Tappi PLACE Extrusion Coating and Blown/Cast Film Short Course

August 24th-26th, 2010

Charleston, SC

Fundamental Concepts of Extrusion Design

Presented By:

Lou Piffer

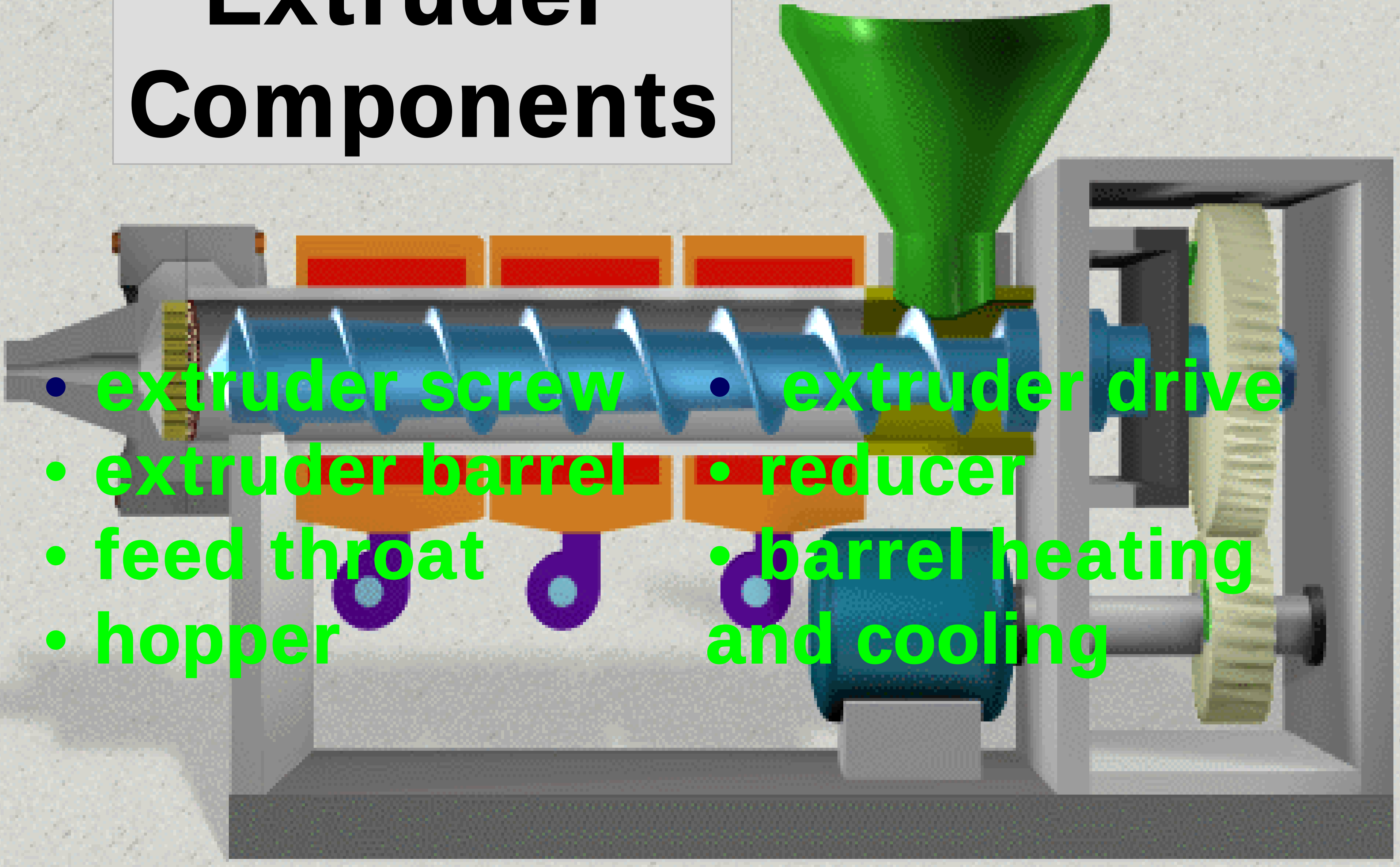
Davis-Standard Corp.

Black Clawson Converting Machinery

EGAN®

ER-WE-PA

Extruder Components

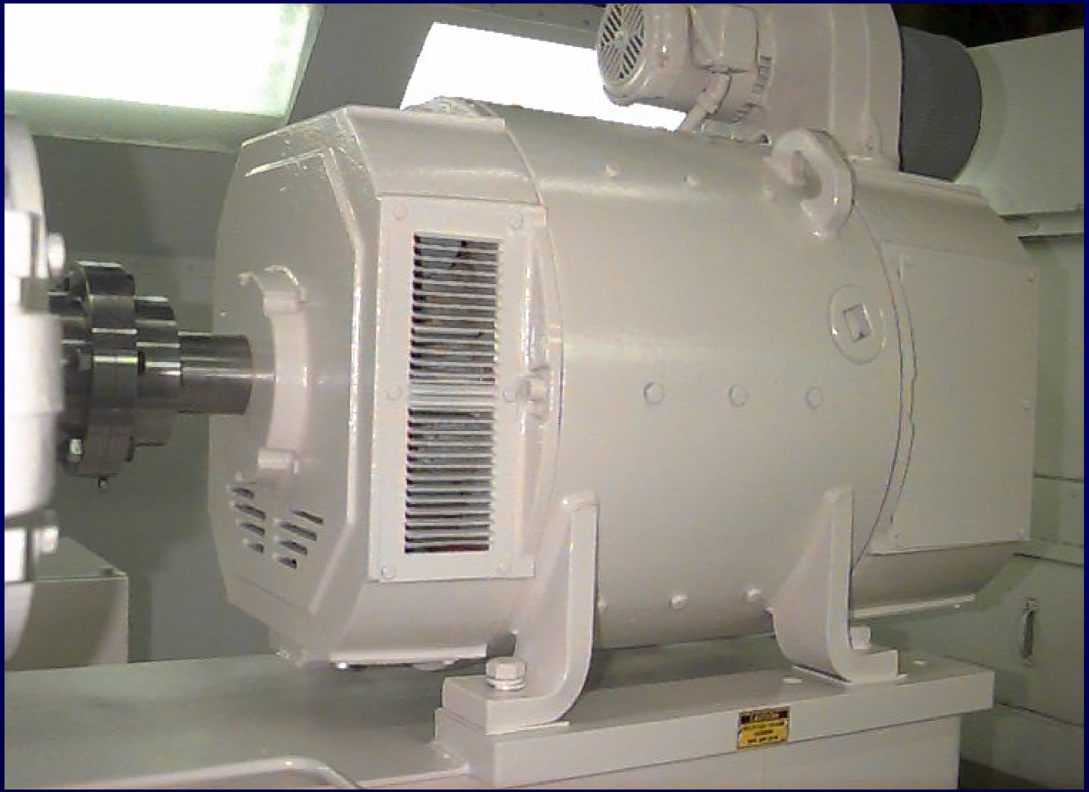


- extruder screw
- extruder barrel
- feed throat
- hopper
- extruder drive
- reducer
- barrel heating and cooling

AC / DC Drives & Motors

Drive Motor

- 6” - 400/500 HP
- 4 1/2” - 250 HP
- 3 1/2” - 150 HP
- 2 1/2” - 75 HP



GearBox

Gearbox

- Converts high speed output shaft from drive (1750 RPM) to screw speed

Gearbox

- Closed loop oil circulation system insures gears do not see excessive heat

Thrust bearing

B-10 Life

Expected Life of 9 out of ten bearings at a given condition

Predictive Maintenance

- Bronze in oil - out of round thrust bearing
- Steel in oil - bad bearing or gear tooth
- Cast iron powder in oil - moving part against gear box casting

