Utilization of Different Combinations of Carbohydrate Sources for Density Control of Aquafeeds

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Product Density Can Be Changed by Three Tools:

1) Recipe adjustment and composition
2) Process Variables (not including recipe changes)
3) Hardware tools

Product Bulk Density Correlation with Buoyance

Pellet Characteristic	In sea water @ 20℃ (3% salinity)	In fresh water @ 20℃
Fast sinking	> 640 g/l	> 600 g/l
Slow sinking	580-600 g/l	540-560 g/l
Neutral buoyancy	520-540 g/l	480-520 g/l
Floating	< 480 g/l	< 440 g/l

Aquatic Feed Requirements
(Importance of density control and SME inputs)

1. Control of floating/sinking properties
2. Pellet durability for handling/transportation
3. Attractive pellet appearance (shape and size)
4. Proper fat absorption characteristics
5. Rapid water absorption while maintaining integrity
6. Fish health

Recommended Starch Levels in Aquatic Feeds

Type	Minimum Starch (%)
Floating	20
Sinking	10

Product Density Can Be Changed by Three Tools

Recipe adjustments and composition

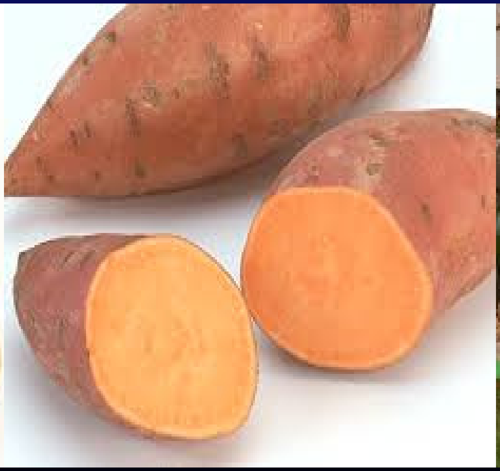
- **Carbohydrates (Starch and Fiber)**
- **Protein**
- **Fat**
- **Moisture**

Carbohydrates Sources

- **Common grains are corn, wheat, rice, oats, barley, and sorghum**

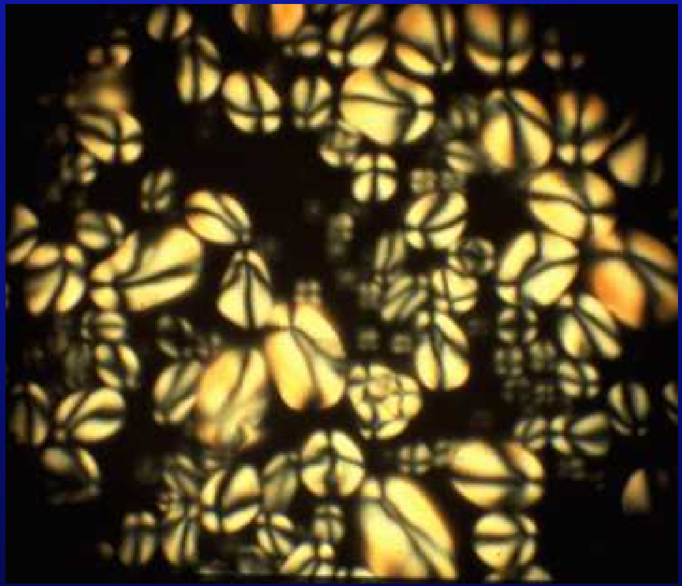
Carbohydrates Sources

- Common root crops include potatoes, sweet potatoes, yams, and cassava (tapioca)

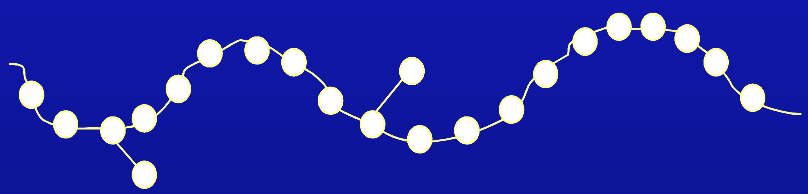
Starch

1. Carbohydrate - energy source
2. Assists expansion
3. Improves binding and pellet durability
4. 10 - 60 % levels in aquatic food

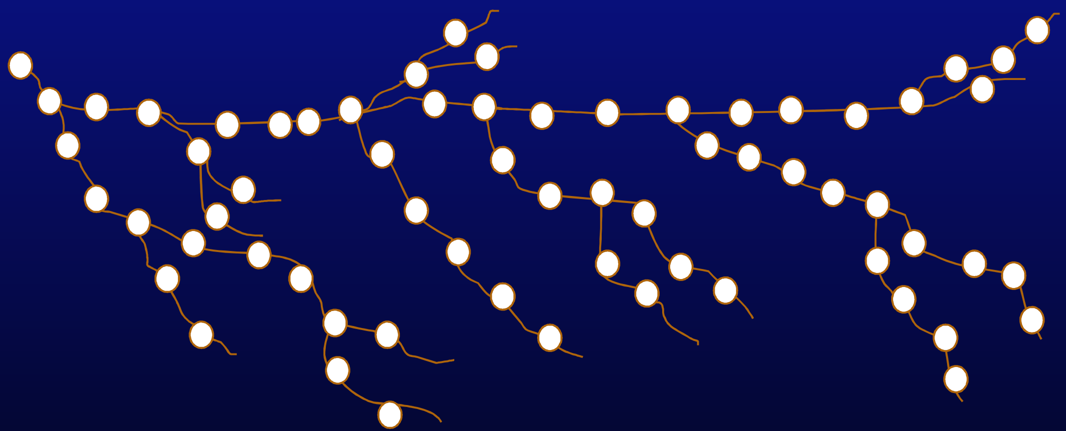


Raw potato starch magnified 450 X

Two Types of Starch Polymers



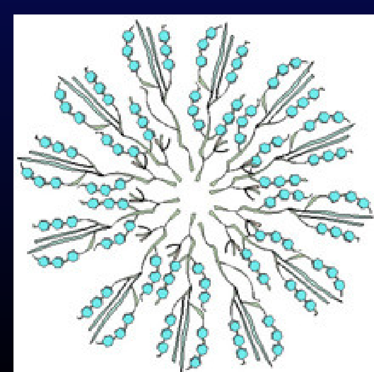
Amylose



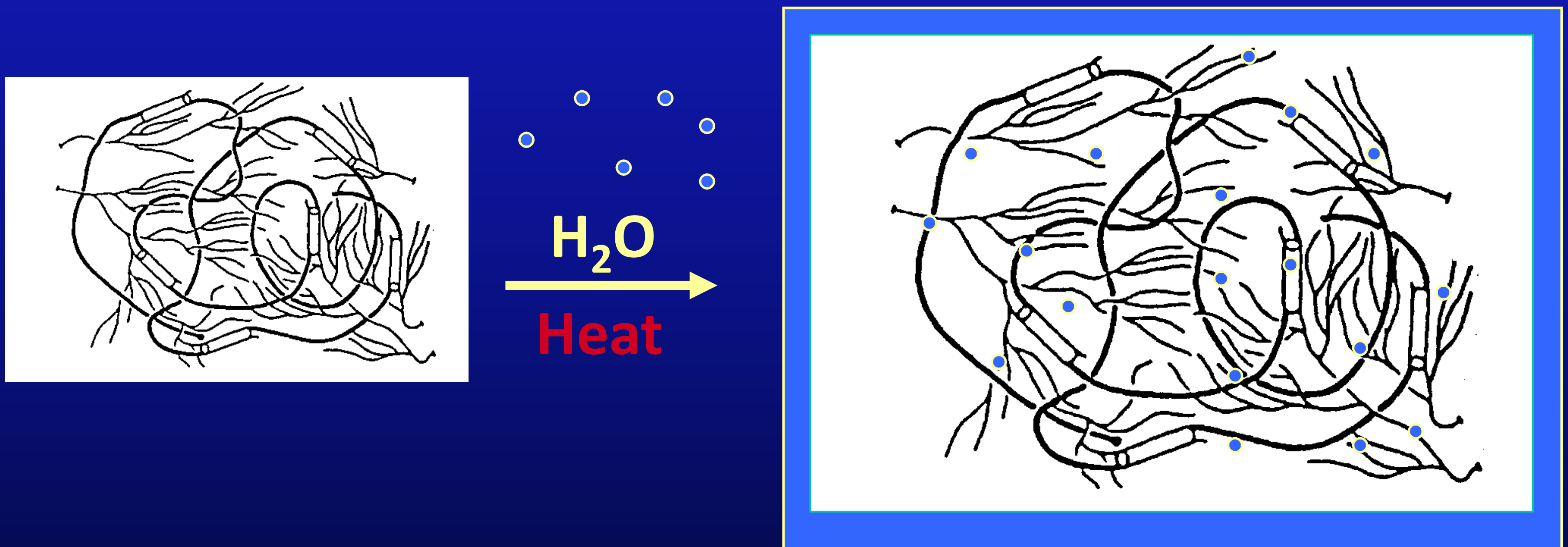
Amylopectin

Approximate Amylose and Amylopectin Content of Common Food Starches

Starch Type	Amylose Content (%)	Amylopectin Content (%)	Granule Diameter (microns)
(Common Dent) Corn	**25**	**75**	**5-30**
Waxy Corn	**<1**	**>99**	**5-30**
Tapioca	**17**	**83**	**4-35**
Potato	**20**	**80**	**5-100**
High-Amylose Corn	**55-70**	**45-30**	**5-30**
Rice	**19**	**81**	**1-3**
Waxy Rice	**11**	**89**	**1-3**



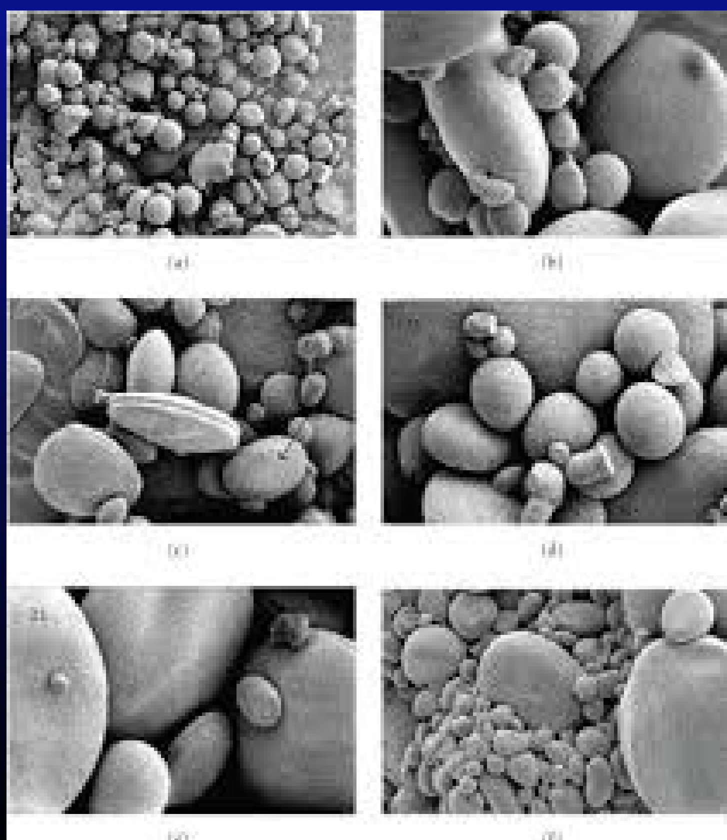
Starch Gelatinization

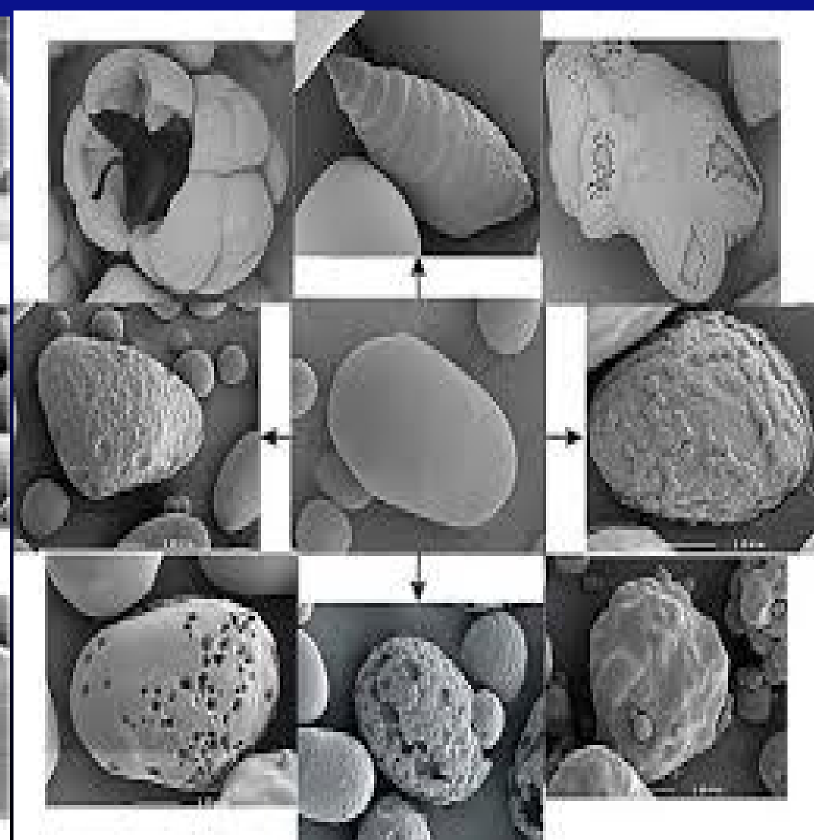


- Starch is heated above its critical temperature
- Water penetrates granule, hydrates molecules
- Granule swells, loses birefringence
- Granule diameter may increase 4X

Starch

Granule size appears to be a contributing factor in how rapidly a starch will gelatinize and at what temperature range





Starch

Larger granules may have less molecular bonding, may swell faster and gelatinize at lower temperatures

