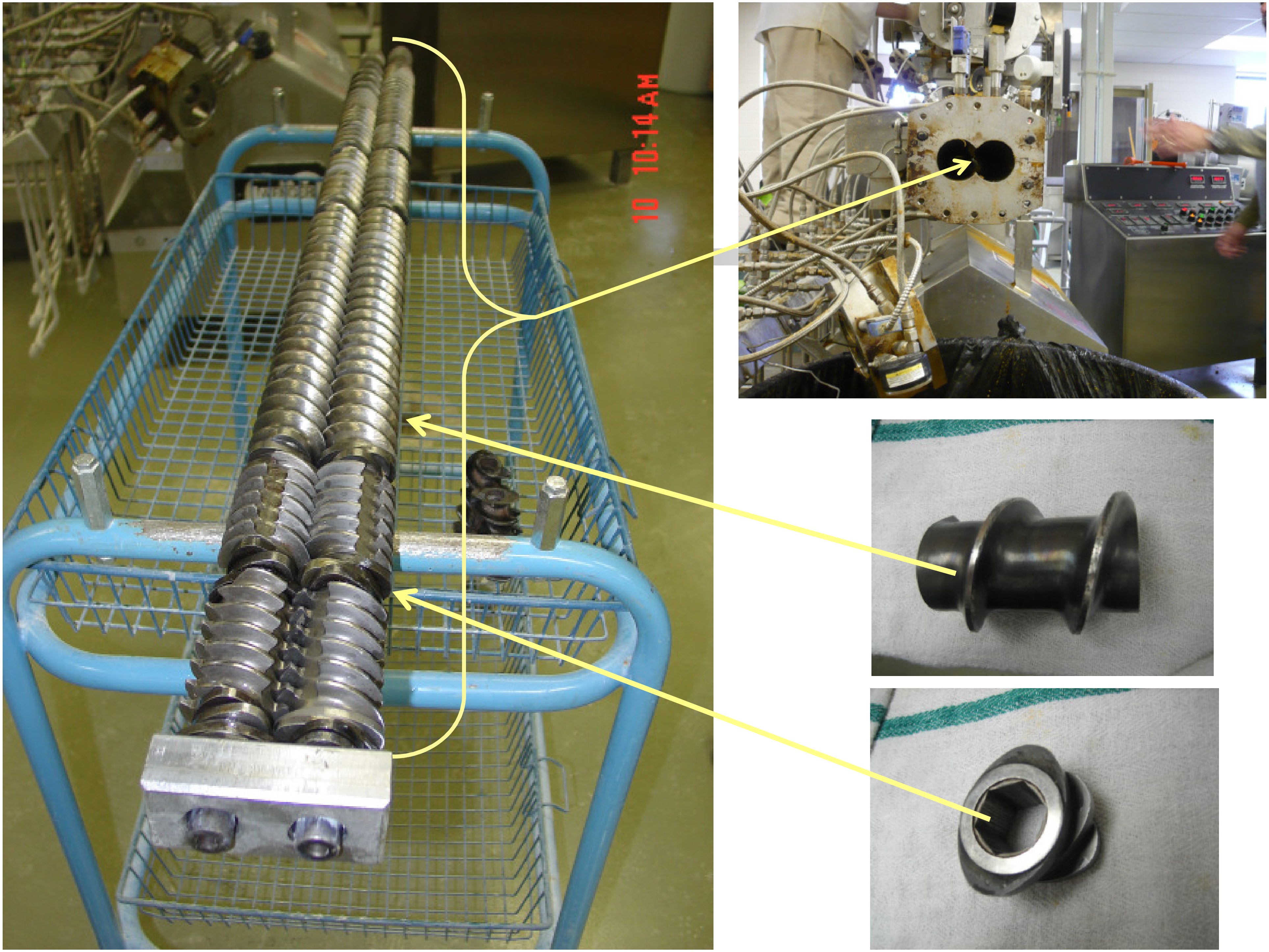


Types of Extruders

- Continuous, single element screws

Types of Extruders

- Multiple element screws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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***)