Feedsection

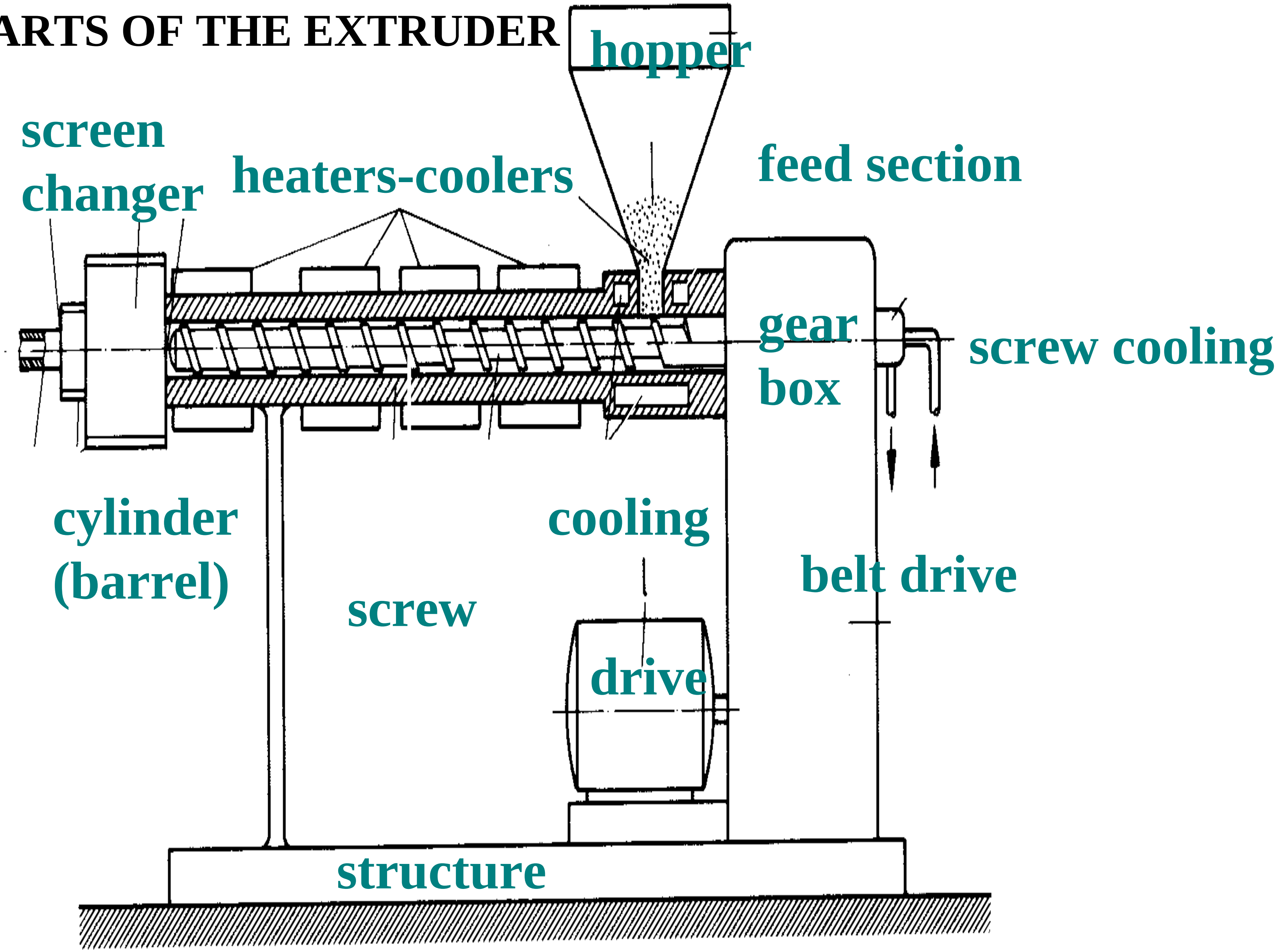
Feed Section

- Cast iron jacketed
- Initial point where resin is introduced
- Space between gear box and resin feeding point

Resin Hopper

- Hopper often cooled to prevent bridging

PARTS OF THE EXTRUDER



Extruder Barrel

- 1/16” Bimetalic Alloy
- Bolted to feedsection
- The barrel is harder than the screw.
- Sliding barrel support

Barrel Types

- Non abrasive environments - Chromium-modified boron-iron alloy.
- Abrasive environments - Tungsten carbide in a matrix of nickel alloy.
- Abrasive style barrel may cost 25% more but last 3X longer!

Barrel Wear

- 1/16” (.0625”) thick when new
- Should look at replacing barrel when there has be .030” of wear.

Screw Wear

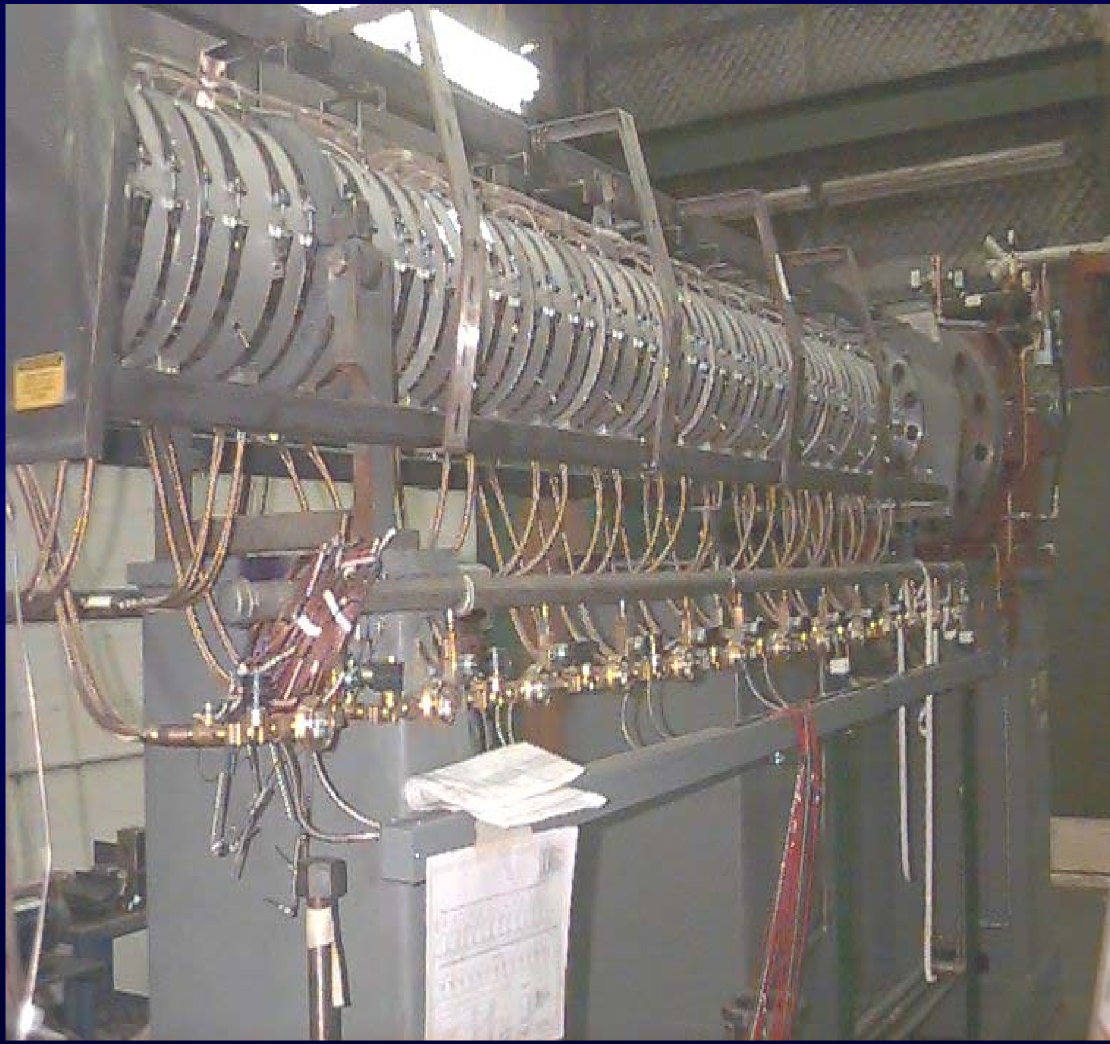
- Initial clearance of 1 mil/extruder diameter/side
- Example . 4.5”extruder will have initial clearance of approximately .0045/side
- Look to replacing screw when clearance doubles to triples. (In above example when clearance is .009 - .0135”)

Barrel Heater Types

- Ceramic Band (heat only)
- Electric Heat - Air Cooled
- Electric Heat - Water Cooled