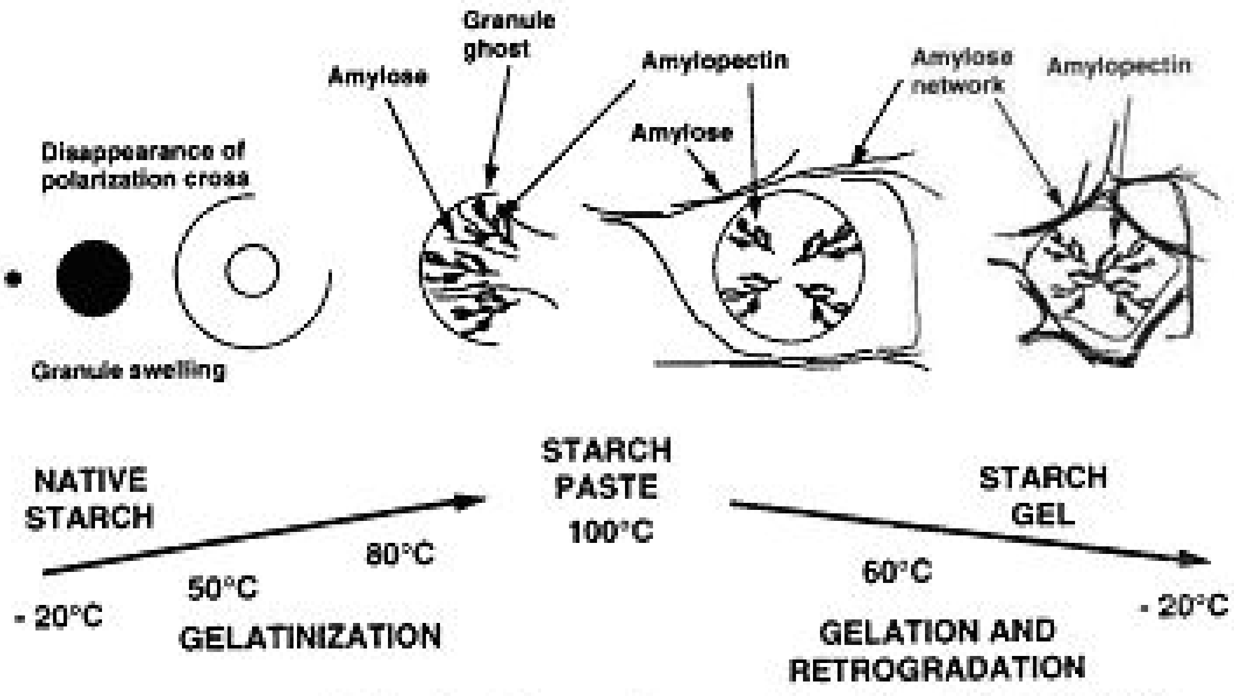
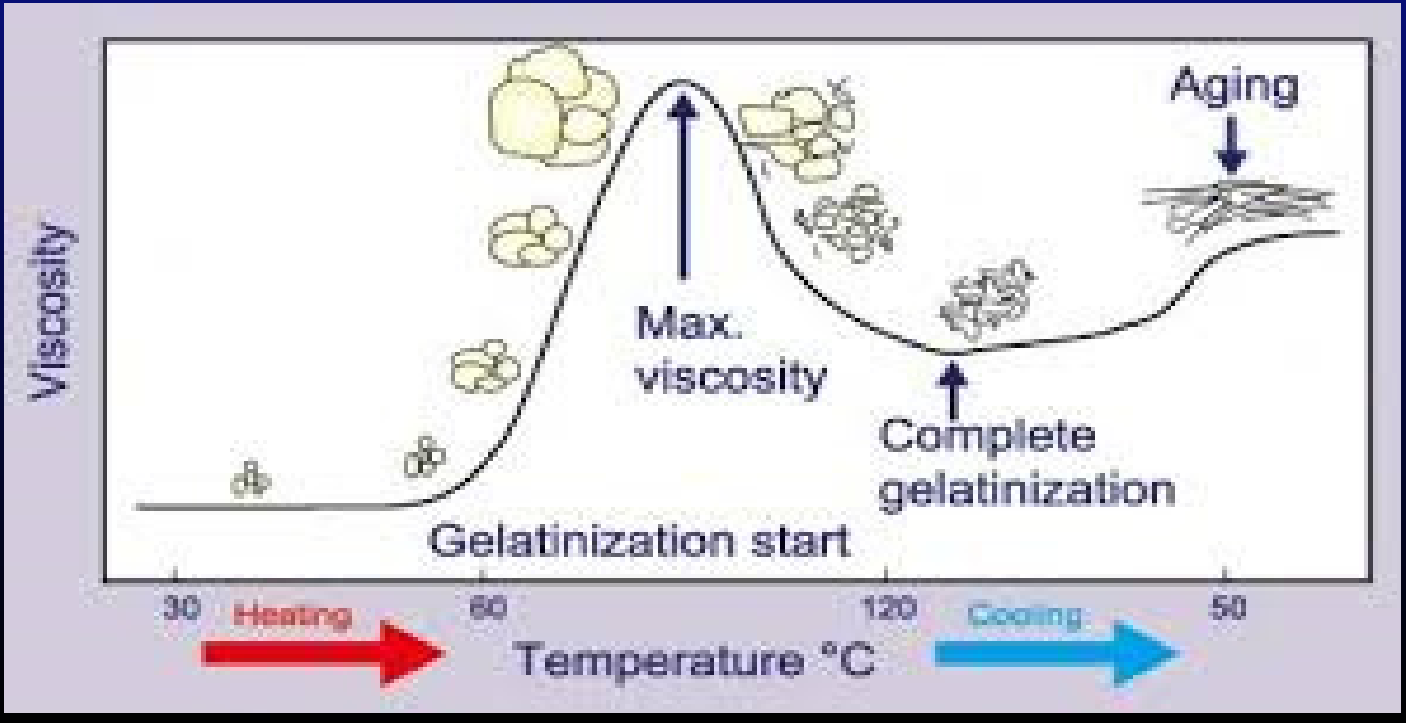


Fig. 1. Influence of hydrothermic processing on physical starch characteristics.

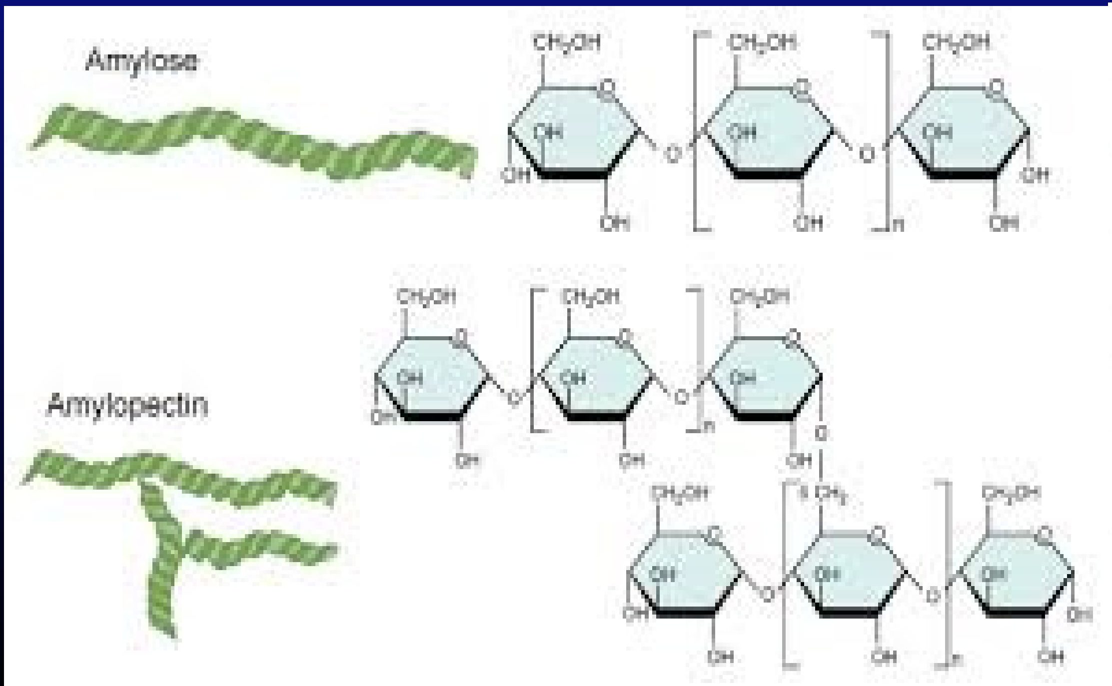
Starch

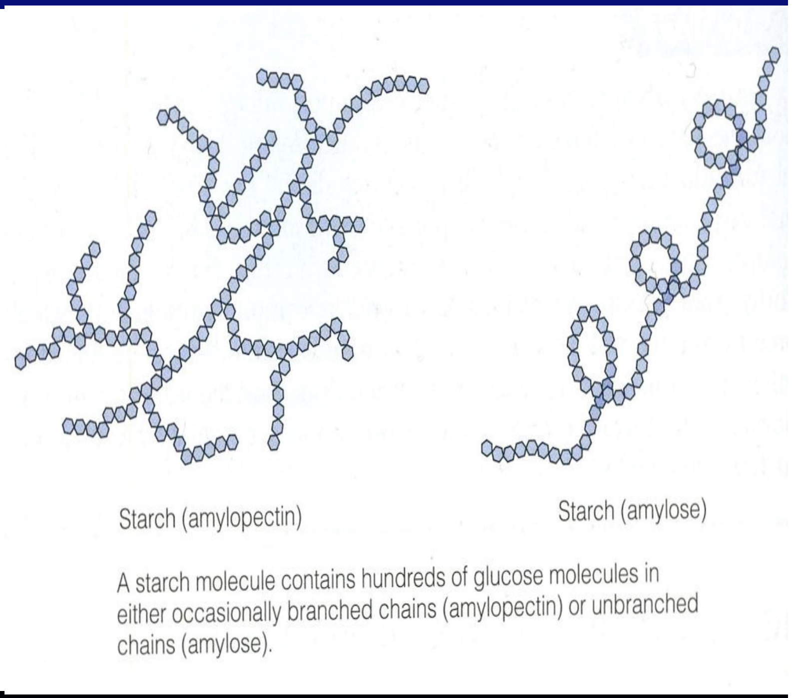
Larger granules may tend to increase viscosity, but this larger physical size also makes it more sensitive to shear (granule breakage) during mixing and extrusion



Starch

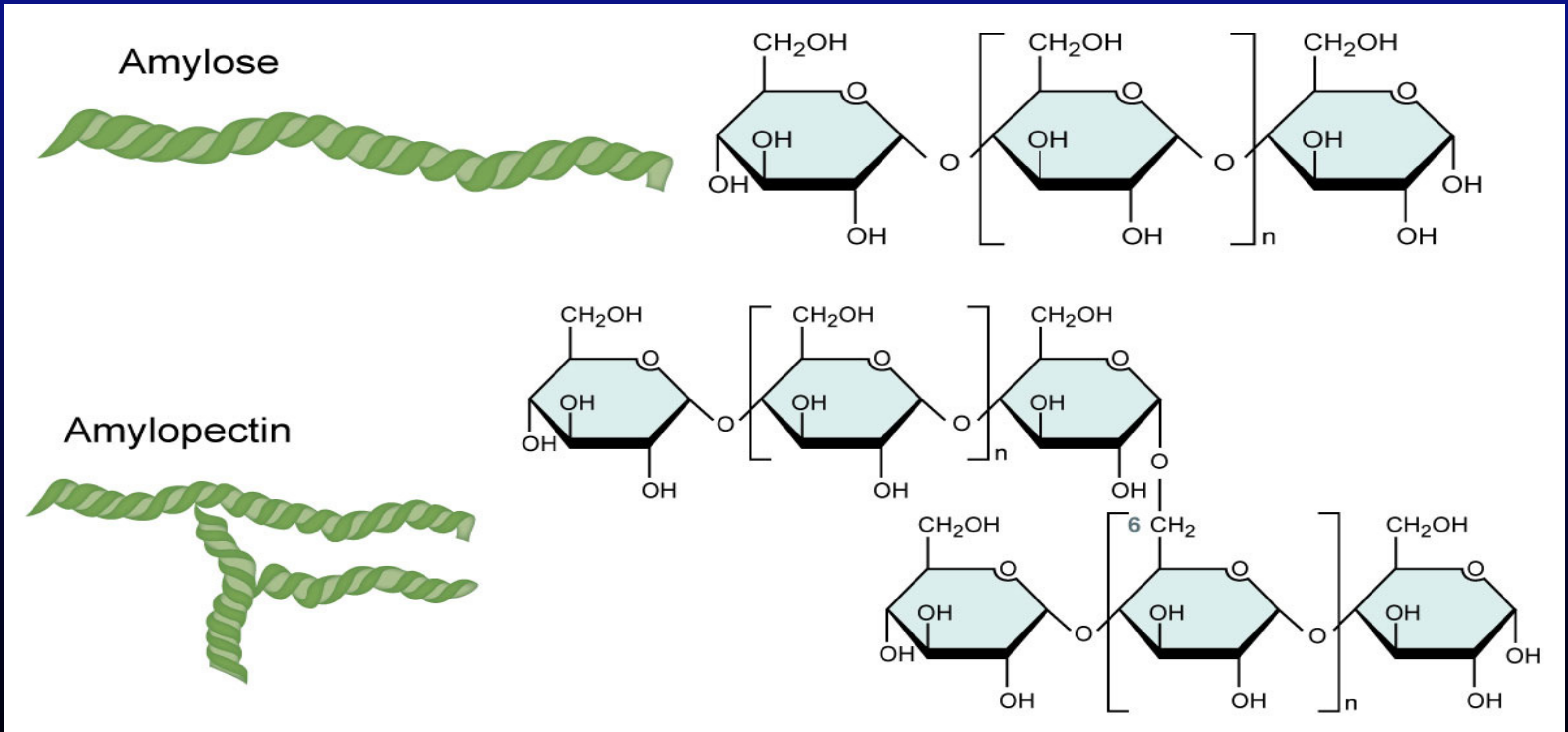
In general, amylose contributes to gel formation during extrusion, while amylopectin contributes to viscosity





Starch

The susceptibility to denature during extrusion is greater for the branched structure of amylopectin than the straight chain amylose



Starch

In extruded products, amylose will provide some crispness (brittleness) in a product, but will not provide much expansion since it retrogrades easily

Amylopectin allows greater expansion due to its large molecular size, but will not provide crispness