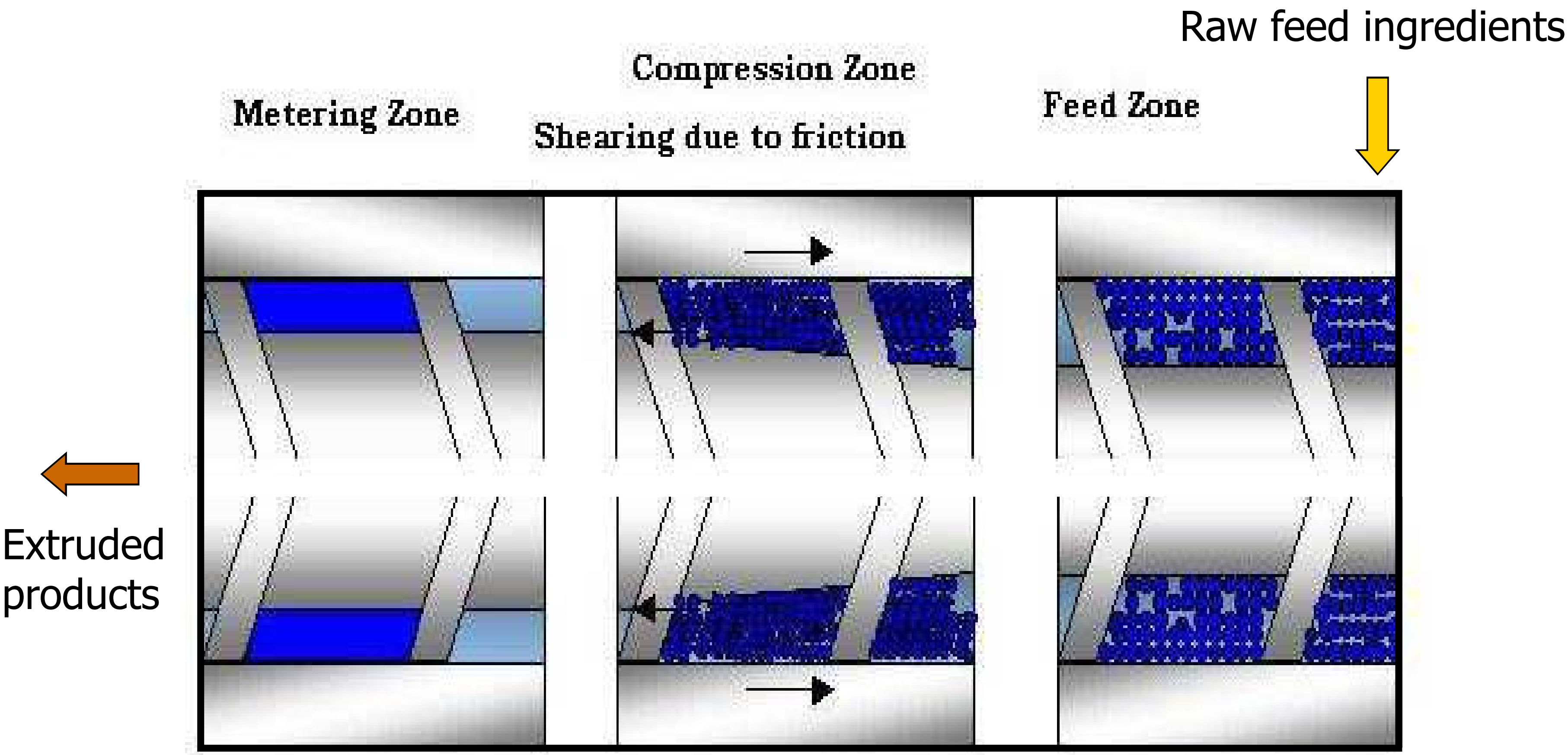
Key Variables

- 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

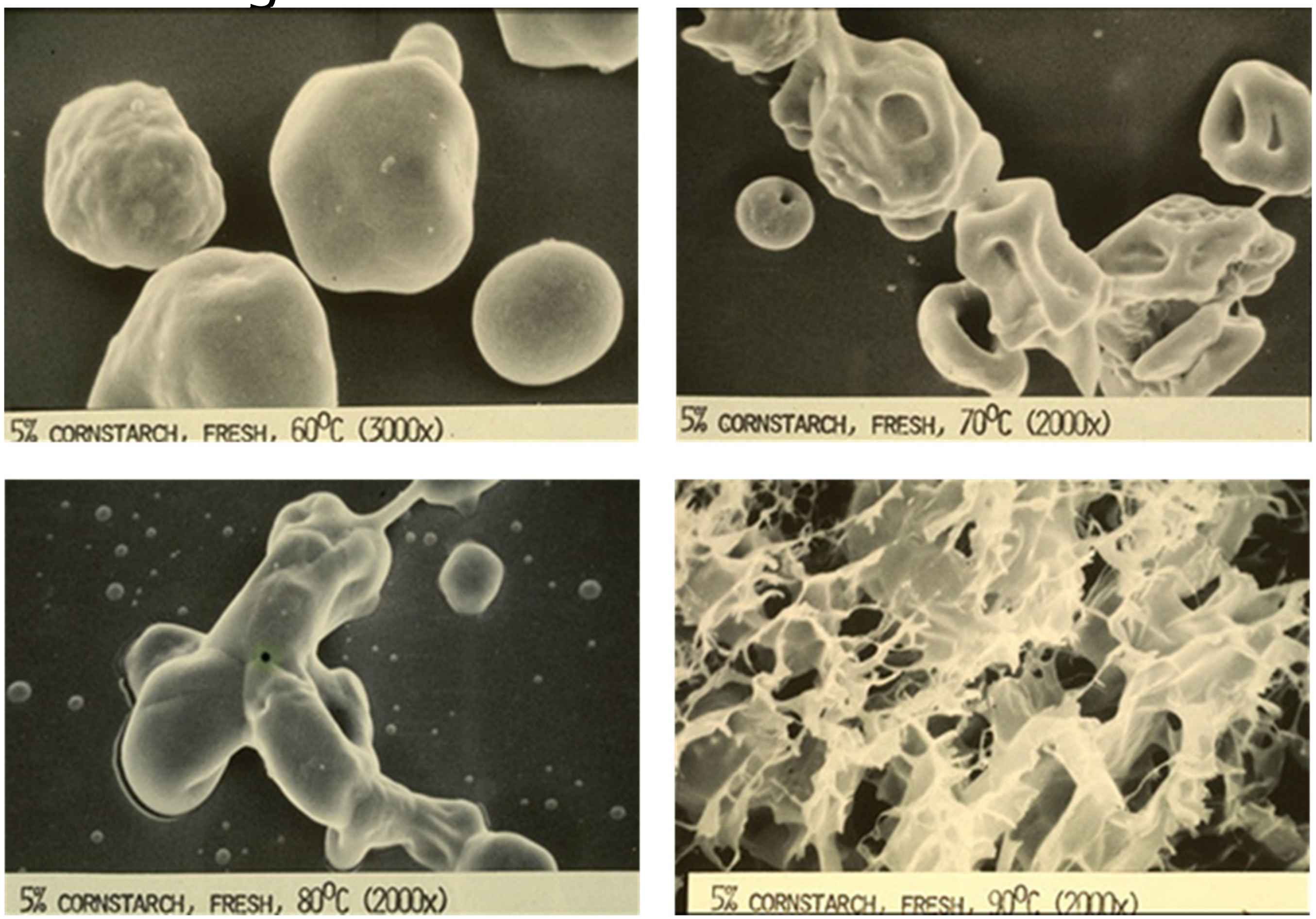


Basic Theory

- 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 ^{o}C

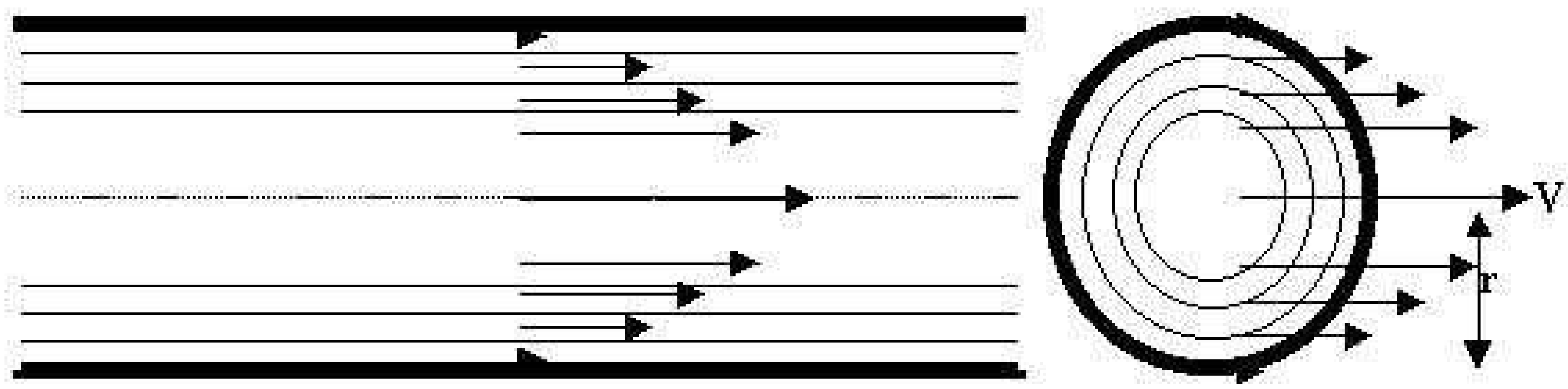
Basic Theory