Water cooled Heaters

- Jacketed Heater
- Solenoid valves
- Inlet/outlet manifolds.
- Water reservoir

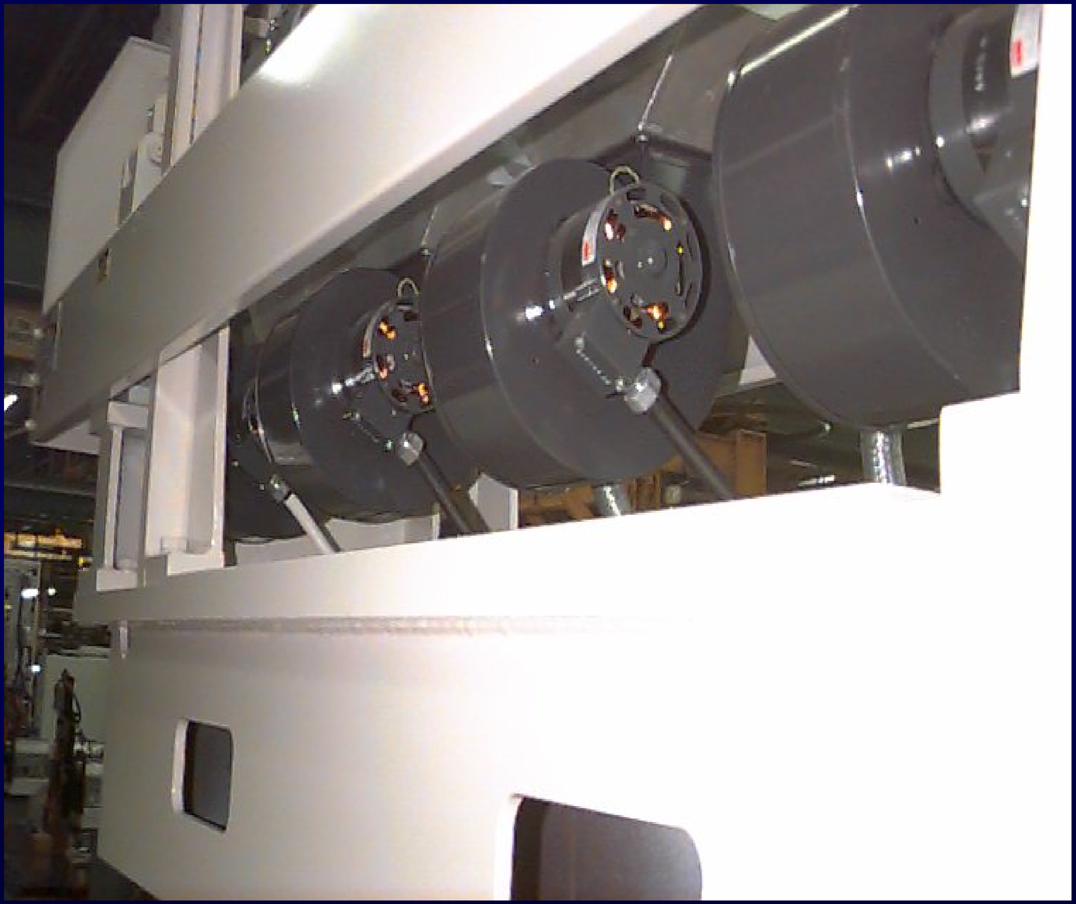


Water cooled Heaters

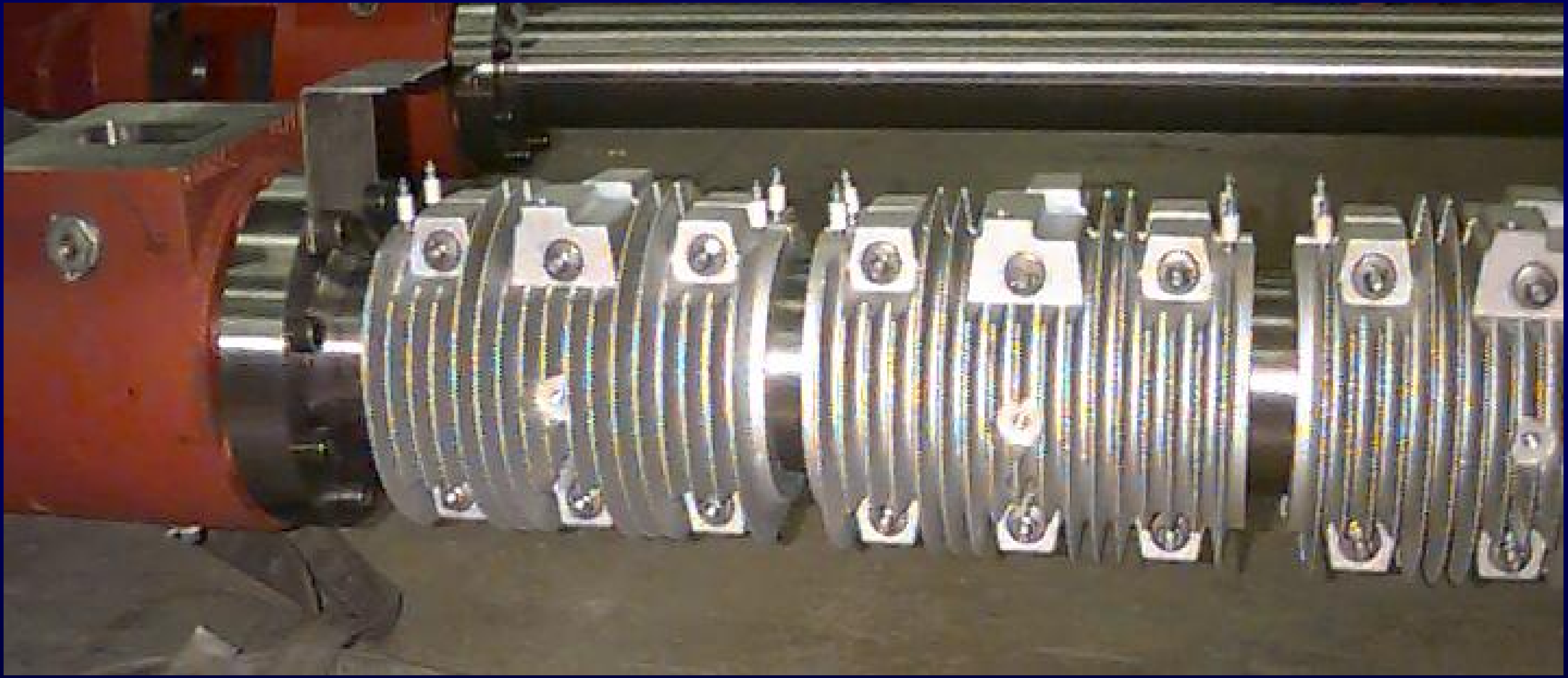
- Jacketed Heater
- Solenoid valves
- Inlet/outlet manifolds.
- Water reservoir