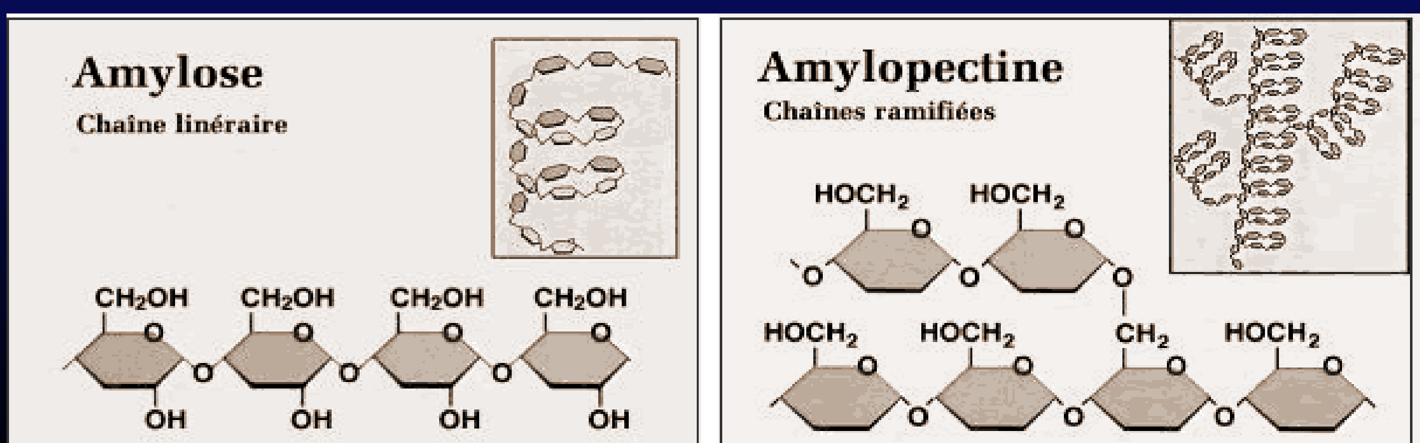
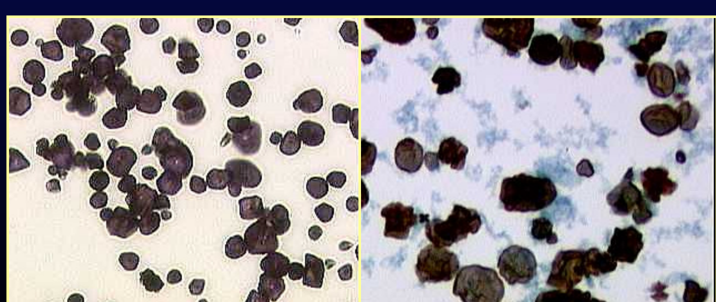
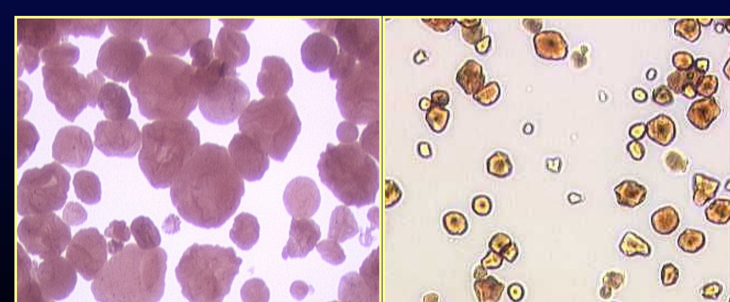


Figure 9 : Amylose et Amylopectine, deux constituants de l'amidon

Properties of Amylose and Amylopectin

Property	Amylose	Amylopectin
Structure	Linear	Branched
Molecular Weight	Varies with source $1 - 2.5 \times 10^6$	Varies with source 200×10^6
"Solubility" in water	Not truly soluble	Soluble
Gels	Tends to re-associate; Retrogradation; Stiff	Stable, only slight tendency towards retrogradation; Non-gelling
Iodine Color	Blue	Reddish brown





Heat of Gelatinization for Various Starches

Starch Source	Heat of Gelatinization (cal / gram)	Amylose Content (%)	Size (microns)
High Amylose Corn	7.6	55	5-25
Potato	6.6	20	15-121
Tapioca	5.5	22	5-35
Wheat	4.7	28	1-35
Waxy Corn	4.7	0	5-25

Rice as a Starch Source

1) Small, tightly packed starch granules that hydrate slowly
2) Becomes sticky when it gelatinizes
3) Choose long grain varieties over medium and short grain varieties as they are much less sticky when cooked
4) Rice is very digestible even when cook values are low
5) Rice bran may contain up to 40% starch

Corn as a Starch Source

1) Good expansion
2) Excellent binding
3) Sticky at high levels (>40%)

Wheat as a Starch Source

1) Good binding
2) Good expansion
3) Can be sticky if overcooked
4) Contains gluten (good binder)
5) Most widely available starch source
6) Often utilized as wheat flour which has most of the bran removed

Cassava

(manioc, tapioca)

Product	Cassava chips	Cassava meal	Cassava refuse	Cassava flour
Protein	1.9	2.6	2.0	0.3
Fiber	3.0	5.6	7.2	0.1
Soluble CHO	80.5	73.9	79.2	84.4
Fat	0.72	0.55	0.5	0.10

Minimum Moisture Levels Necessary to Initiate Starch Gelatinization

Starch Source	% Moisture
Wheat	31
Corn	31
Waxy Corn	28
High Amylose Corn	34

Lower moistures during extrusion require higher extrusion temperatures to achieve same level of cook.

Gelatinization Temperature* of Starches

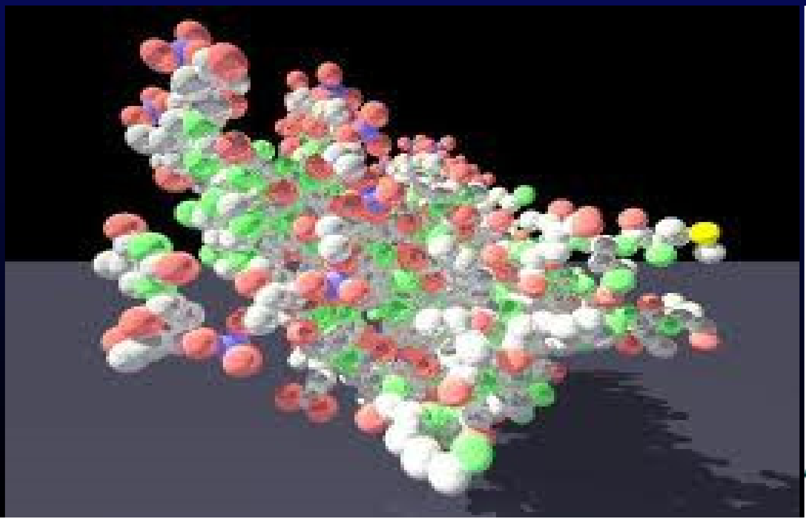
Starch Source	Gelatinization Temperature (°C)
Barley	56
Triticale	59
Wheat	61
Rye	64
Oats	56
Corn	67
Waxy Corn	68
Sorghum	73
Rice (short)	68
Rice (medium)	68
Rice (long)	71
Potato	61
Tapioca	65

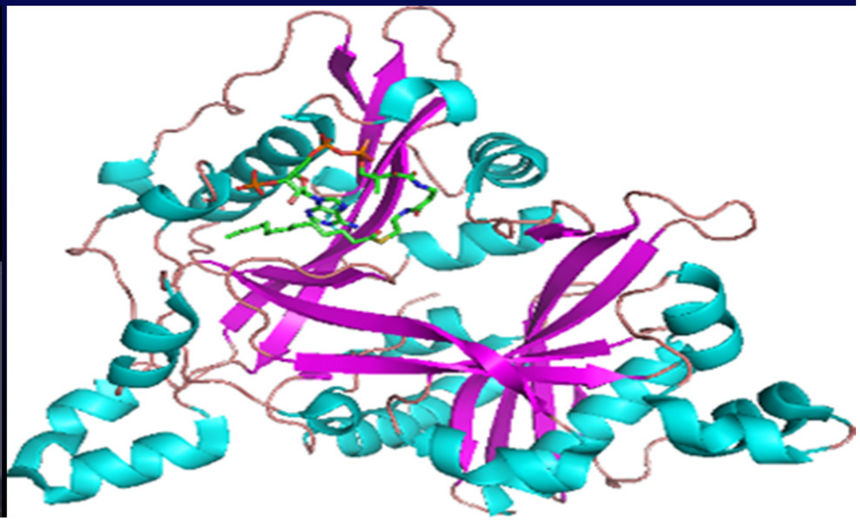
* In excess water environment – typically greater than about 30% wb.

	Protein	Fat	Fiber	Starch	Ash
Corn Flour	5.6	1.4	1.9	80.9	0.5
Whole Grain Corn Flour	6.9	3.9	13.4	63.5	1.5
Wheat, hard red spring	15.4	1.9	12.2	55.8	1.9
Wheat, hard red winter	12.6	1.5	12.2	59.0	1.6
Wheat, soft red winter	10.4	1.6	12.5	61.7	1.7
Wheat, soft white	10.7	2.0	12.7	62.7	1.5
Whole Wheat Flour	13.7	1.9	12.2	60.4	1.6
Wheat Flour (all purpose)	10.3	1.0	2.7	73.6	0.5
Rice Flour	6.0	1.4	2.4	77.7	0.6
Rye	14.8	2.5	14.6	55.2	2.0
Oat Flour	16.9	6.9	10.6	55.7	1.7
Barley	12.5	2.3	17.3	56.2	2.3
Sorghum	11.3	3.3	0.0	74.6	1.6
Tapioca Starch	0.2	0.0	0.9	87.8	0.1
Arrowroot flour	0.3	0.1	3.4	84.8	0.1

Protein:

- Most important constituent of aqua feed
- It ranges from 20-60% in diets
- Play several roles other than nutrition
- Such as, water absorption, elasticity,





Protein

1) <u>Plant Sources</u>

Soy, Legumes, Wheat/corn glutens, Cereal grains

a) Good functional properties

b) Low cost

c) Amino acid profile requires



Protein

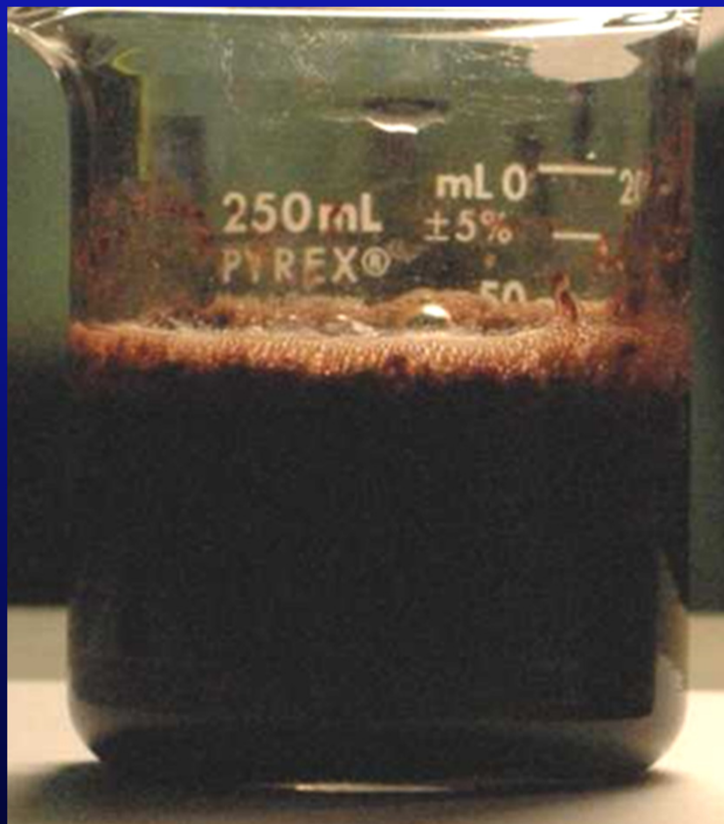
2) Animal Sources

Meat, Fish, Poultry, Blood, Gelatin

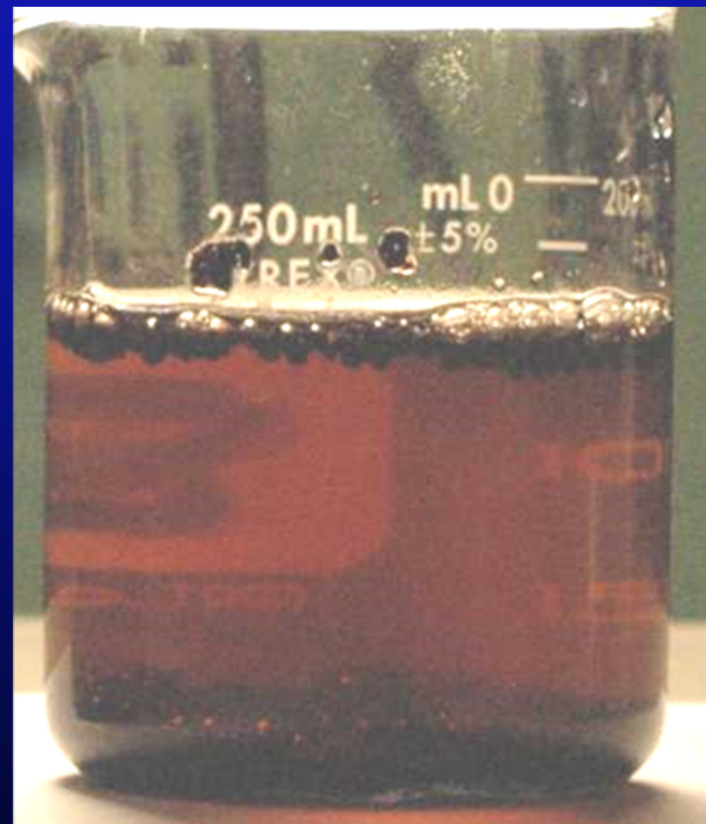
- **a) Poor functional properties unless fresh or spray dried**
- **b) Higher costs but usually more palatable**
- **c) Good amino acid profile**




Solubility Comparison of Animal Proteins



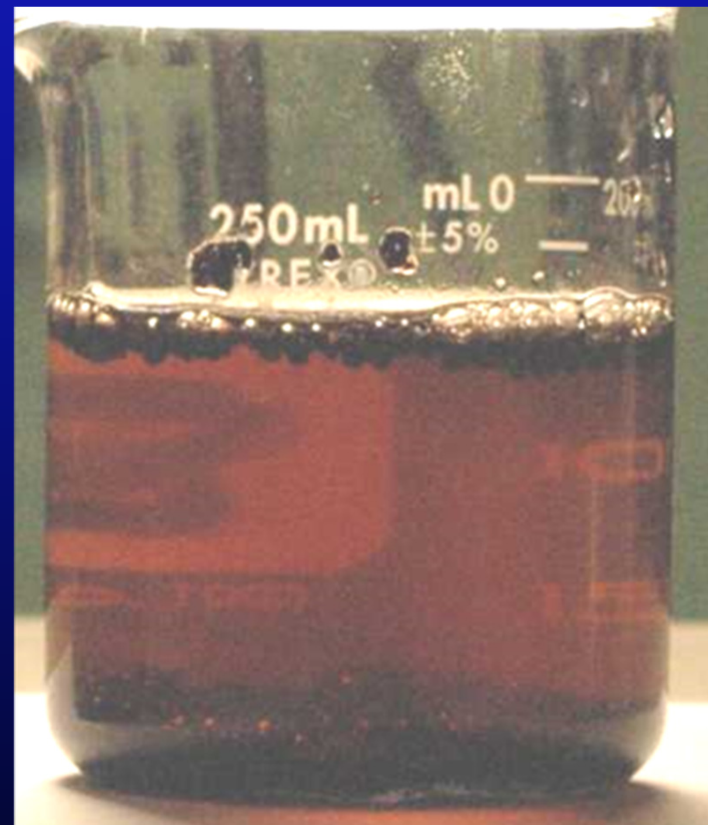
Spray-Dried Blood Hemoglobin



Ring-Dried Blood Meal

Solubility Comparison of Animal Proteins

Spray-Dried Blood Hemoglobin



Ring-Dried Blood Meal

Benefits of Vegetable Proteins in Aquatic Diets

1) More expansion potential for floating diets
2) More binding potential for improved durability
3) Reduced ingredient costs
4) Lower incidence of white mineral deposits in screw and die area
5) Higher oil absorption levels possible in coating operations
6) Reduce dependence on fish meal

Extruded Floating and Sinking Diets Containing High Levels of Vegetable Protein

Made from base recipe containing 70% soybean meal, 20% wheat flour, and 10% fish meal.