- Starch gelatinization



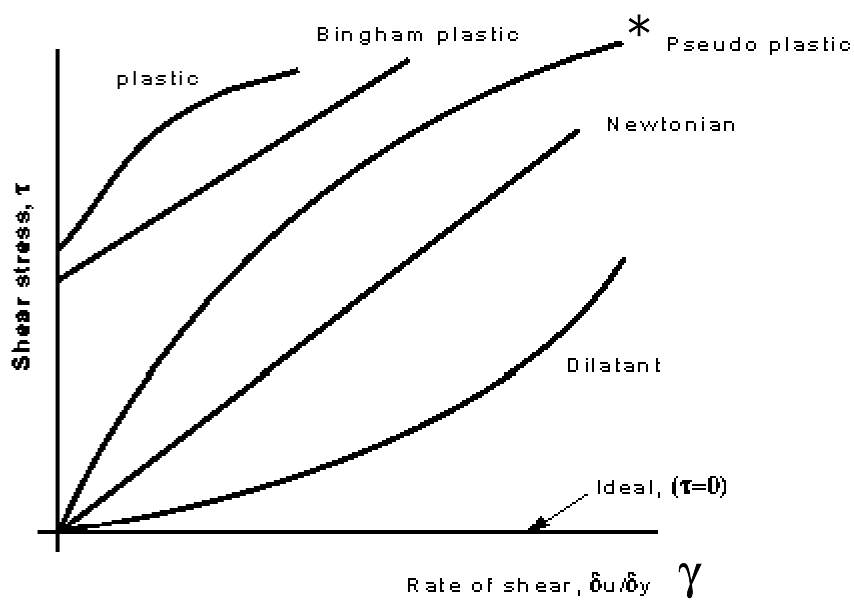
Basic Theory

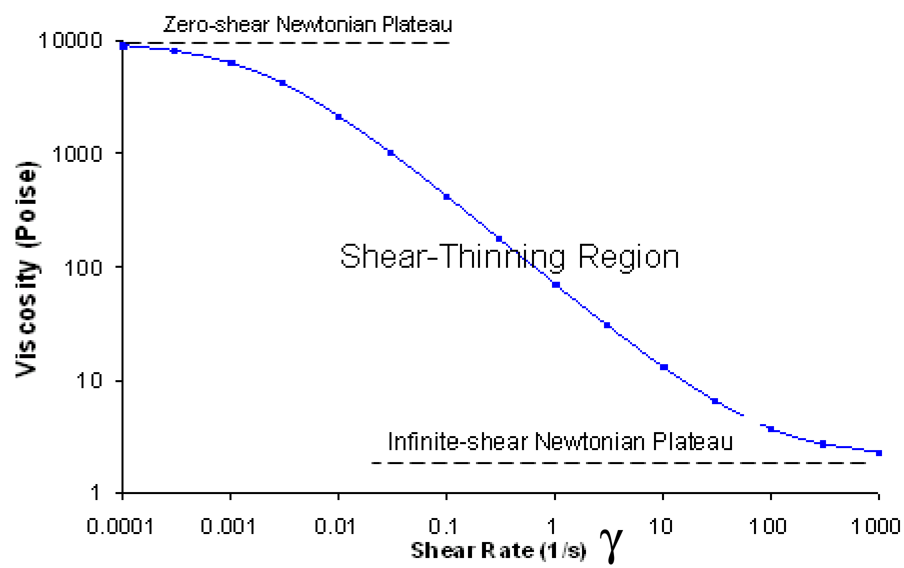
- Flow – viscosity



Basic Theory

- Flow – viscosity

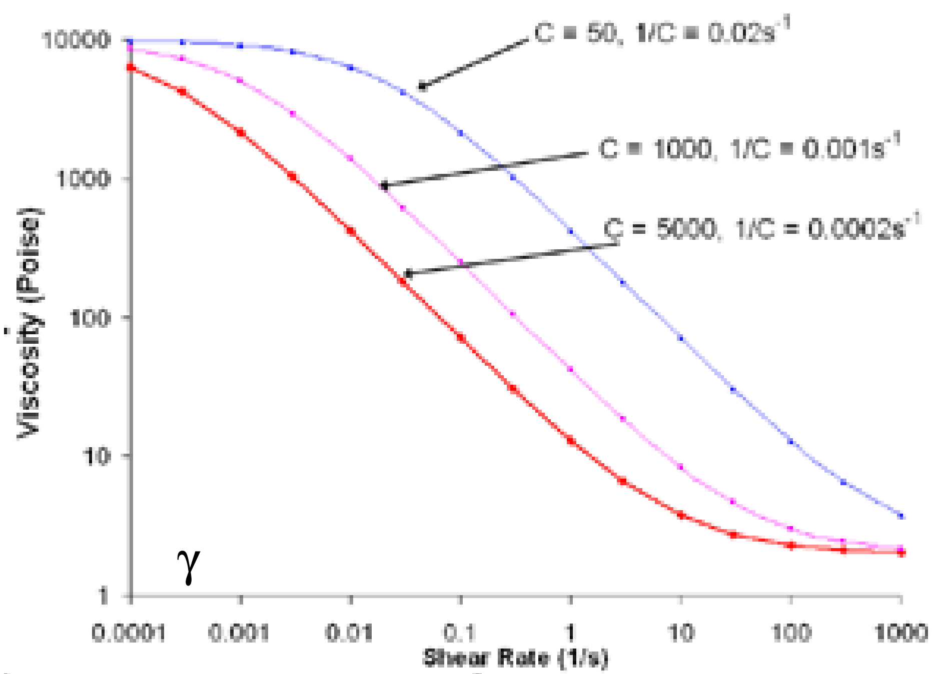




$$\tau = (\eta)\left(-\dot{\gamma}\right)$$

Basic Theory

- Flow – viscosity



Basic Theory

- Flow rate (material throughput)

$$Q = \overset{\text{drag}}{Q_d} + \overset{\text{pressure}}{Q_p}$$

$$Q = \frac{\dot{m}}{\rho}$$

Basic Theory

- Energy consumption

Drive shaft — Heated jackets — Steam

$$E_{total} = E_{mech} + q + \dot{m}_s \lambda$$

(J)