Air cooled Heaters

- Finned Heater
- Air Blowers



Air cooled Heaters

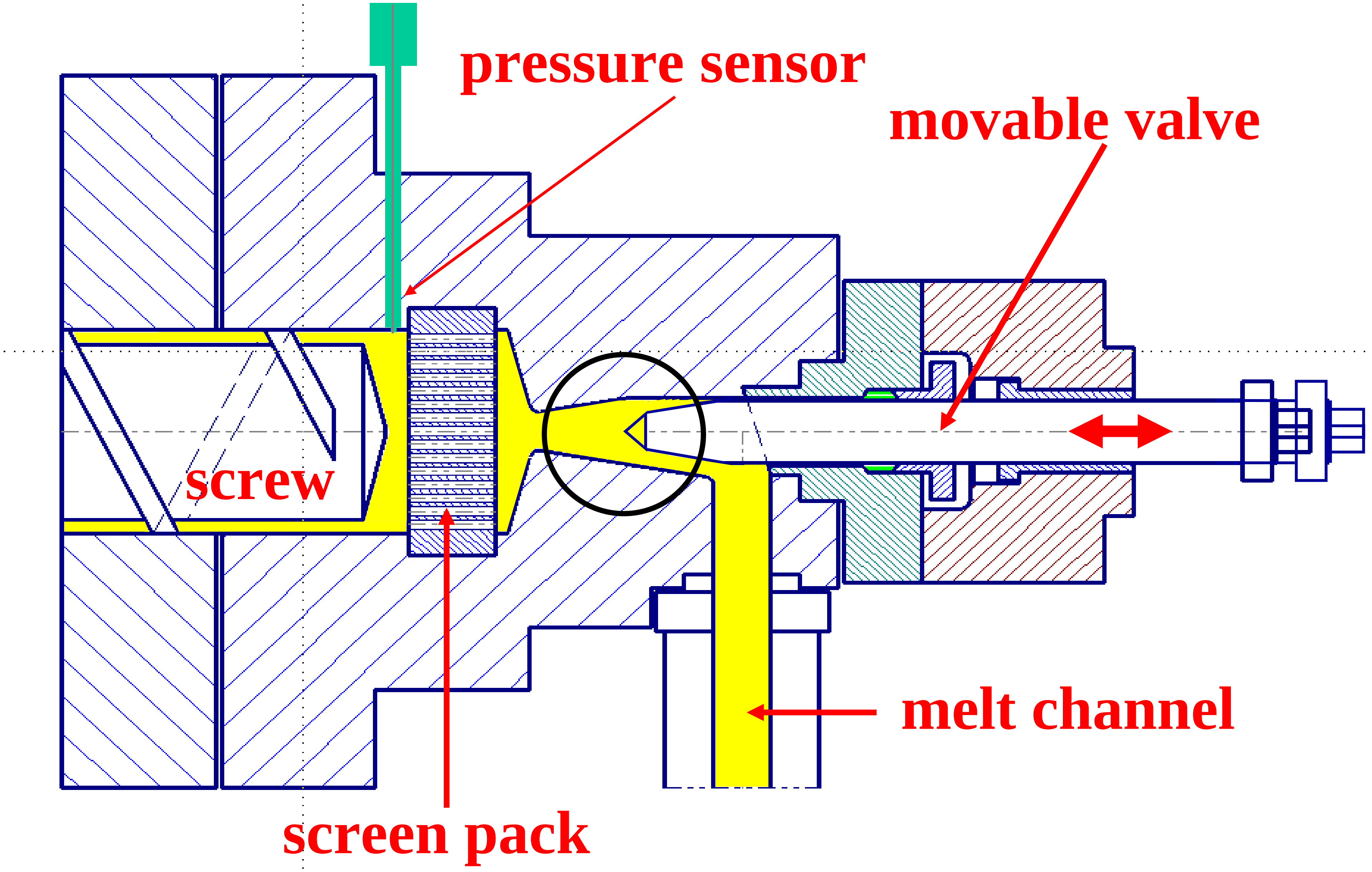


Extruder Adapter

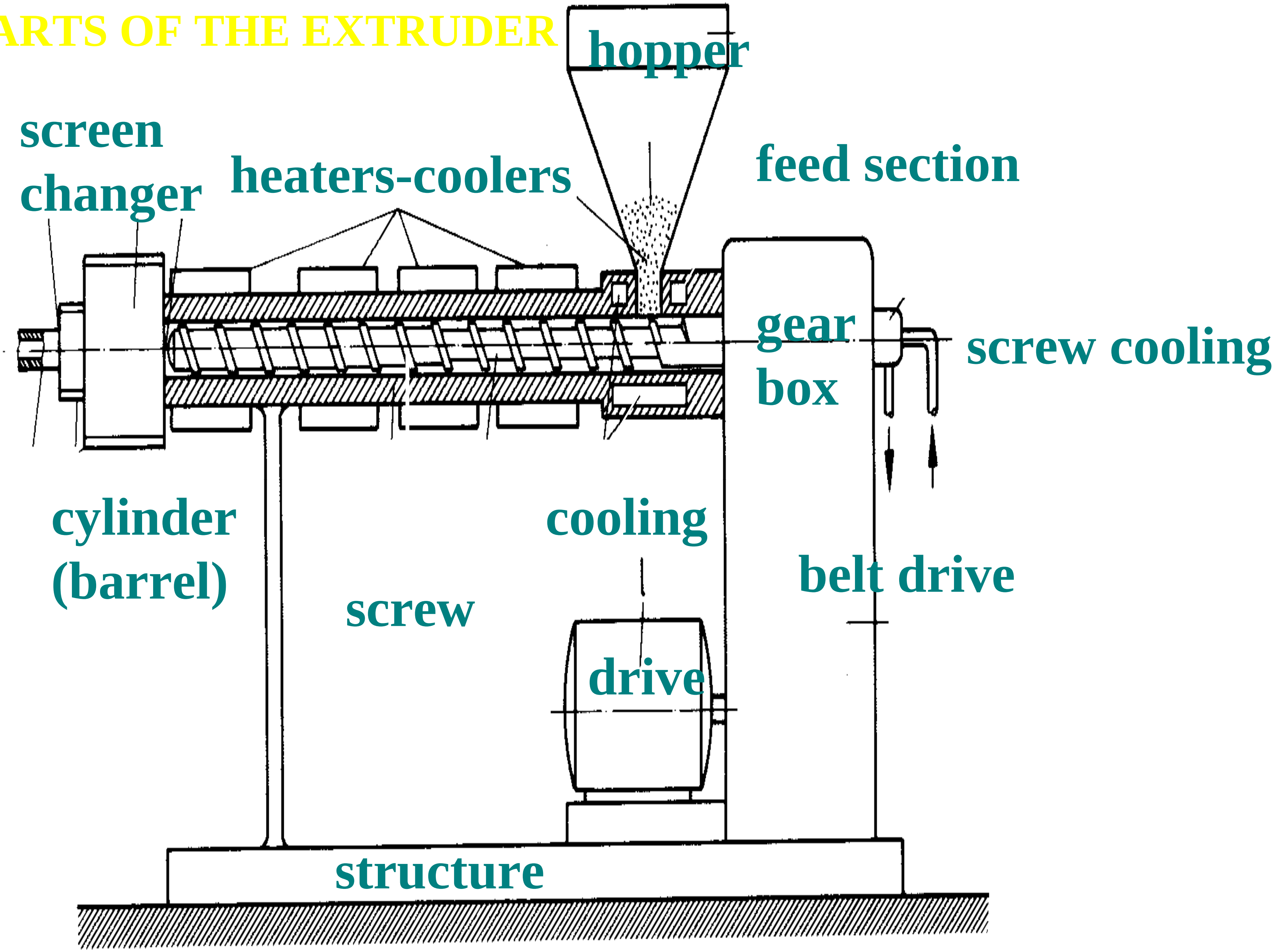
Extruder Adapter

- Change resin flow
- Change pressure
- House screen pack

Valved Adapter



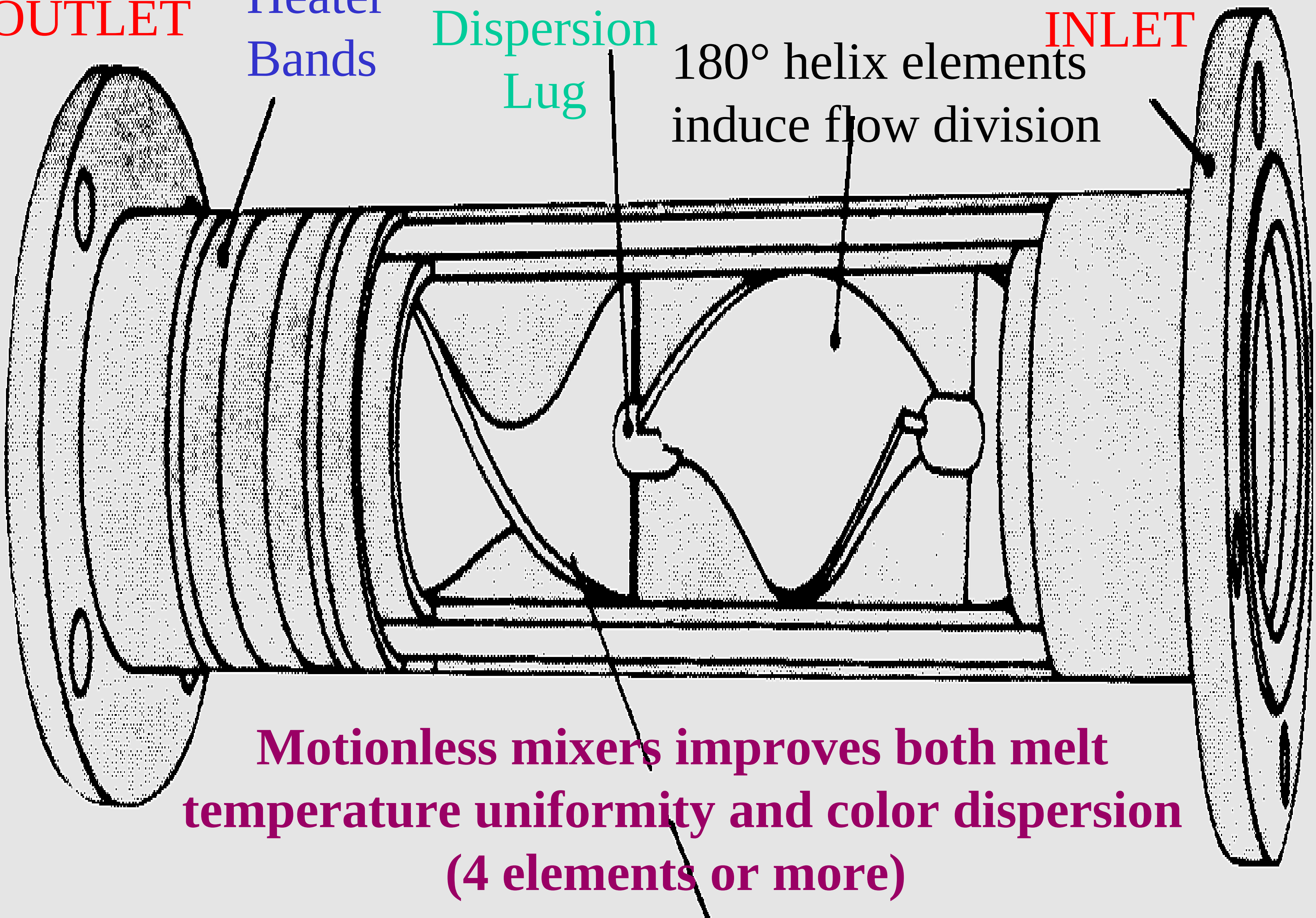
PARTS OF THE EXTRUDER



Extruder Adapter

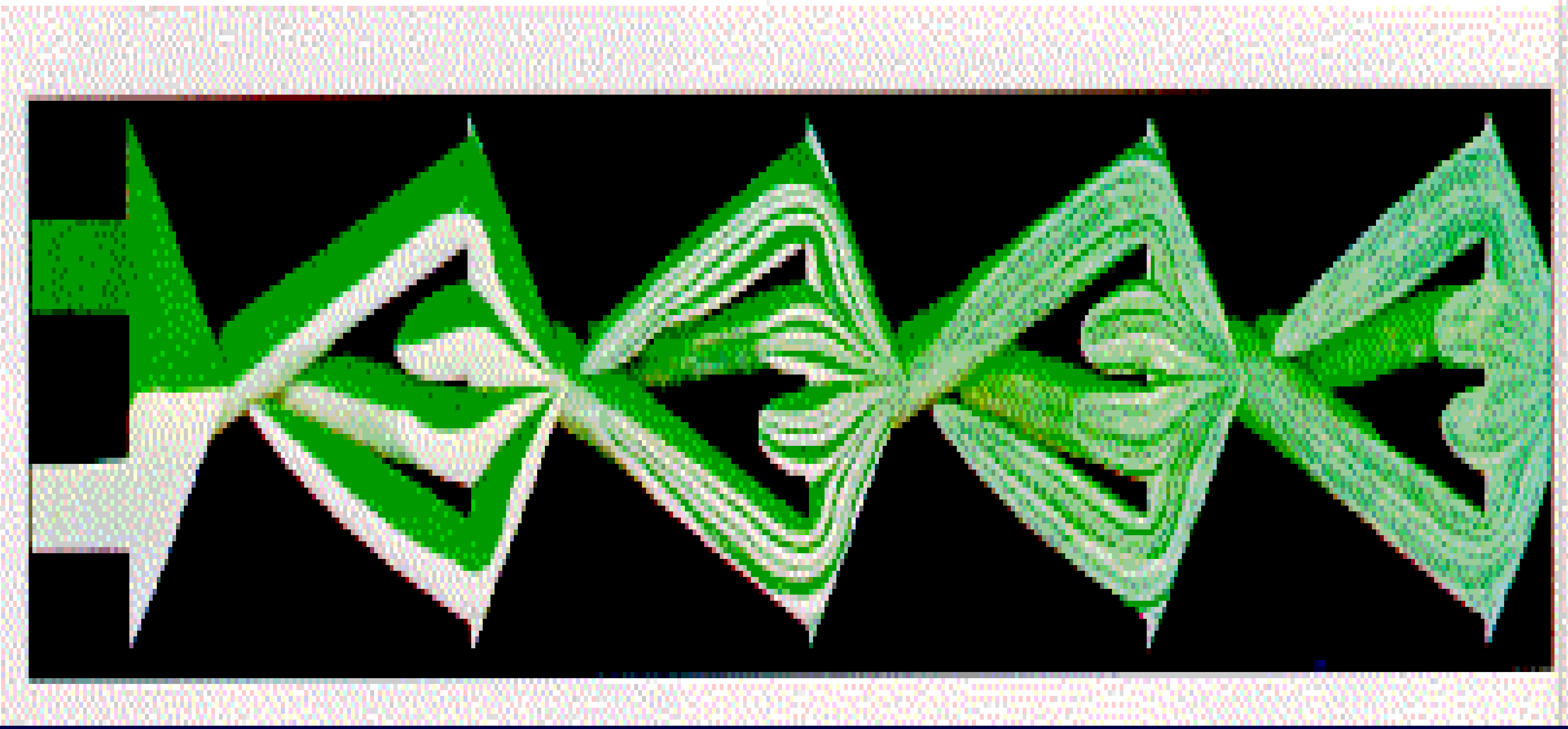
- Change resin flow