After coating, these products contained 22% fat and 35.5% protein

494 g/l product density

750 g/l product density

FIBER

Effects on expansion of extruded products

1. Up to 5% may increase expansion (if finer than 400 microns particle size).
2. Finer particle size has less detrimental effects on expansion (<50 microns particle size gives very fine cell structures).
3. Coarse particle size limits expansion and can give a rough surface appearance.
4. More soluble forms of fiber have less impact on expansion.

Fiber Solubility

Solubility	Insoluble fiber	Soluble fiber
Fermentability	Partial or low	Readily or high
Examples	Whole grain brans, vegetables (celery, zucchini), fruit skins, vegetable peelings, resistant starches	Beta-glucans from oats, barley, fruit pectins, psyllium seed, inulin, root vegetables, legumes, natural gums

High Fat Feeds

- Aquatic feeds
- Pet foods
- Carnivore fur-bearing animals
- Formulated livestock feeds and Ingredients

>7 % internal fat for single screws and

>12 % internal fat for twin screws systems

Aquatic Feed Product Categories

Product Category	Low Fat	Medium Fat	High Fat	Ultra-high Fat
Total Product Fat (%)	<15	15-25	25-35	>35
Added Fat (%)*	<9.4	9.4-24.0	24.0-43.0	>43.0
Max. Vacuum Oil Absorption (%)	<23.0	23.0-41.5	41.5-51.6	>51.6
Max. Atmospheric Oil Absorption (%)	<7.8	7.8-14.7	14.7-18.3	>18.3
Type of Coating Process Required	Atmos-pheric or Vacuum	Atmos-pheric or Vacuum	Vacuum	Vacuum

Assume 7% fat indigenous to recipe ingredients

Purpose of Fat in Aquatic Feeds

1. Energy source
2. Increases palatability/acceptance
3. Provides essential fatty acids
4. Carrier for fat-soluble vitamins
5. Dust control

Fat Sources

1) Animal Fat
2) Poultry Fat
3) Marine Oils
4) Blended Animal and Vegetable Fats
5) Feed Grade Vegetable Fats

Must use FAH (fat acid hydrolysis) method for determining fat levels in extruded products.

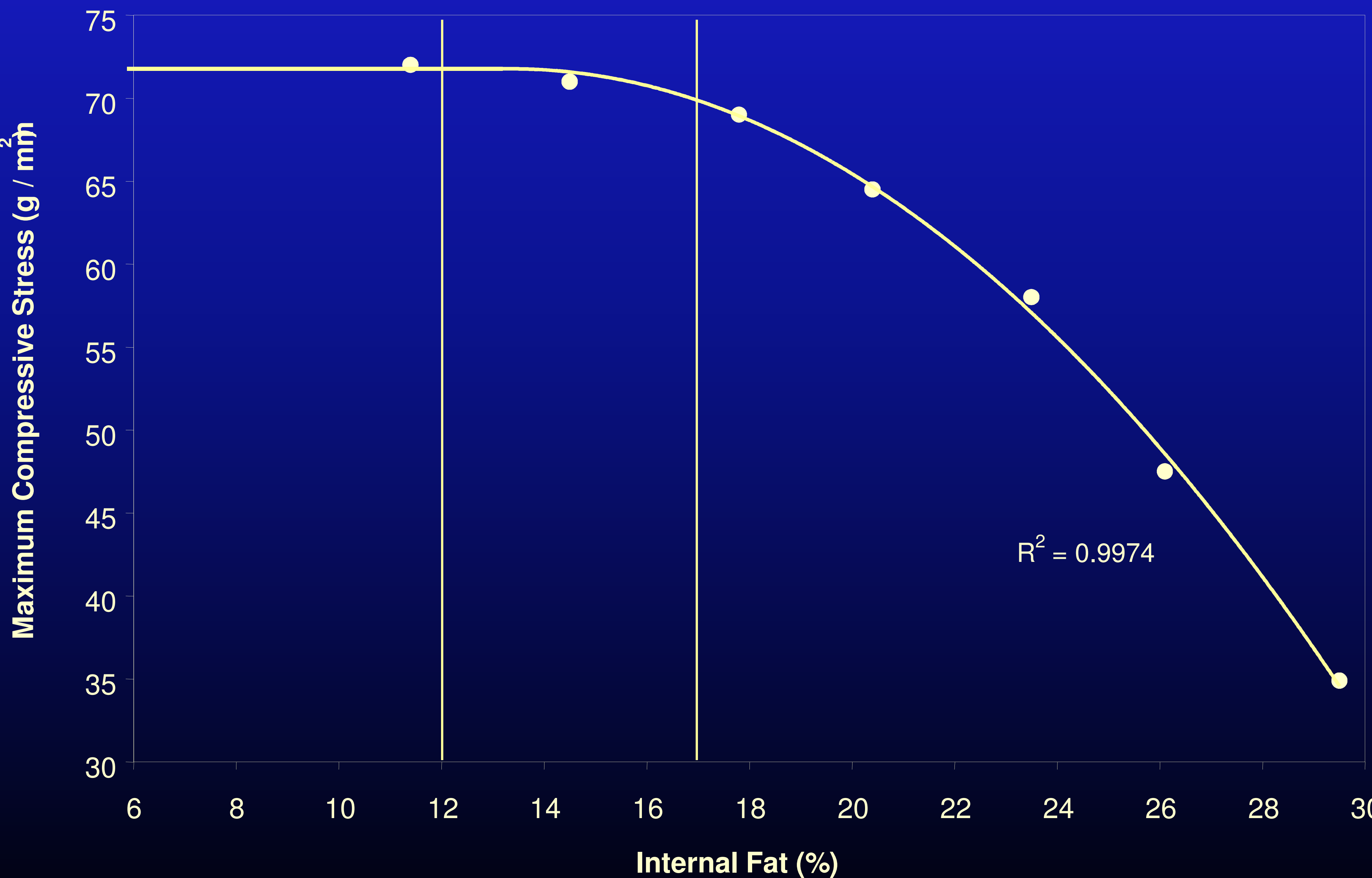
Effect of Fat Levels on Product Quality

Level of Total Fat in Extruded Mix	Effect on Product Quality
0 - 12%	Little or no effect
12 - 17%	For each 1% of Fat Above 12%, the final bulk density will increase 16 g/l
17 - 22%	Product will have little or no expansion, but will remain durable
Above 22%	Final product durability will be poor

Effect of Internal Levels of Fat on Expansion of Extruded Feeds

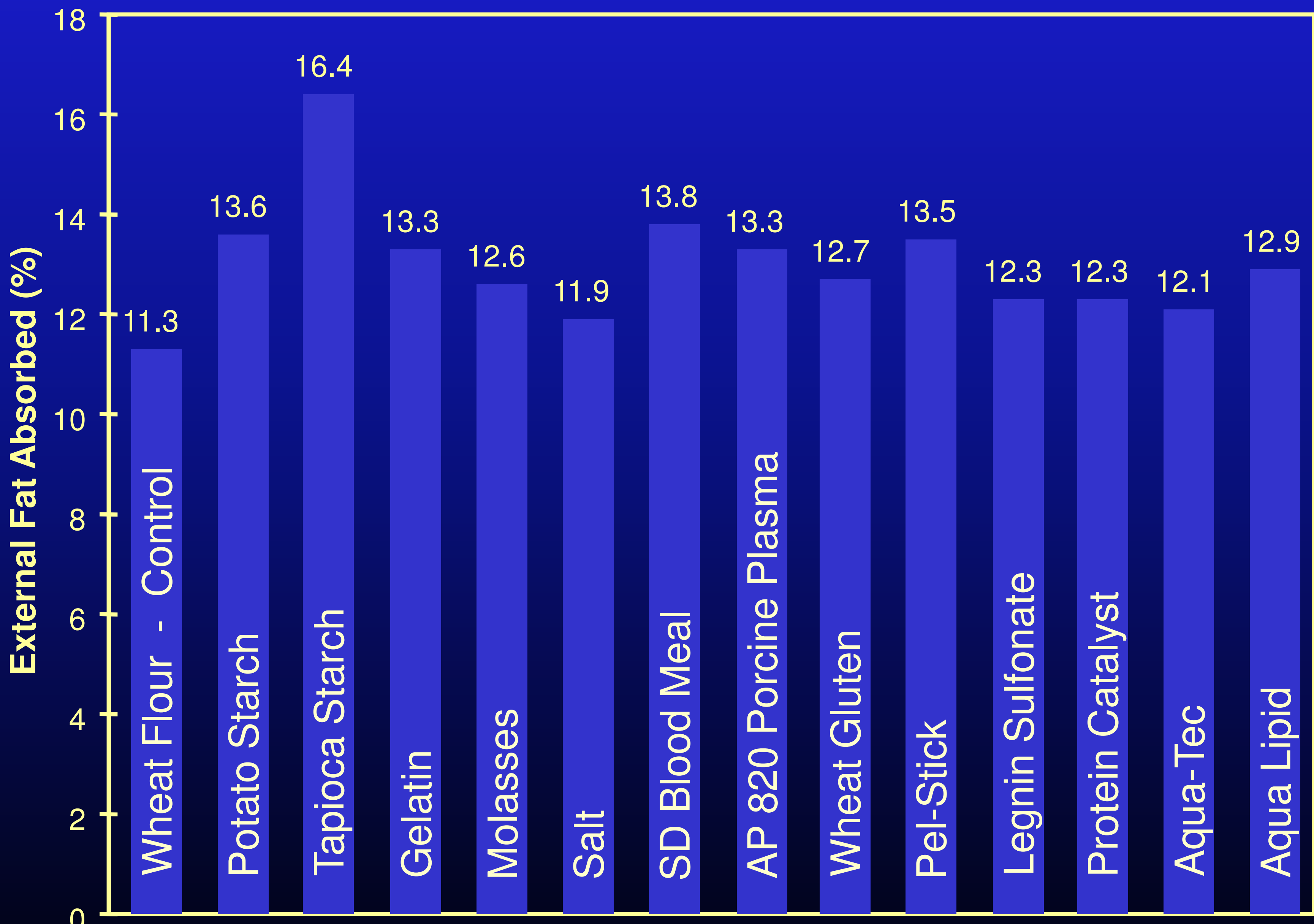
% Added Fat	Bulk Density g / l
0	253
5	308
10	408
15	528

Internal Fat vs. Pellet Durability



To Maximize Lipid Inclusion Levels

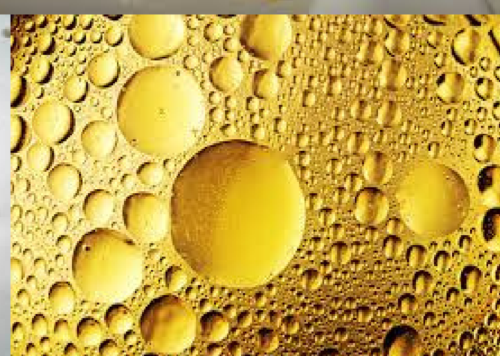
1. Use lipids indigenous to other ingredients
2. Heat lipids to 40 - 60^{0}C prior to inclusion
3. Add late in the process
4. Maintain starch / function protein levels
5. Increase thermal and/or mechanical energy inputs
6. Increase moisture levels during extrusion



Effect of 2% of each additive in a 80% fish meal and 20% wheat flour recipe

Density Control with Ingredients

- Proteins, lipids and fiber and their interactions with starches are factors that complicate the estimates of density
- All of these factors will play a role in the density of the finished product



Density Control with Process Variables

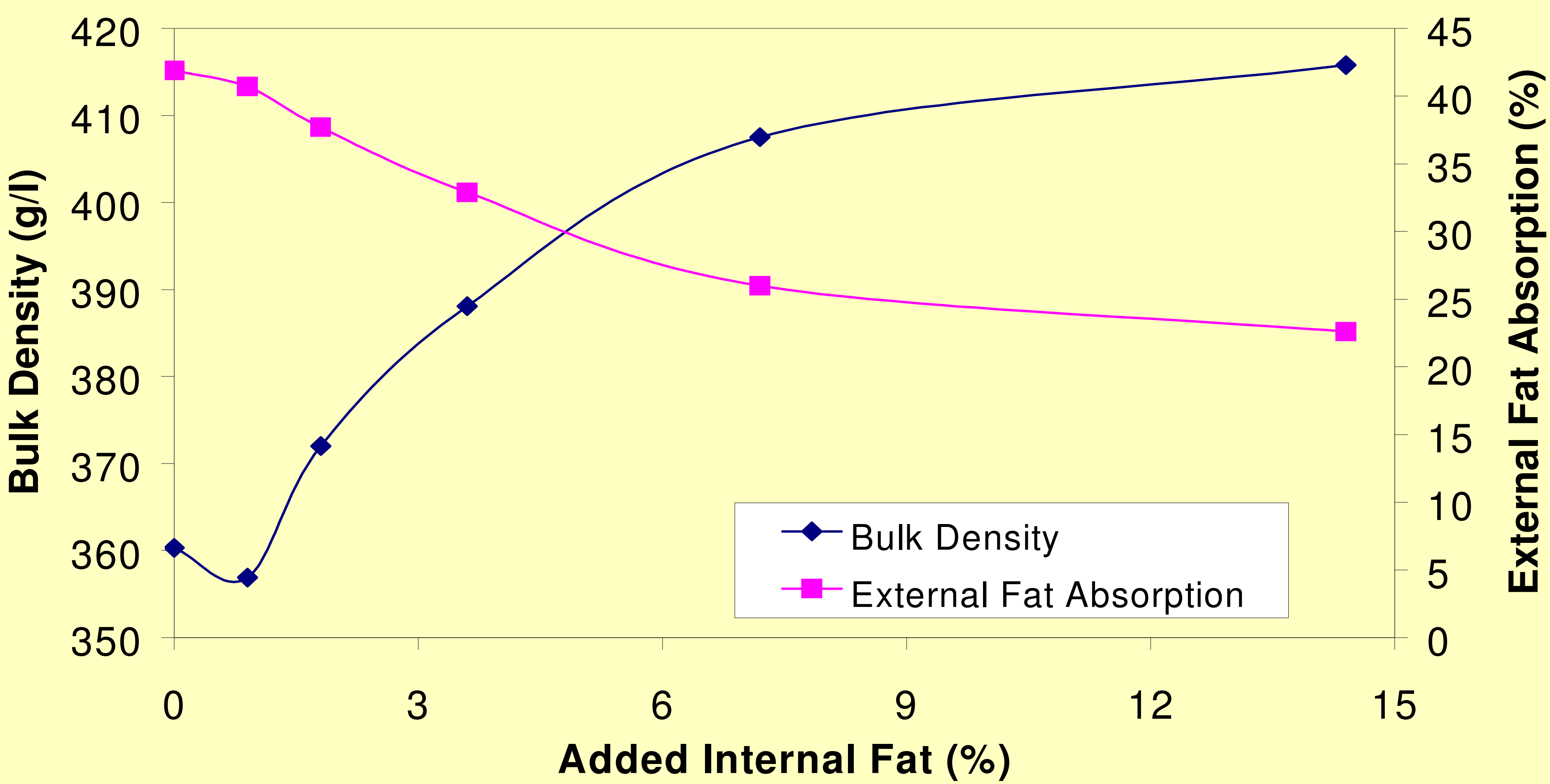
Changes in the energy input

- Rpm of the extruder shaft
- Feed rate of material into the extruder,
- Temperature and moisture (added water and steam)