Basic Theory

- Energy consumption

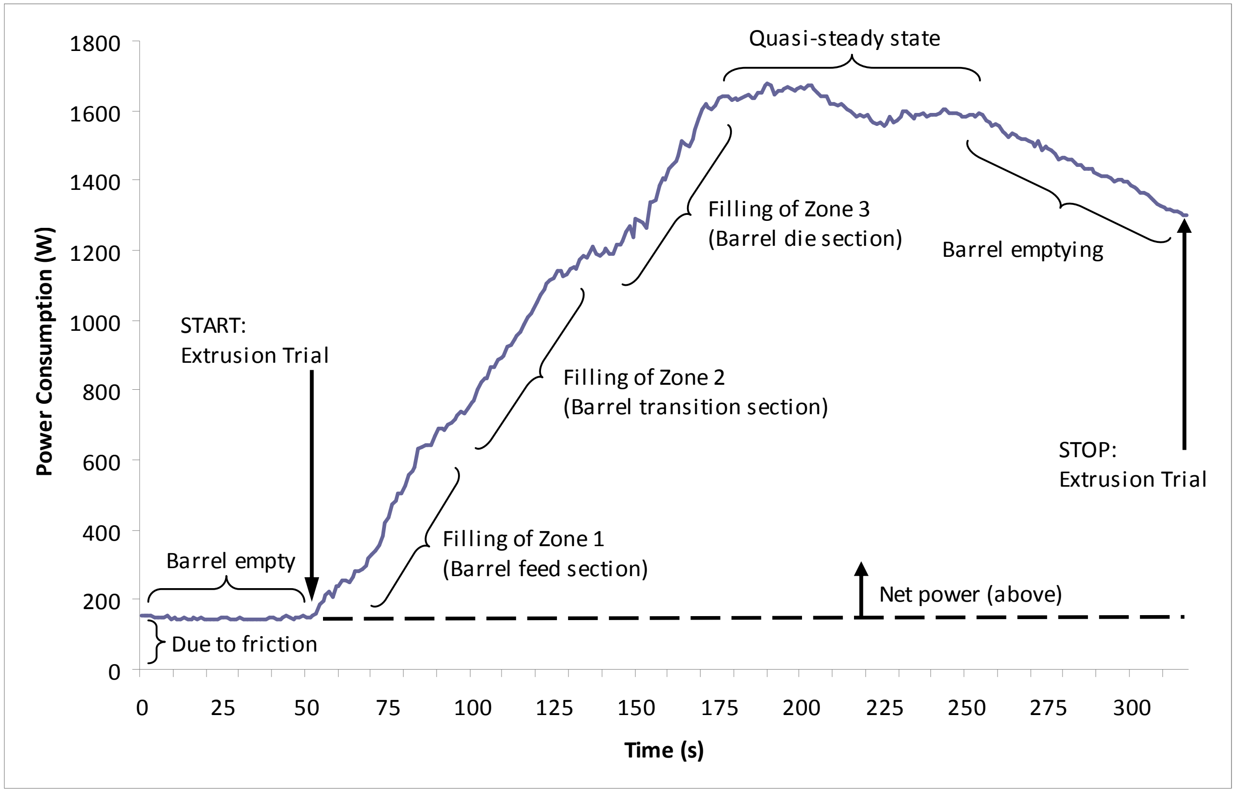
$$E_{mech} = p\left(\frac{(\pi ND)^2 L}{\sin\theta}\right)\left(\left(\mu\frac{W}{H}\right)\left(\cos^2\theta + 4\sin^2\theta\right) + \mu_\delta\frac{e}{\delta}\right) + p\left(\frac{\pi NDWH}{2}\right)(\Delta P\cos\theta)$$

$$E_{mech} = \frac{\mu(\pi ND)^2 WL\left(\cos^2\theta + 4\sin^2\theta + 3a\cos^2\theta\right)}{H\sin\theta}$$

$$SME = \frac{E_{mech}}{\dot{m}}$$

(J/kg)