- Change pressure
- House screen pack

Static Mixer Principle



Motionless mixers improves both melt temperature uniformity and color dispersion (4 elements or more)

Static Mixer Principle



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Fundamental Concepts of Screw Design

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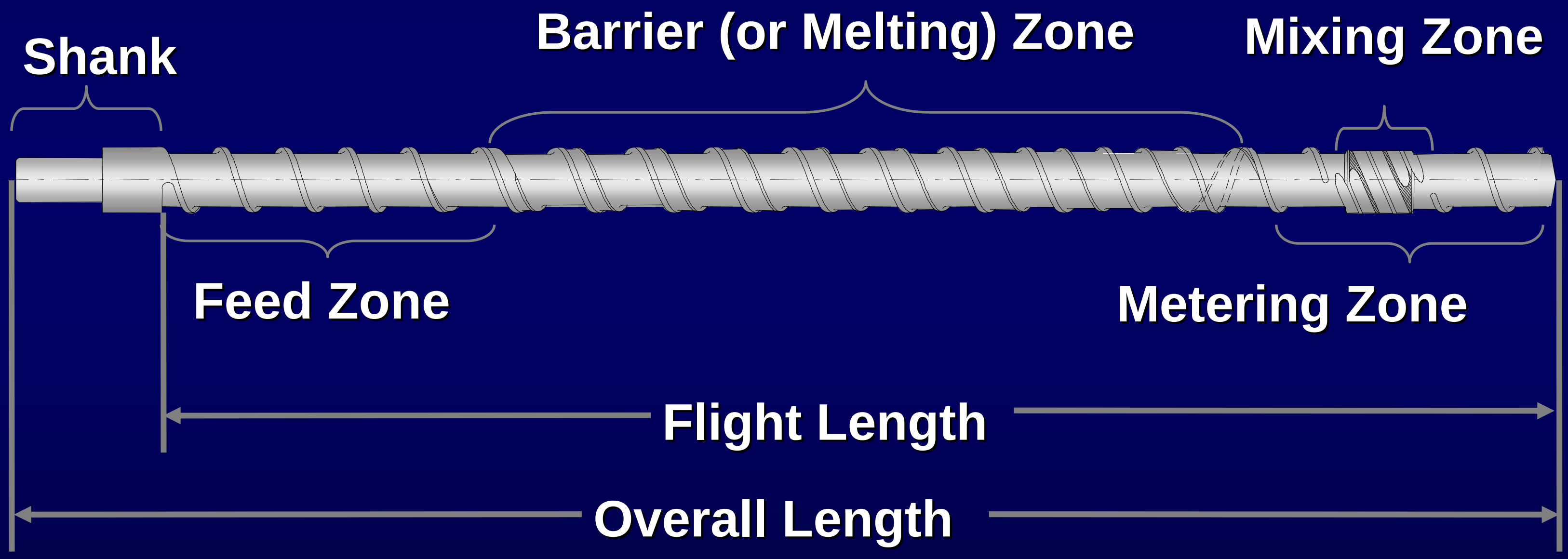
What will I learn?