Adjusting Process Variables To Increase Product Density

1) Increase levels of fat (internal or external)
2) Increase feed rate
3) Decrease mechanical and thermal energy inputs
4) Adjust moisture levels during extrusion

Effect of Added Extrusion Fat Levels on Bulk Density and External Fat Absorption



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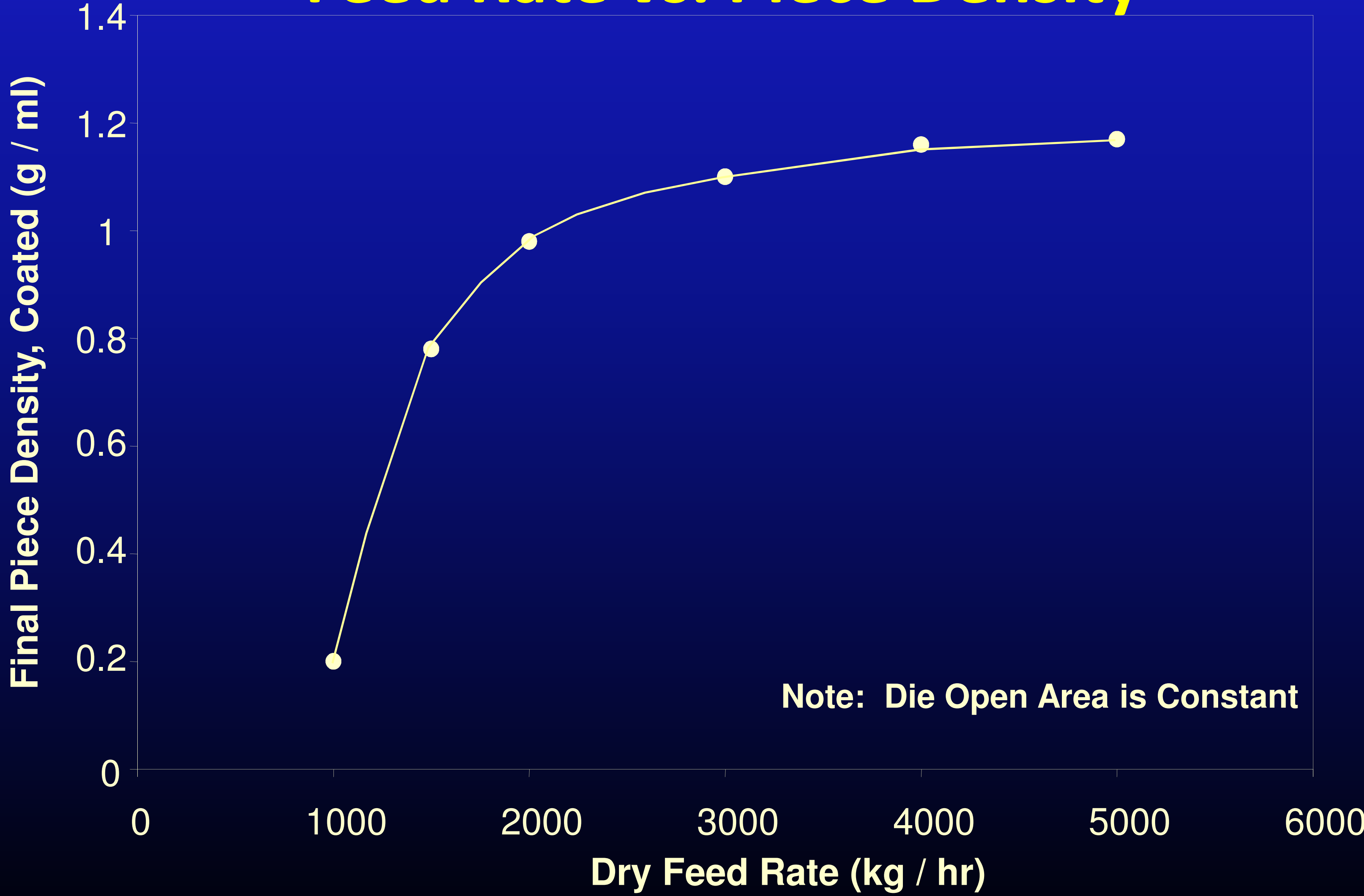
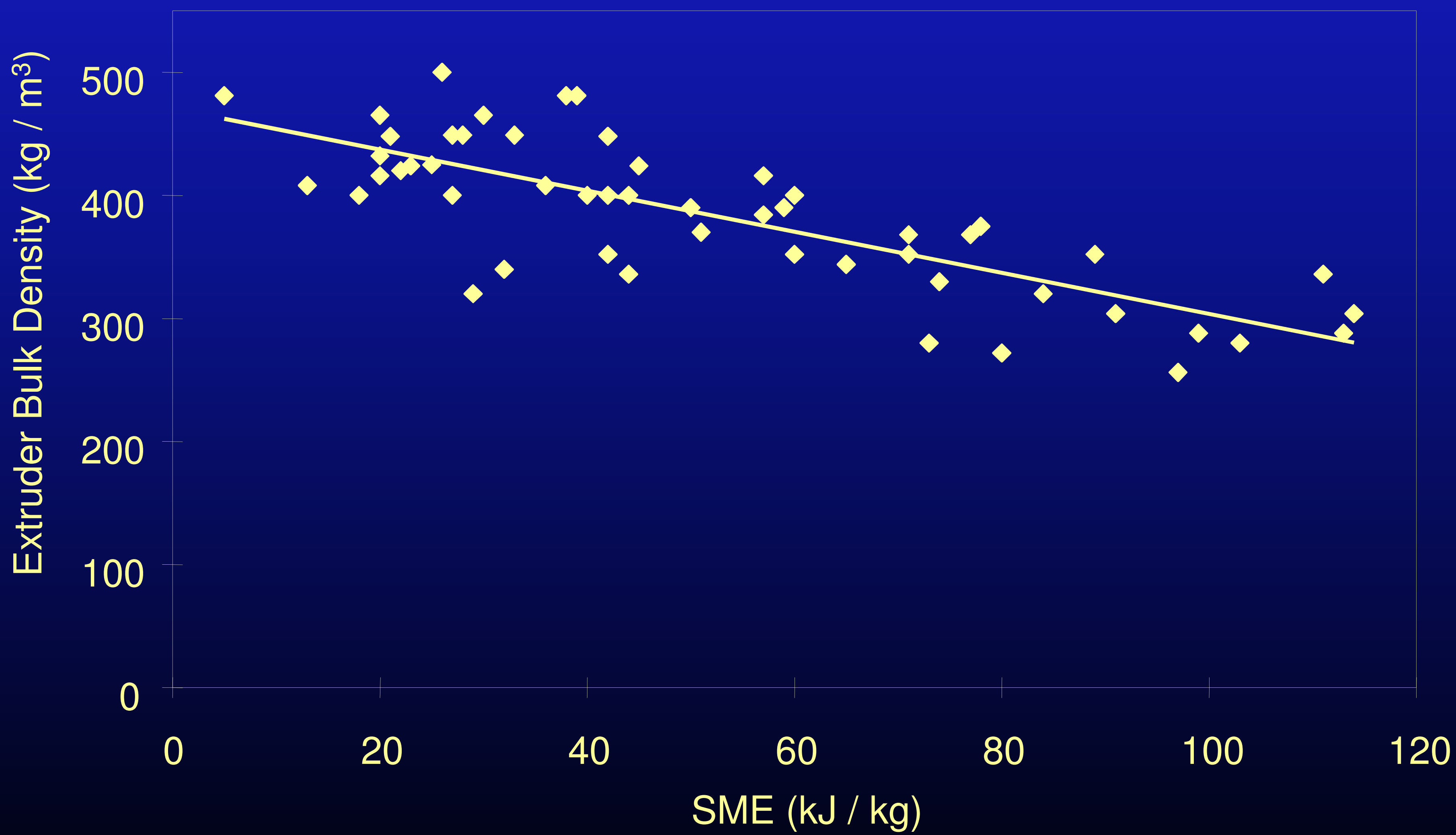
Feed Rate vs. Piece Density



Adjusting Process Variables To Increase Product Density

1) Increase levels of fat (internal or external)
2) Increase feed rate
3) Decrease mechanical and thermal energy inputs
    a) Screw speed
    b) Steam inputs
    c) Extruder and die configuration change
4) Adjust moisture levels during extrusion

Specific Mechanical Energy vs. Extruder Bulk Density



Adjusting Process Variables To Increase Product Density

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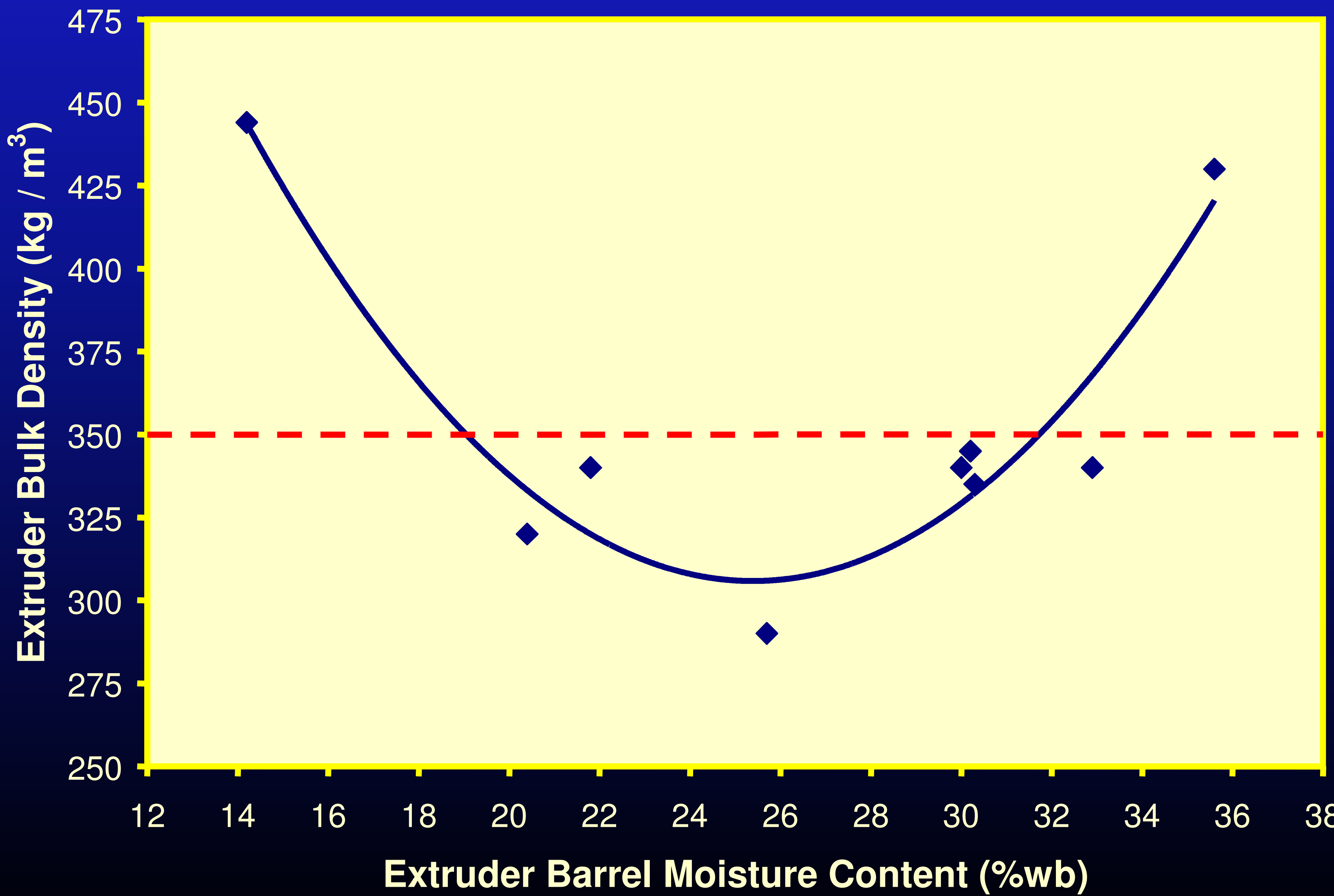
Effect of Extrusion Moisture on Bulk Density