Basic Theory



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

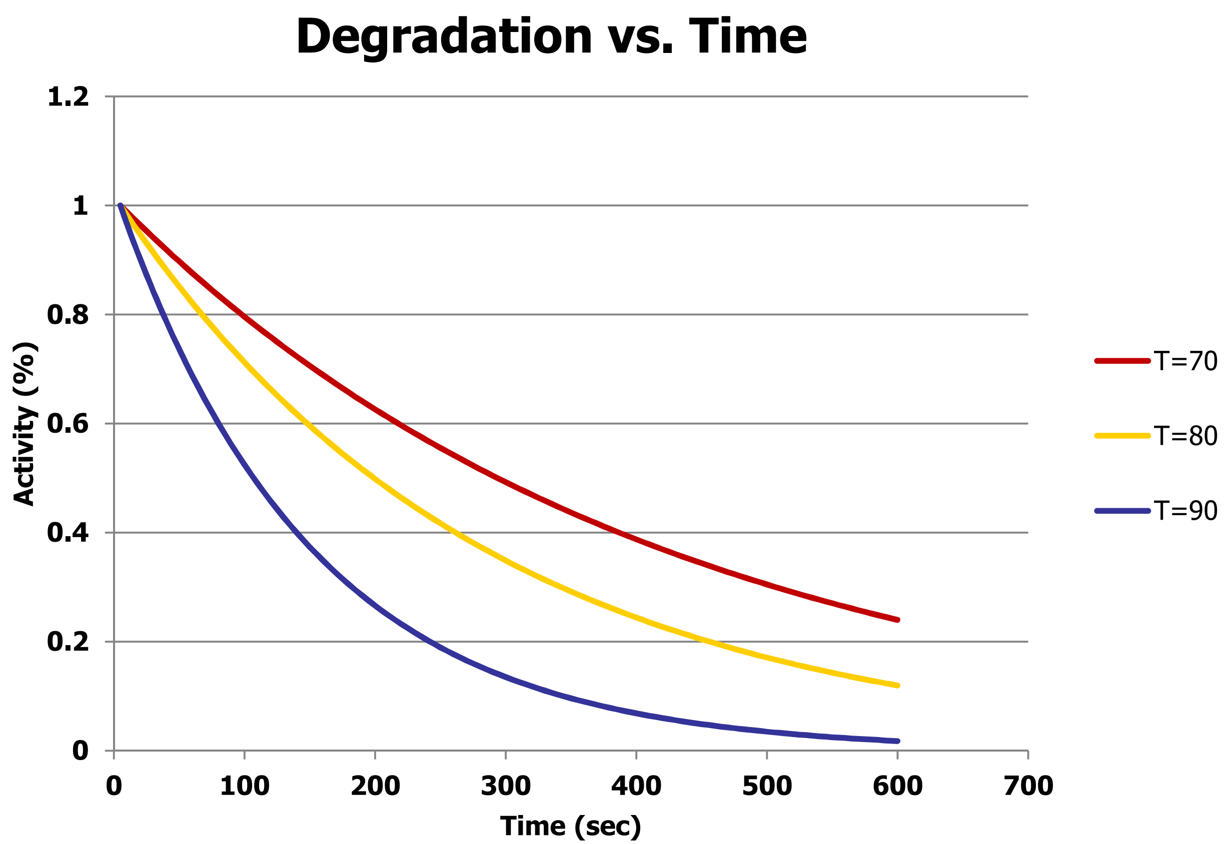
- As temperature ↑
  - Viscosity ↓
    - Temperature effects
  - SME ↓ at same screw speed
    - Energy to turn screw decreases
  - Expansion ↑
    - Greater water evaporation at die exit

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



Competing Effects during Extrusion

- As moisture content ↑
  - Viscosity ↓
    - Less resistance to flow
  - SME ↓ at same screw speed and temperature
    - Energy to turn screw decreases
  - Pressure drop ↓
  - Expansion ↓