- Why can’t my screw run all resins?
- Why are barrel profiles unique to a screw design?
- Why can increased barrel temperature sometimes result in less output?
- What happens when my screw wears out?

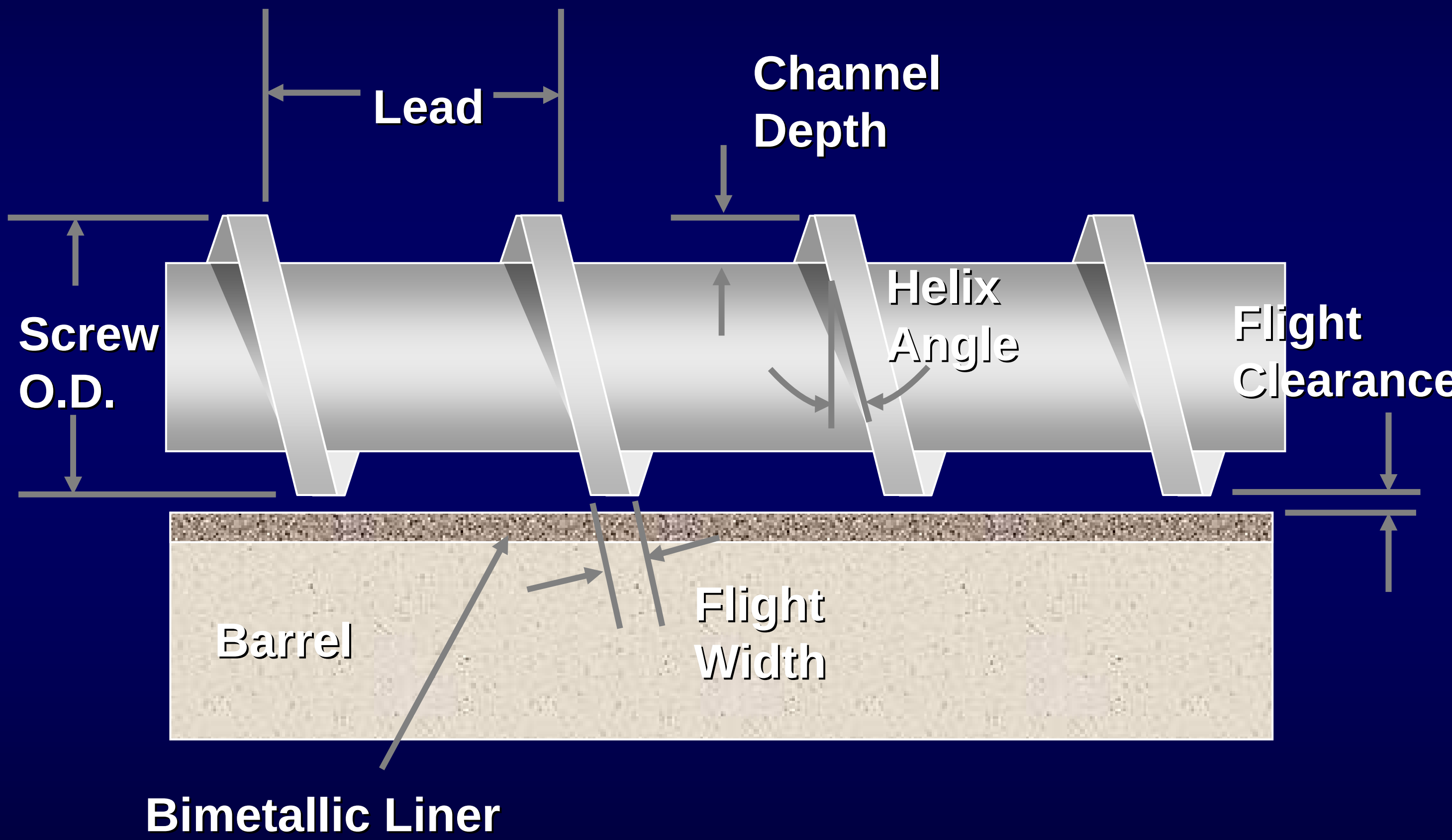
Viscous Heat Generation

$$\text{Heat} = \text{Viscosity} \times \text{Shear Rate}^2$$

Screw Terminology

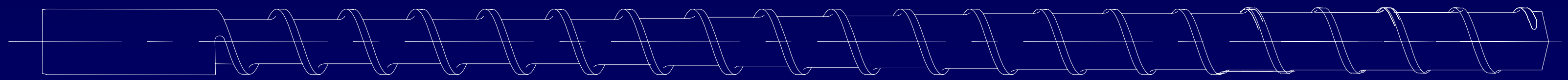


Screw Terminology

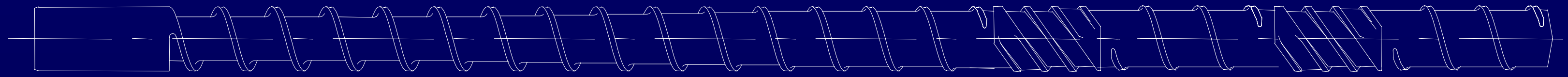


Typical Screw Classifications

- Metering Screw



- Mixing Screw



- Barrier Screw

Important Ratio Terms

- L/D = Length/Diameter
- CR = Compression Ratio

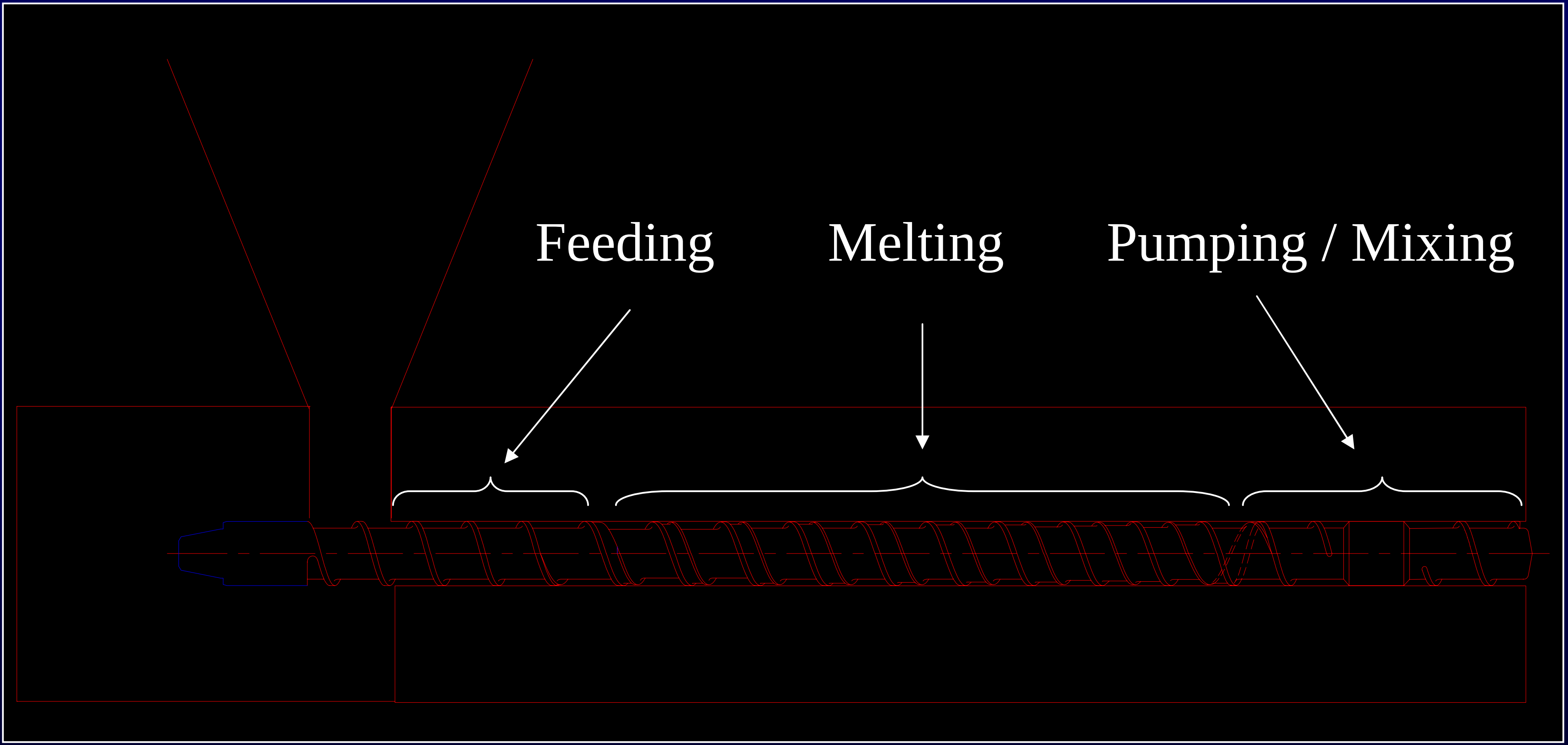
$$CR = \frac{\text{Feed Channel Depth}}{\text{Meter Channel Depth}}$$