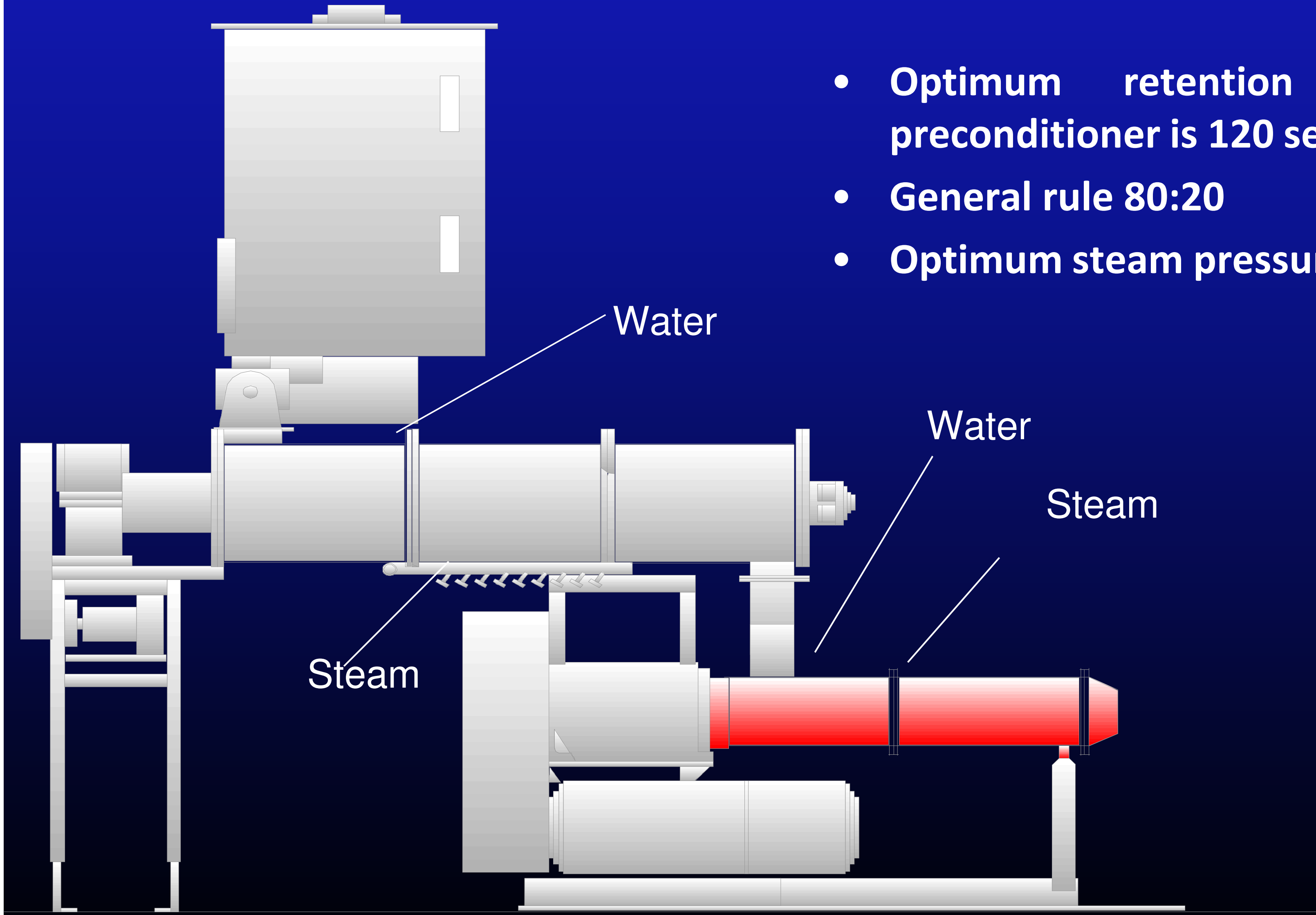
Effect of Extruder Moisture

11.1 18.4 20.7 22.2 25.2 28.1 35.0

Extruder Moisture Content (%)

Water and Steam Injection

- Optimum retention time in preconditioner is 120 sec.
- General rule 80:20
- Optimum steam pressure is 30 PSI



Hardware Tools To Control Product Density

SINKING AQUATIC / **FLOATING AQUATIC**

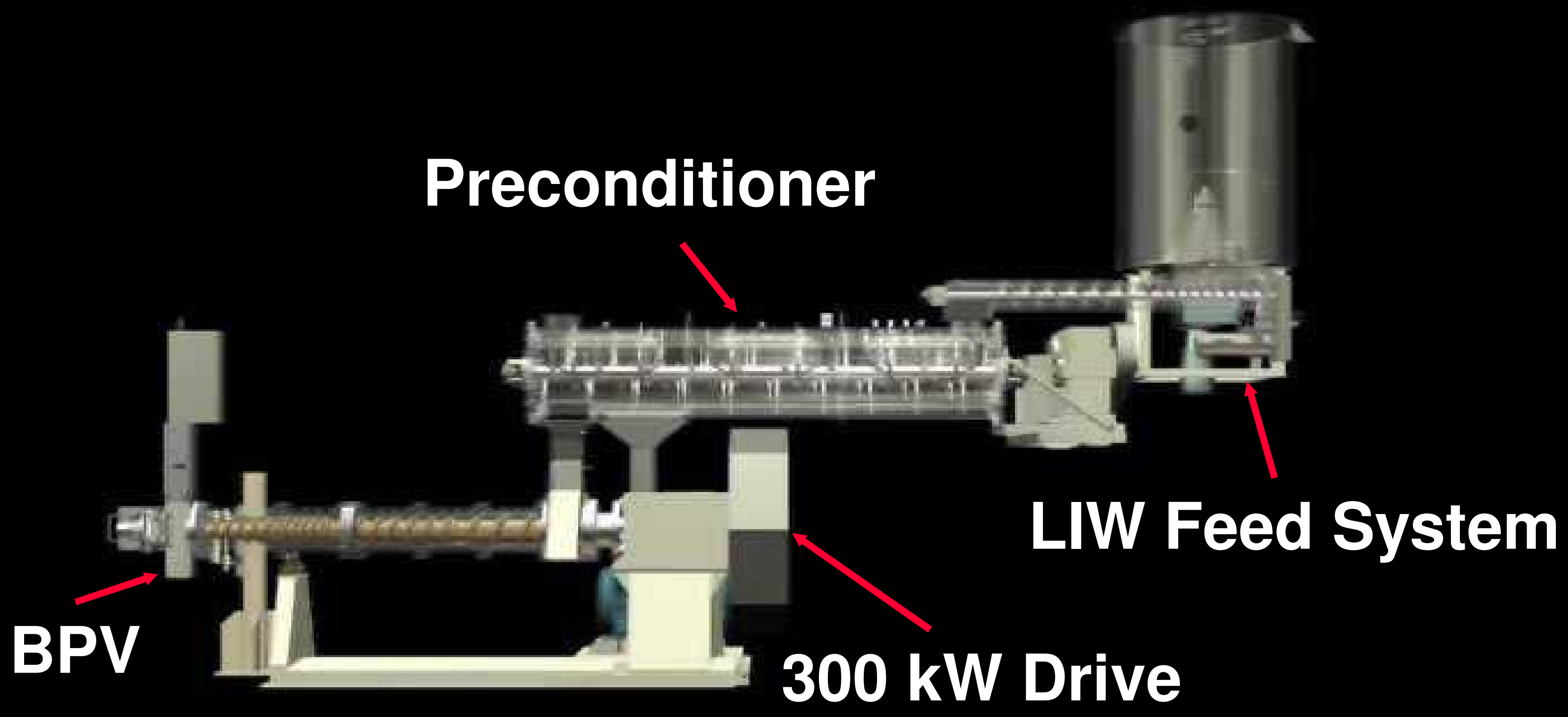
SHRIMP YELLOW TAIL SALMON TILAPIA EEL CATFISH

FLOUNDER SEA BREAM FLATFISH MILKFISH

COD SEA BASS

HALIBUT TROUT MOI

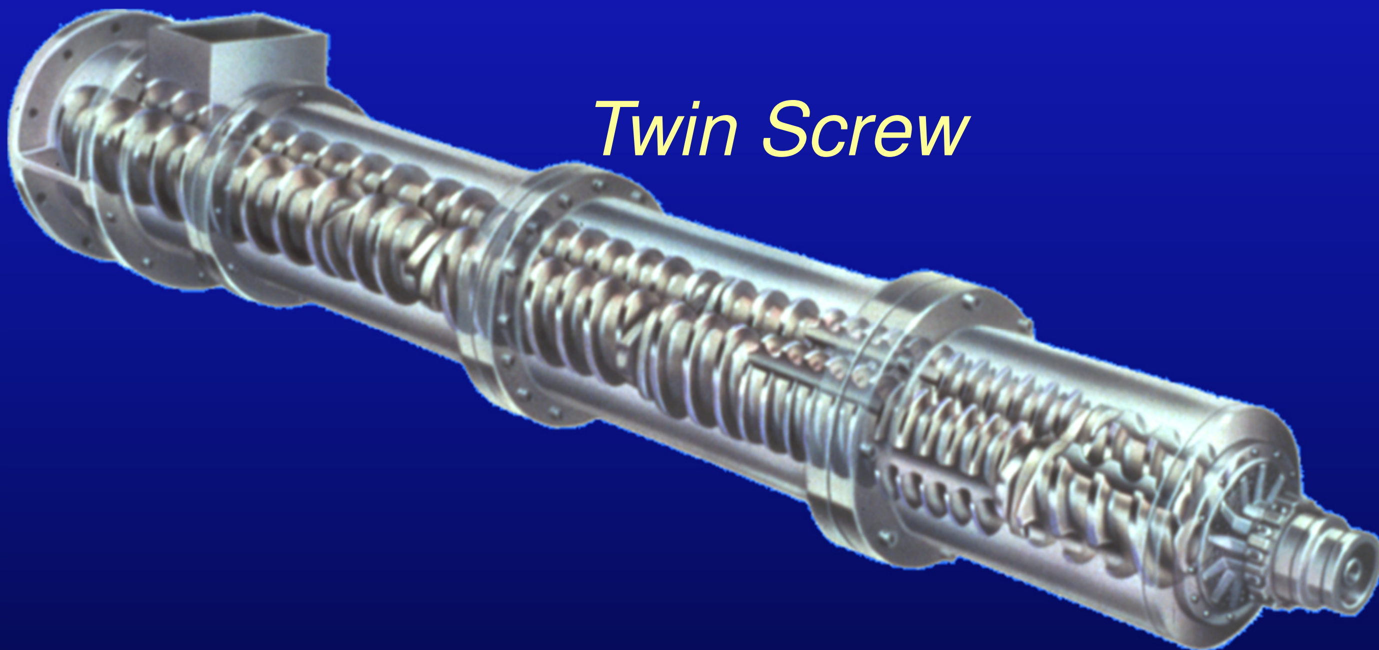
MAIMAI TURBOT



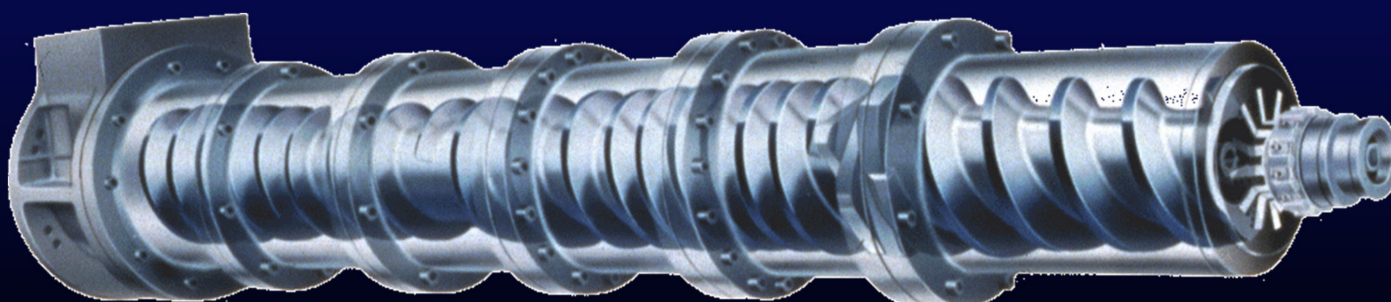
Common Aquatic Extrusion System

Two Choices of Extruder Barrel

Twin Screw

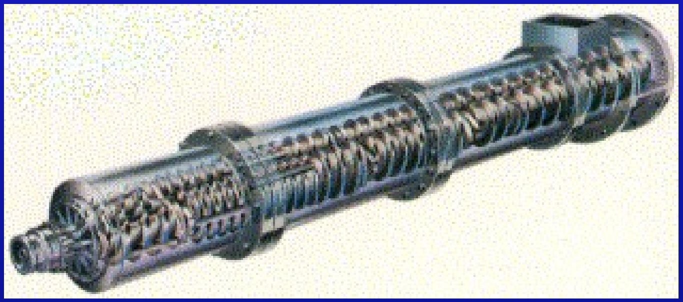


Single Screw



TWIN SCREW EXTRUSION

is the process of choice when:



- Ultra high levels of internal fat (above 12%)
- Ultra high levels of wet slurries (above 35%)
- Very uniform size and shape (portioned feeds)
- Ultra small product sizes (less than 1.5 mm dia.)
- Greater ingredient flexibility is required

Hardware Tools To Control Product Density

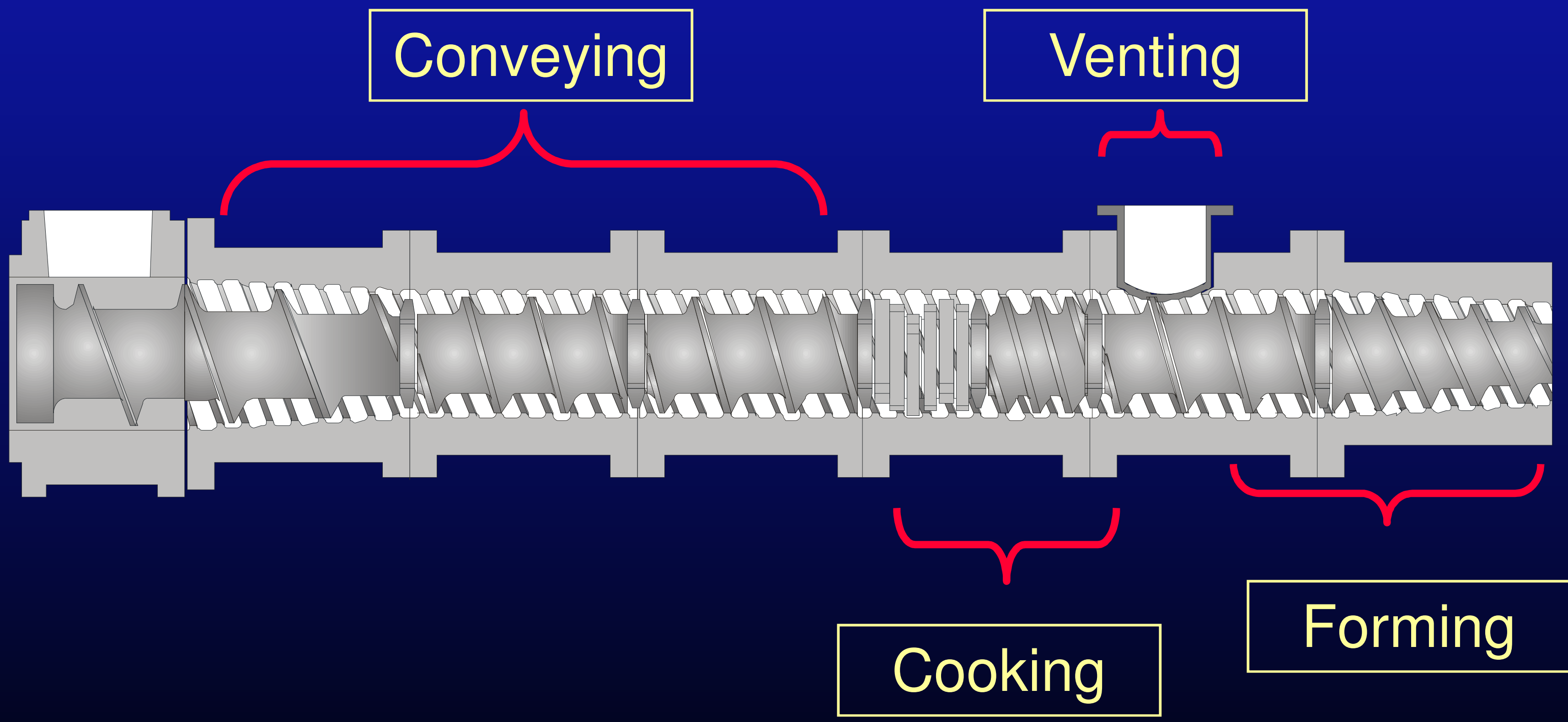
1) Extruder barrel that can be vented with or without vacuum assist (DMS)
2) Separate cooking and forming extruders (PDU)
3) Restriction valve inside extruder barrel (MBV)
4) Restriction valve at end of extruder (BPV)
5) Pressure chamber at extruder die (EDMS)