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

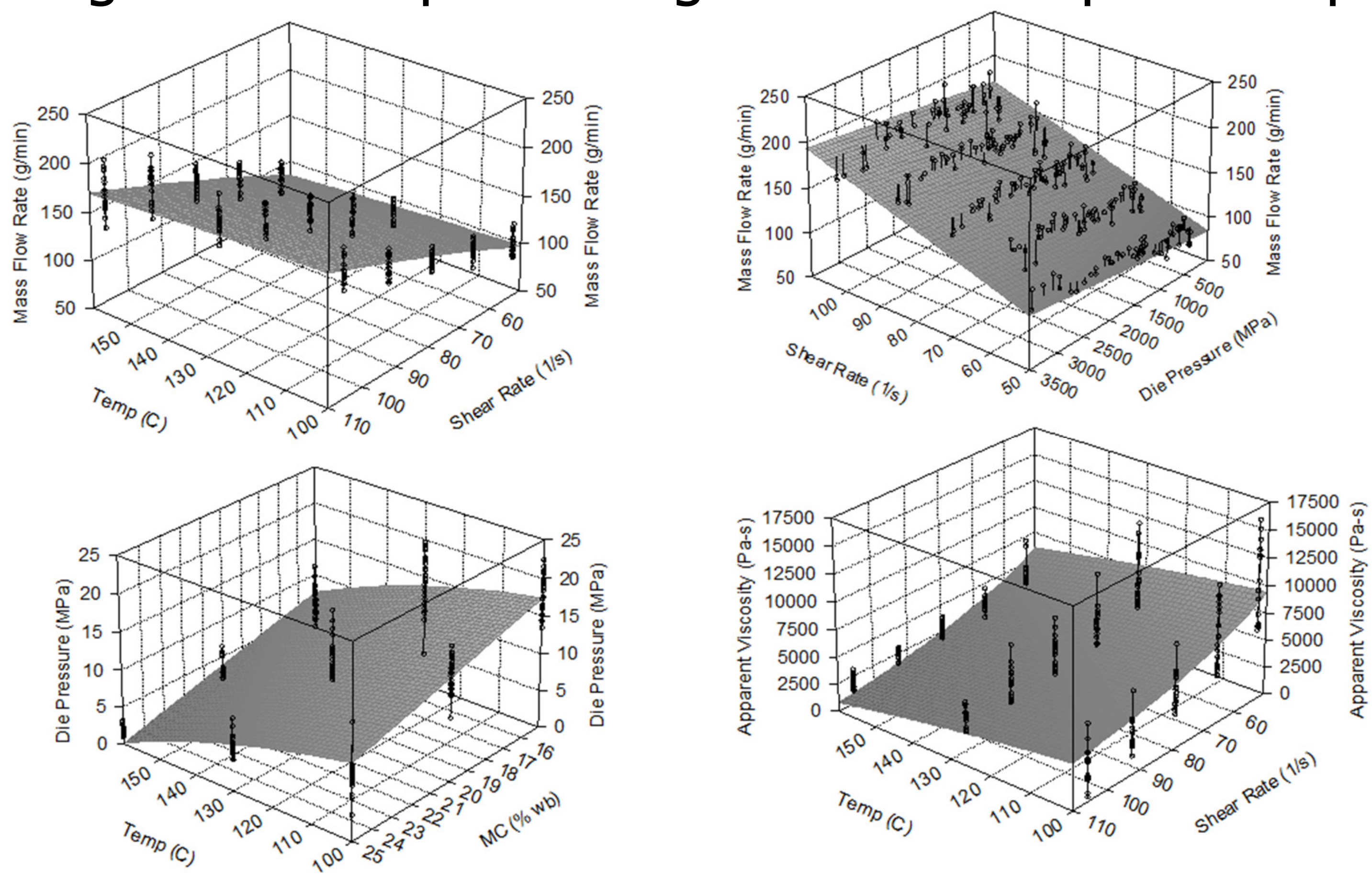
- As die diameter ↑
  - Pressure drop ↓
    - Less resistance to flow
  - SME ↓ at same screw speed and temperature
    - Energy to turn screw decreases
  - Expansion ↓
    - Less water evaporation at die exit