  - Compression Ratio has no meaning for barrier type screw designs

Primary Functions of a Single Screw Extruder

- Optimized screw design must accomplish
  - Solids Conveying
  - Melting
  - Pumping
  - Mixing
- Each component is critical to the extrusion process

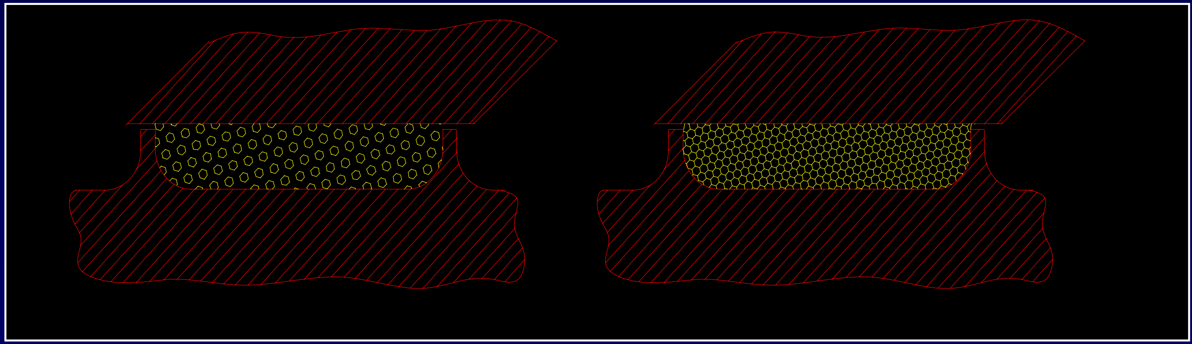
Primary Functions of a Single Screw Extruder



Feeding/Solids Conveying

Solids Conveying

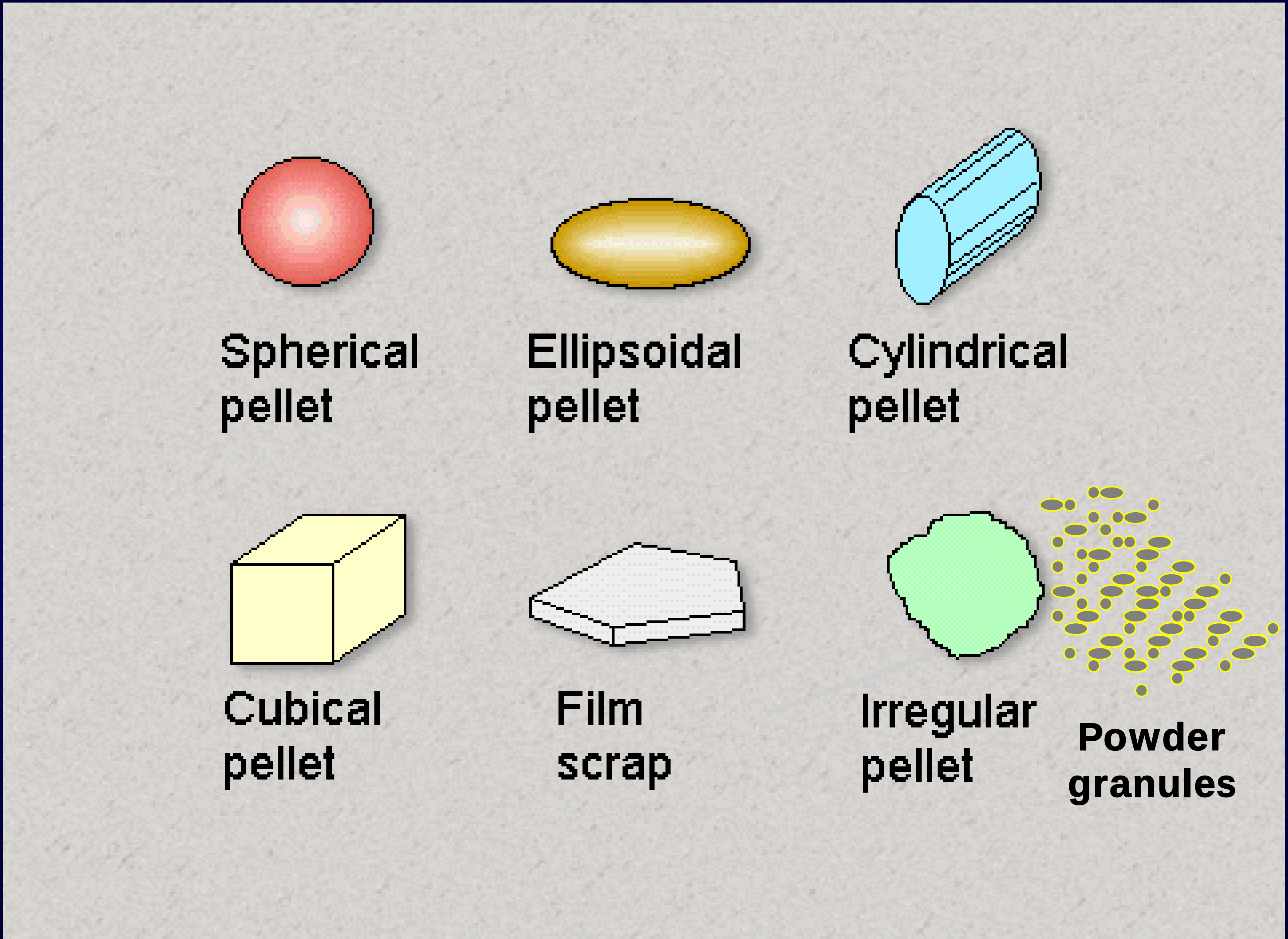
- Formation of a compacted solid bed



Some of the Most Important *Bulk Properties:*

- bulk density
- compressibility
- internal coefficient of friction
- external coefficient of friction
- particle size and particle distribution
- particle shape and particle distribution