Hardware Tools To Control Product Density

Vented Barrel:

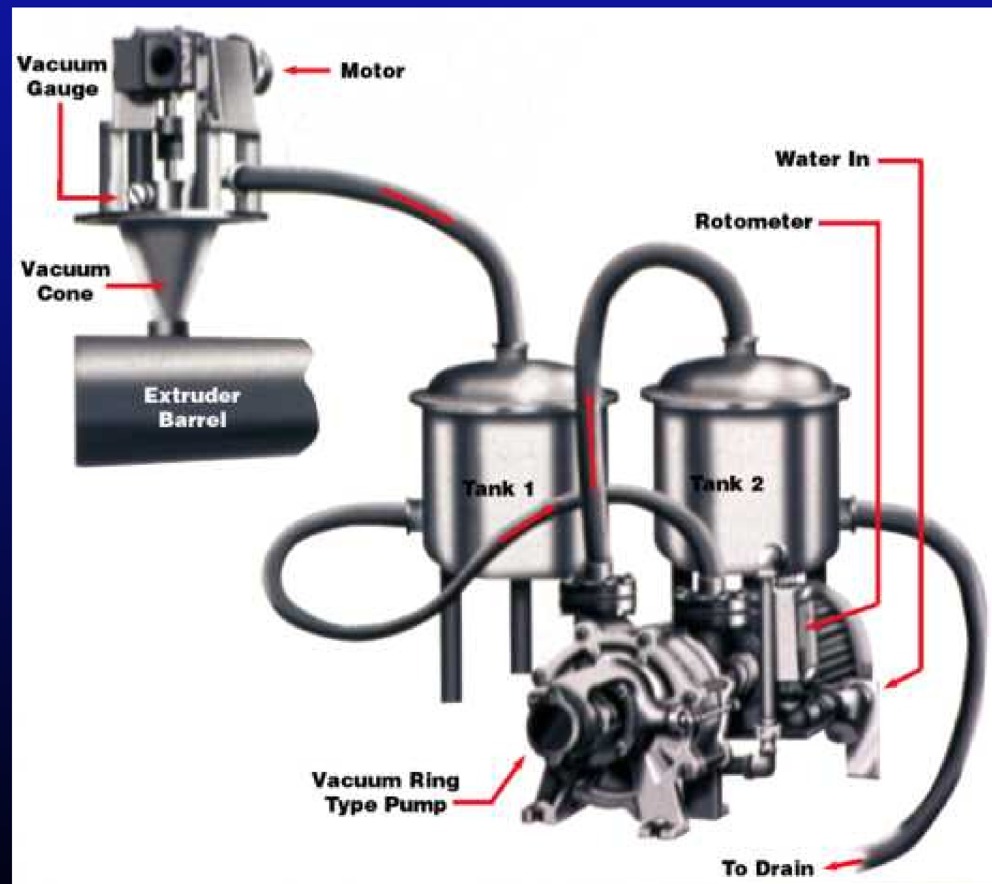
1) Vent to atmosphere for medium density products
2) Add vacuum assist to vent for heavy density products
3) Close vent and inject steam for light density products

CONFIGURING FOR VENTING



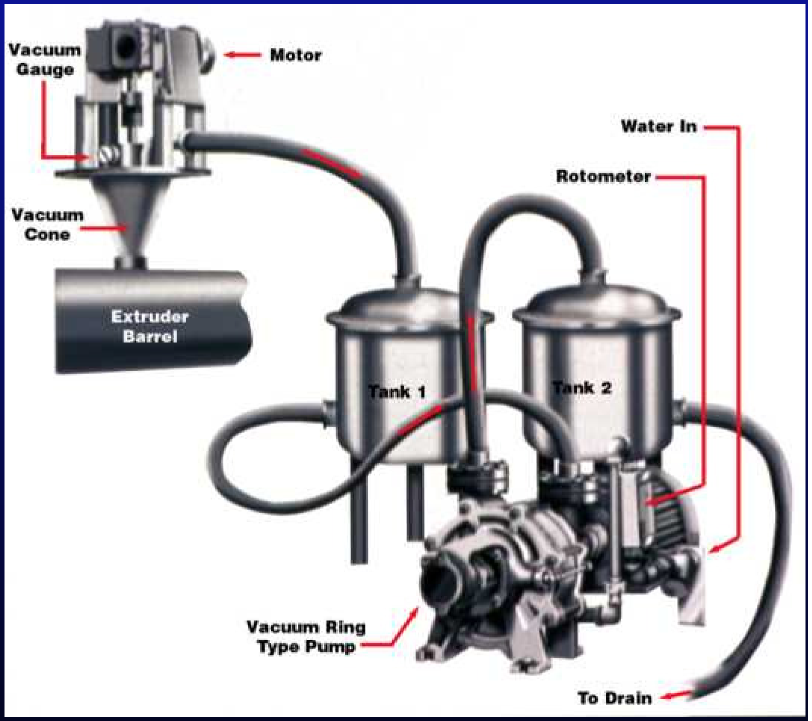
Advantages of vacuum assist on vented extruder barrel

1) Improved pellet durability
2) Increased piece density
3) Reduced extrudate moisture



Disadvantages of vacuum assist on vented extruder barrel

1) Hardware investment
2) Potential capacity of extruder reduced 25-50%
3) Disposal of water and product fines from vent
4) Only minimal control of SME inputs



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Hardware Tools To Control Product Density

Two separate extruders for cooking and forming:

1) First extruder used for expanded products or as cooking extruder for cooking/forming process
2) Second forming extruder (PDU) used only when processing dense products

Two separate extruders for cooking and forming

<u>Advantages</u>:

1) Both extruders can be operated at maximum rate potential
2) Wide density range (Can make 100% sinking product)

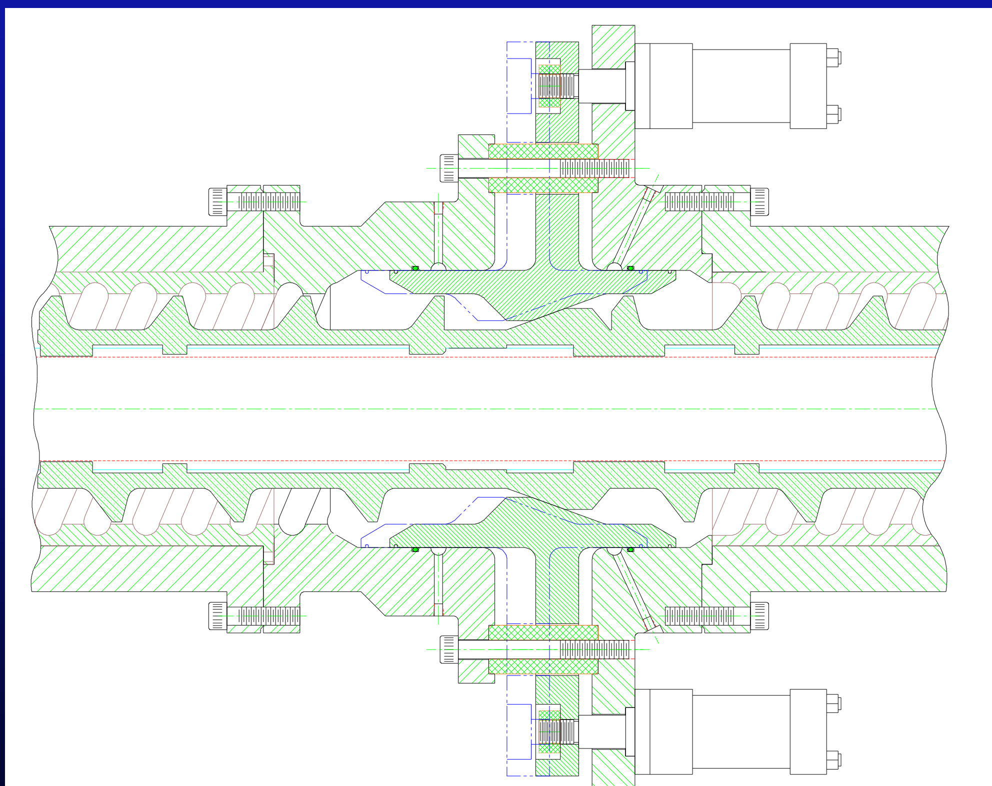
<u>Disadvantages</u>:

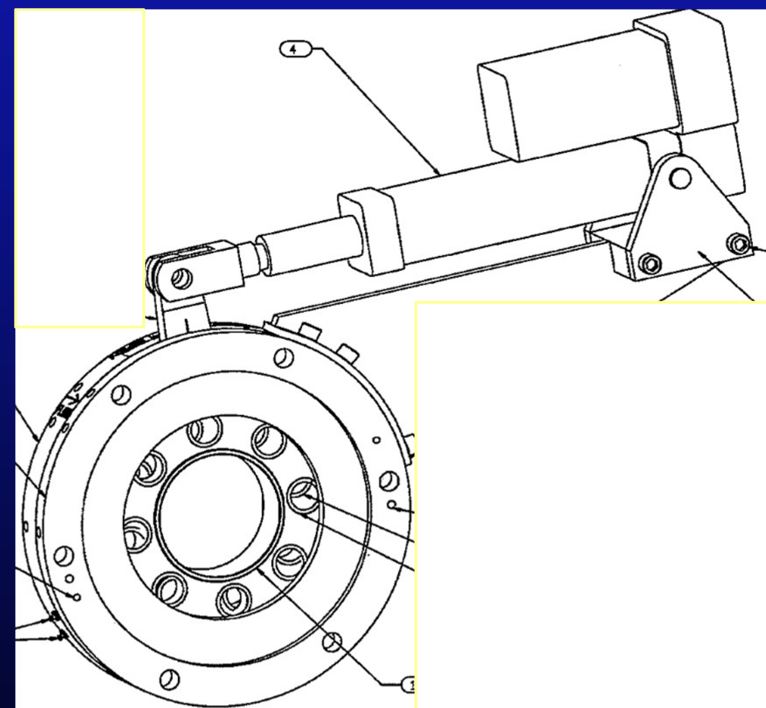
1) Capital investment
2) Idle equipment when proc light density products

Hardware Tools To Control Product Density

1) Extruder barrel that can be vented with or without vacuum assist (DMS)
2) Separate cooking and forming extruders (PDU)
3) Restriction valve inside extruder barrel (MBV)
4) Restriction valve at end of extruder (BPV)
5) Pressure chamber at extruder die (EDMS)

Restriction valves inside extruder barrel for Single or Twin Screw Extruders





for SME and Density Control

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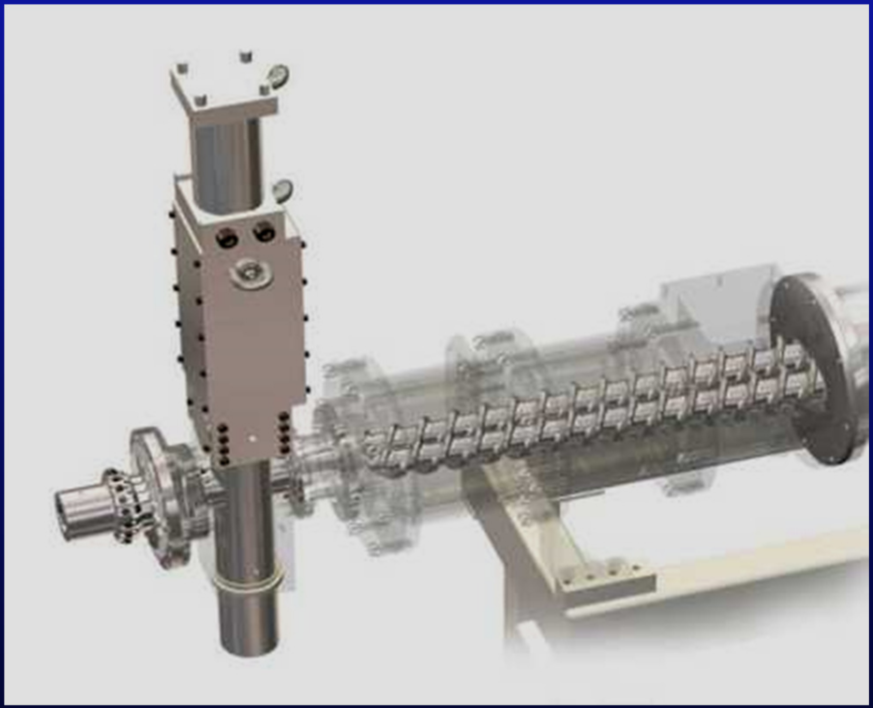
Hardware Tools To

Control Product Density

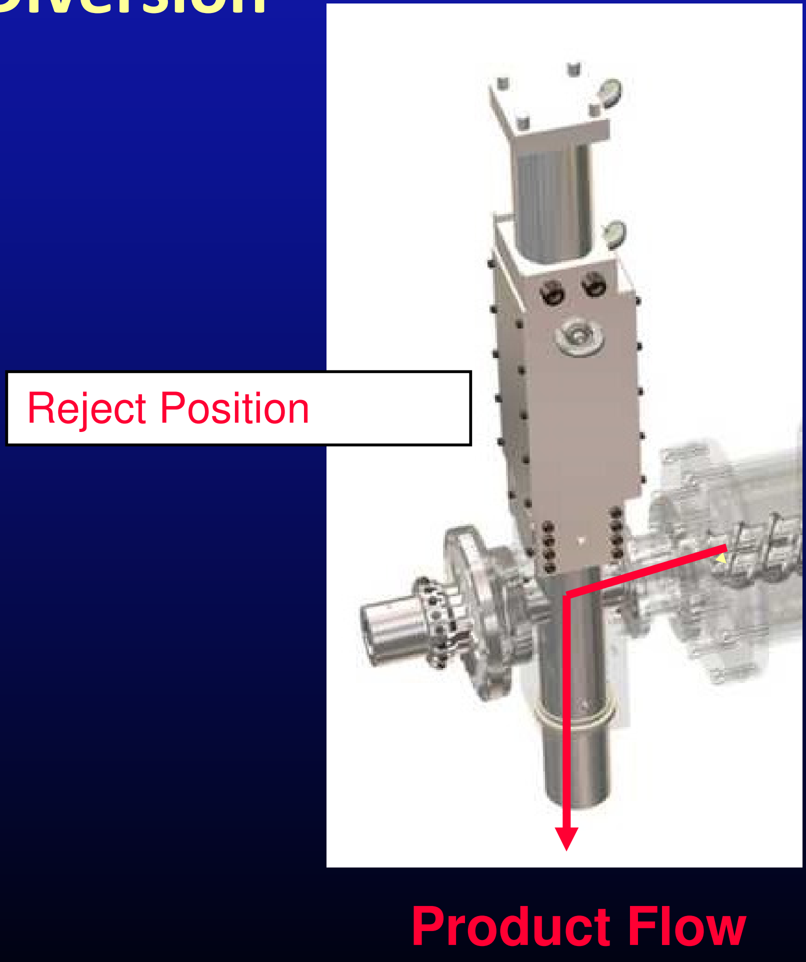
Restriction valve located at discharge of extruder to adjust extrusion pressure and SME inputs