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

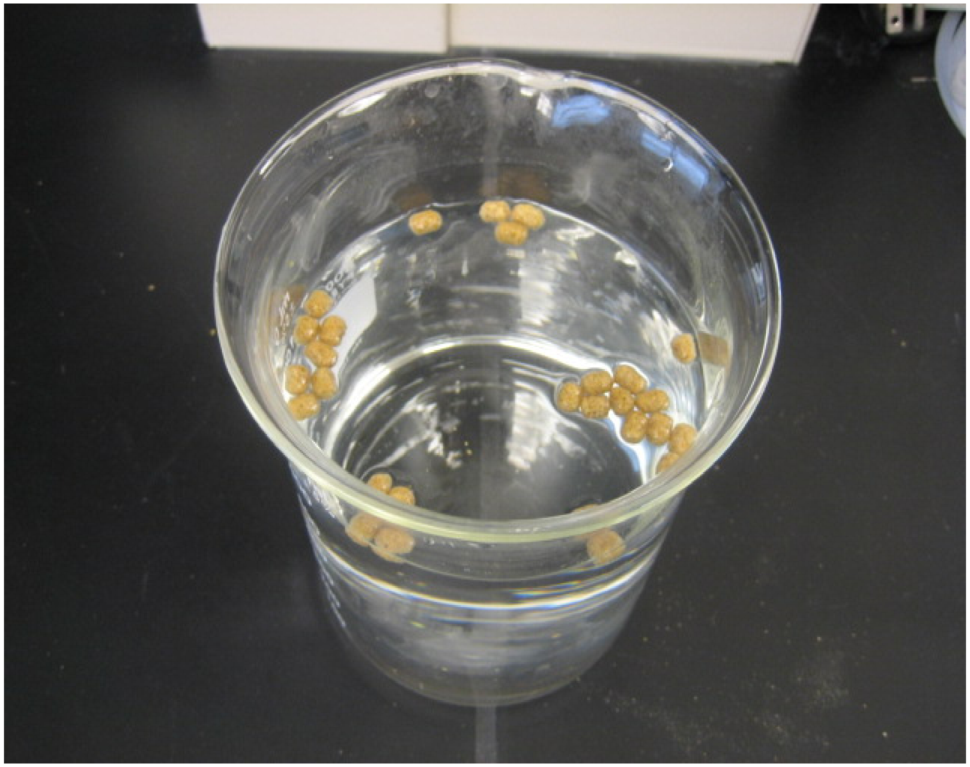
Quality Considerations

Some examples of high quality pelleted feeds

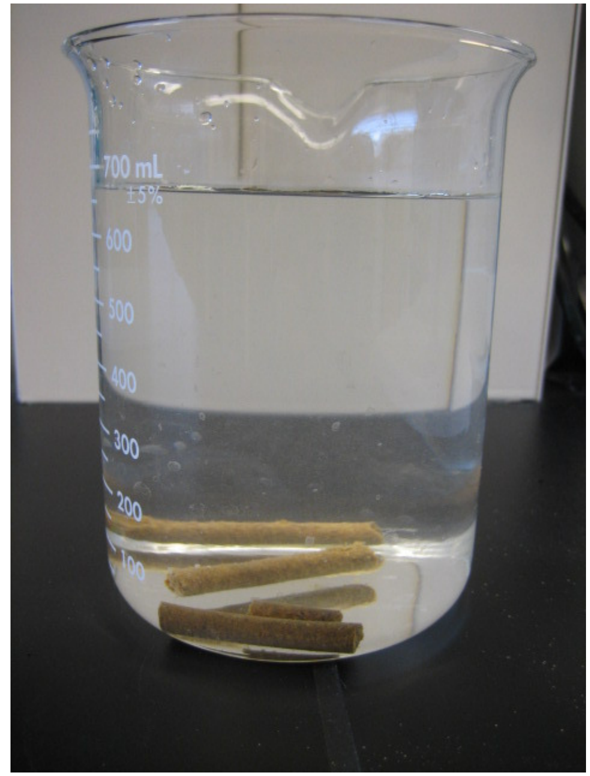
Quality Considerations

Some examples of poor quality pelleted feeds

Quality Considerations

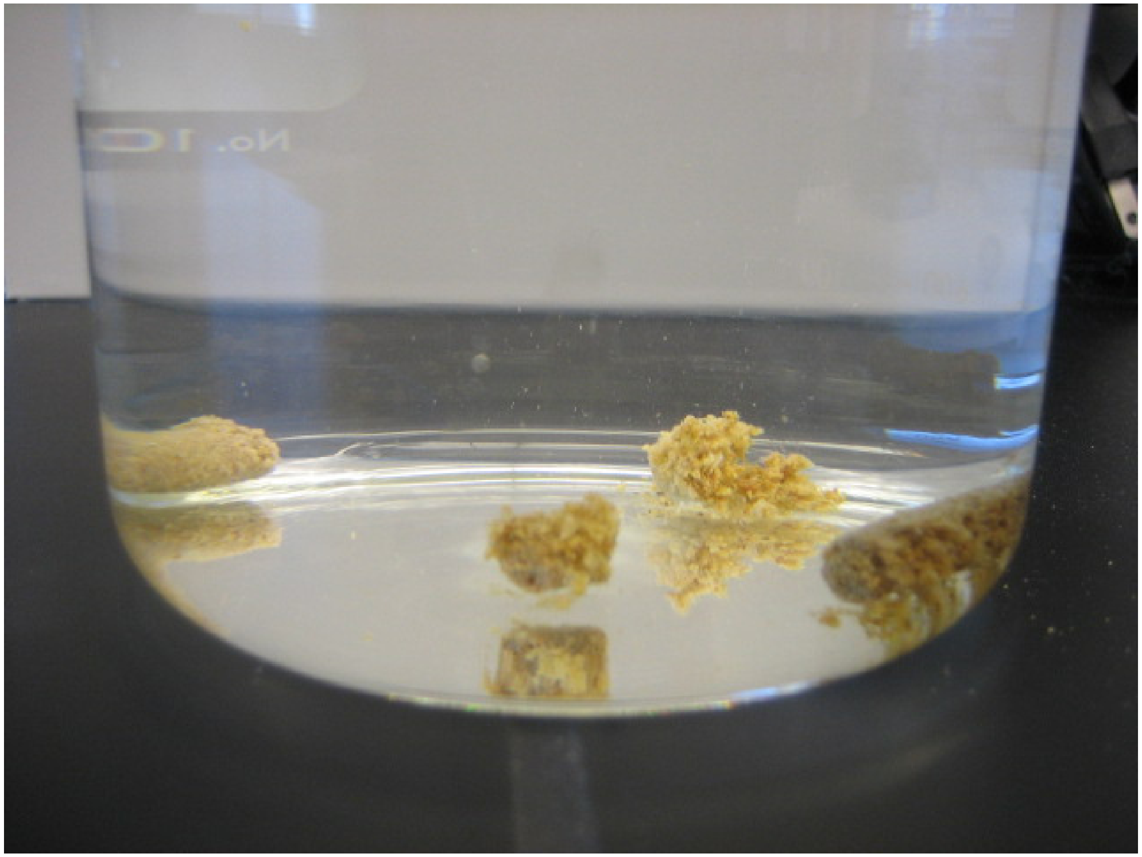


Floating feeds



Sinking feeds

Quality Considerations



Low water stability

Small-scale extruder

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?