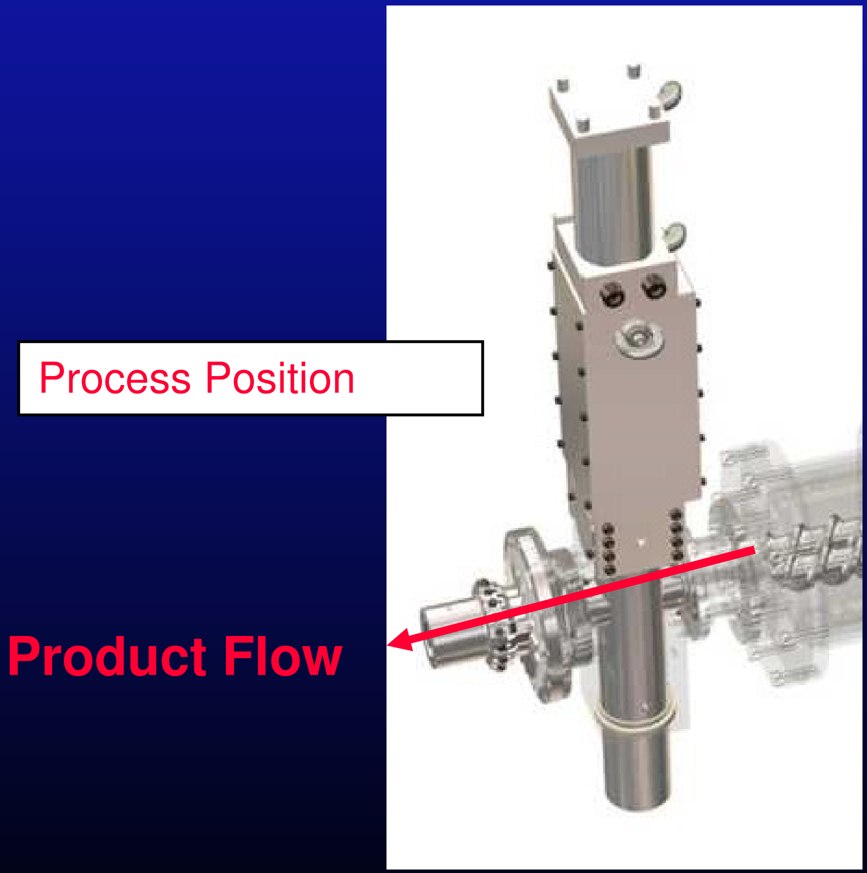
Back Pressure Valve (BPV)

BPV (Back Pressure Valve)

BPV – Product Diversion



BPV – Control Restriction by Valve Position



Back Pressure Valve (BPV)

Advantages:

1) Divert off-spec product for improved sanitation and quality control

2) Service die/knife/conveyor without stopping extruder

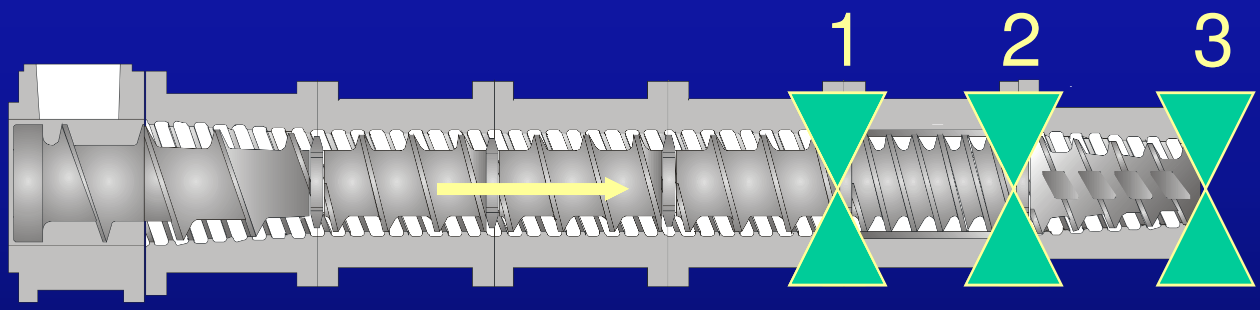
3) On-line adjustment of SME to control product properties (cook, density, shape, water stability, oil absorption

4) Eliminate extruder configuration changes

Use of BPV as a Tool to Vary Product Bulk Density Without Extruder Configuration Changes

BPV % Closed	Wet Bulk Density (g/l)	Dry Bulk Density (g/l)	SME (kWh/t)
50	440	438	38
60	423	420	39
70	392	393	42
80	358	348	46

Effect of Valve Location on SME and Product Density



Sample	Valve position	SME (kW-hr/t)	Product density (g/l)
060512001	All open	28	430
060512005	#1 closed	34 (21%)	393 (9%)
060512011	#2 closed	42 (50%)	376 (13%)
060512010	#3 closed	43 (54%)	355 (17%)
060512015	#2 & #3 closed	59 (111%)	275 (36%)

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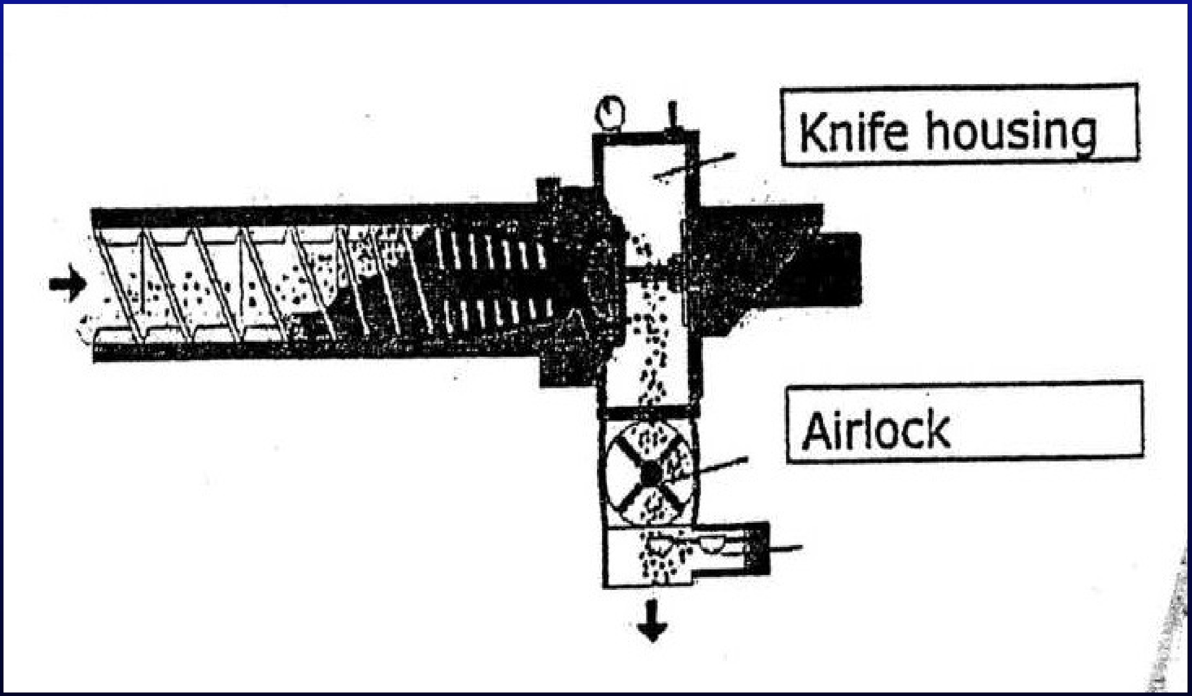
Hardware Tools To Control Product Density

Pressure chamber external to extruder die - "EDMS"



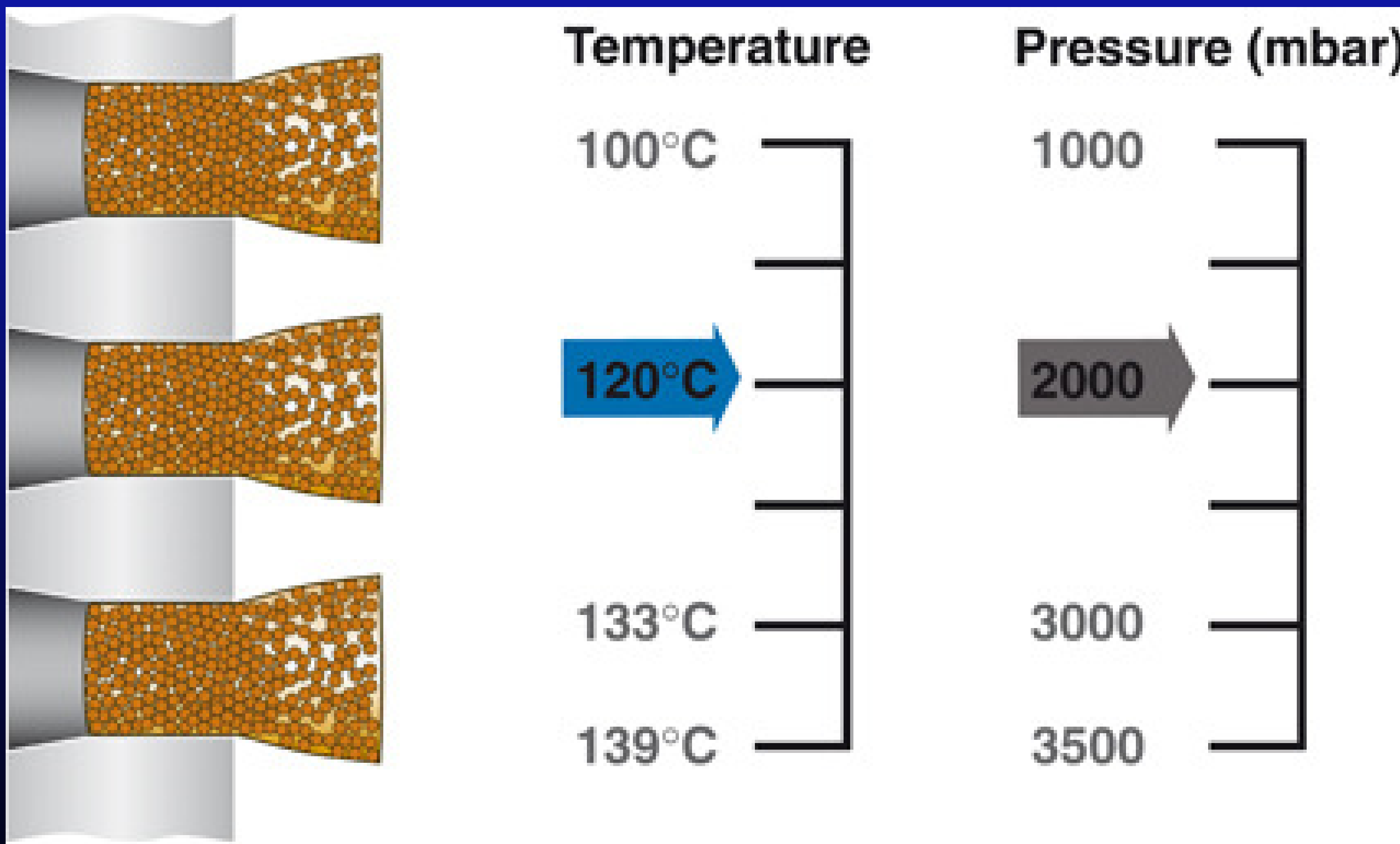
Effect of Increasing Pressure in Chamber

Pressure (bar)	Over-pressure bar (psig)	Boiling point of water ℃ (℉)	Increase in density (%) *
1.0**	0 (0)	100 (212)	-
1.5	0.5 (7.4)	112 (237)	10.0
2.0	1.0 (14.7)	121 (250)	18.3
2.5	1.5 (22.1)	128 (263)	25.0
3.0	2.0 (29.4)	134 (273)	28.3
3.5	2.5 (36.8)	139 (282)	NA

*Density increase depends on pellet size

**Atmospheric conditions

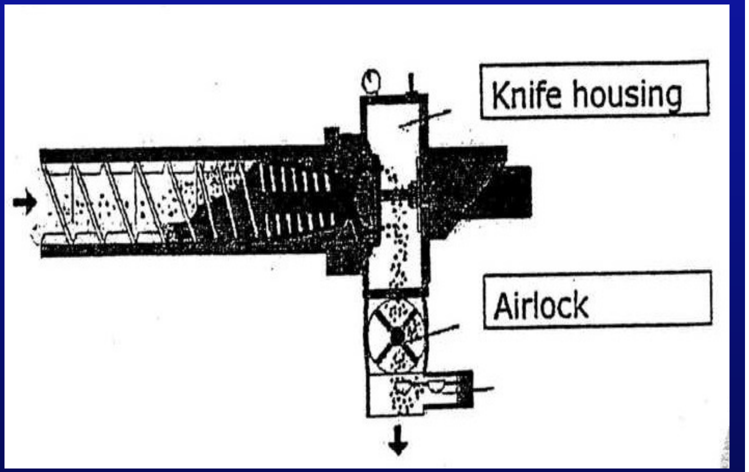
Effect of Increasing Pressure in Chamber



Pressure chamber external to extruder die - EDMS

Advantages:

1) Increase product density without changing extrusion process
2) High product densities possible



Sprout Matador ECS

Disadvantages:

1) Not suitable for large diameter pellets or recipes that are sticky
2) High operational and maintenance costs

Back Pressure Valve Coupled with Pressure Chamber for Density Control (EDMS)

Density control with valve = ± 20%

Density increase with pressure chamber = + 25%

Combined effect yields density adjustment = ± 30%

Summary

Density Control in aqua feed can be achieved by

1. Recipe adjustment and composition
2. Process Variables

(not including recipe changes)

3. Hardware tools