Plastic Forms for Extrusion



Resin Hopper

- Hopper often cooled to prevent bridging

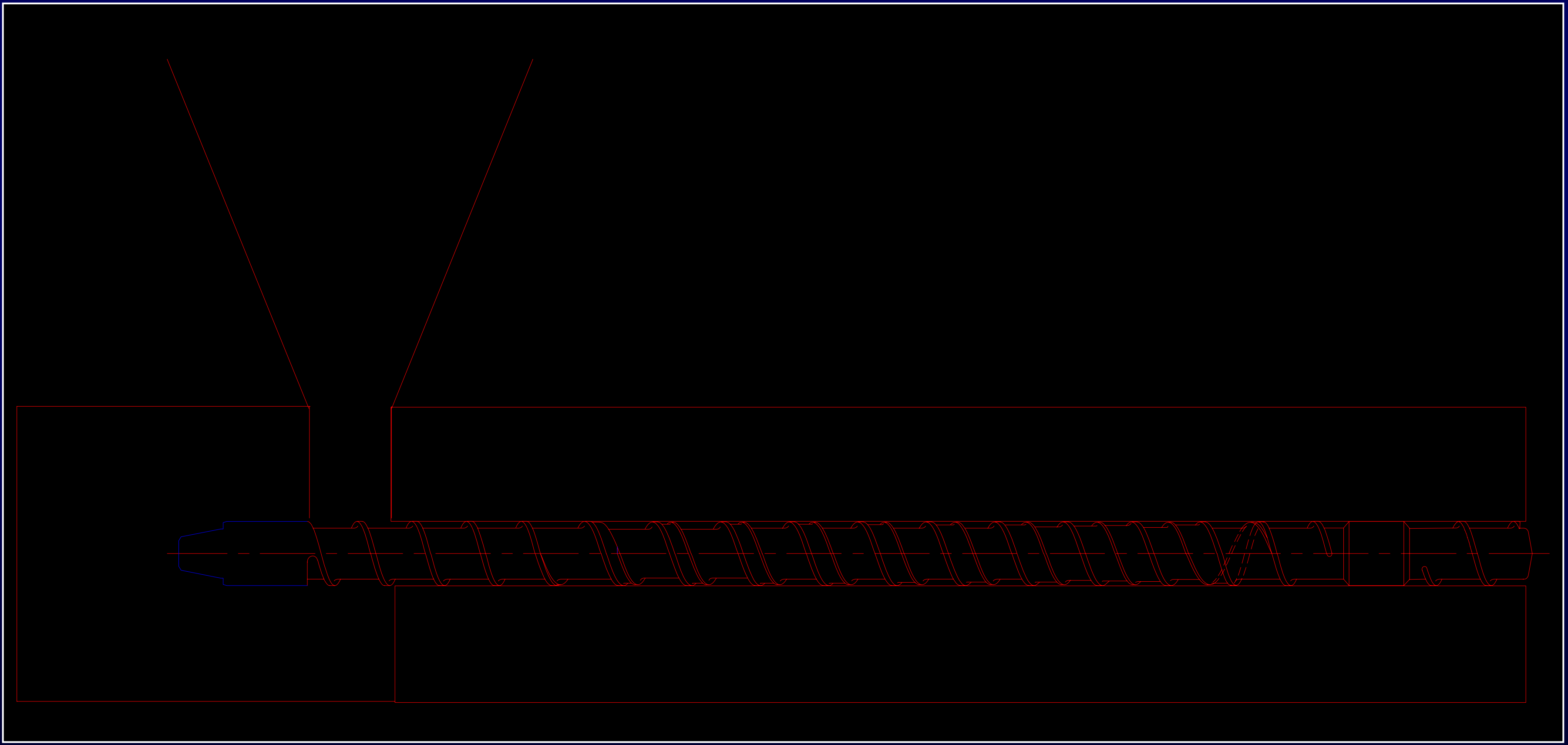
Drag Induced Conveying

The frictional force *at the barrel* is responsible for moving the material forward

For efficient forward conveying we want high friction on the barrel and low friction on the screw

If there is no barrel friction, then there can be *no* forward conveying

Solids Conveying

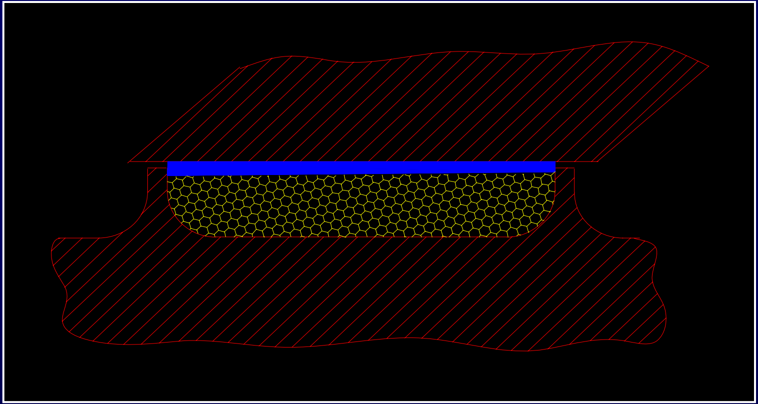


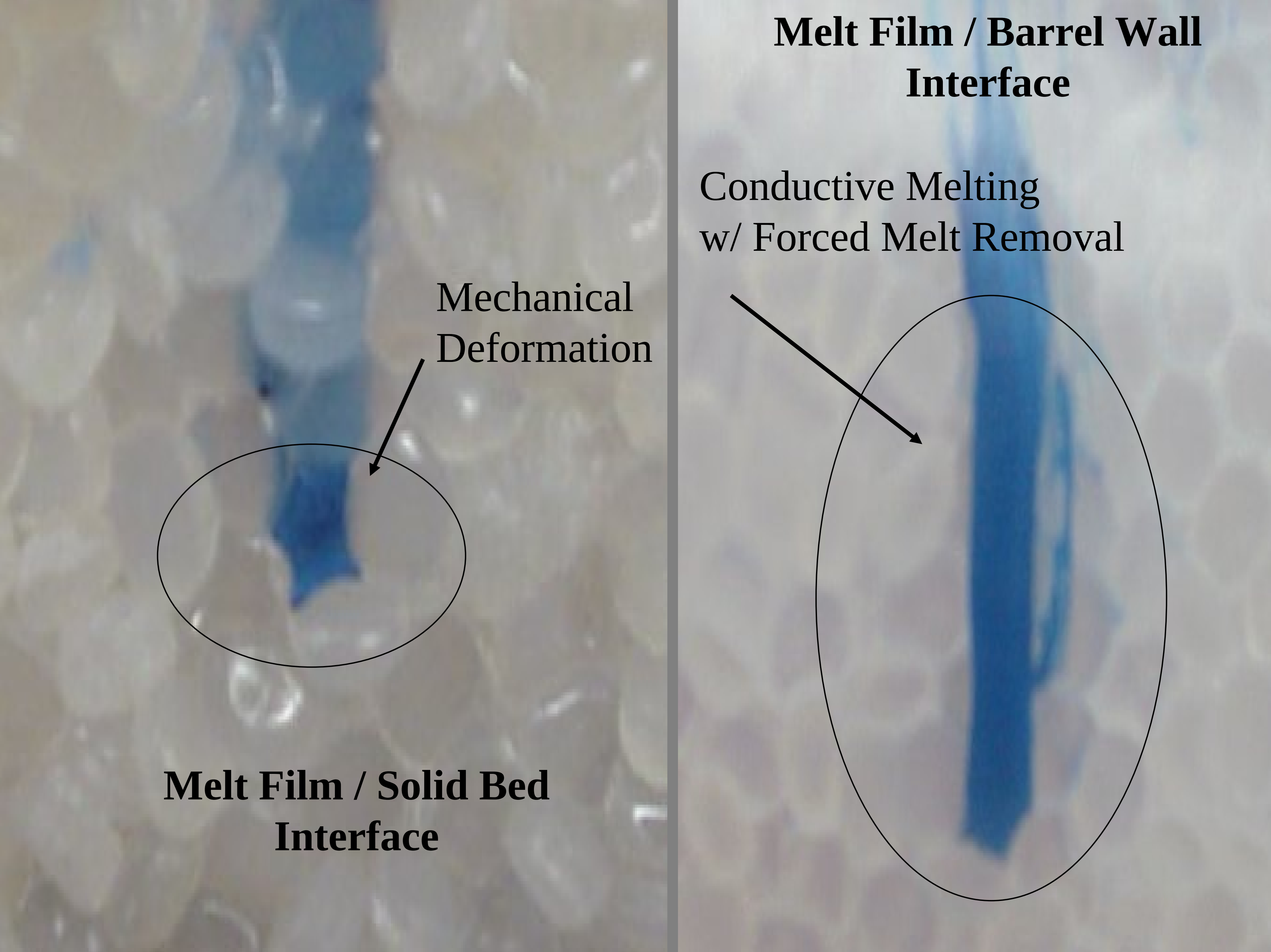
A wide distribution in particle size makes the material more difficult to convey and can lead to separation

Melting

Melting

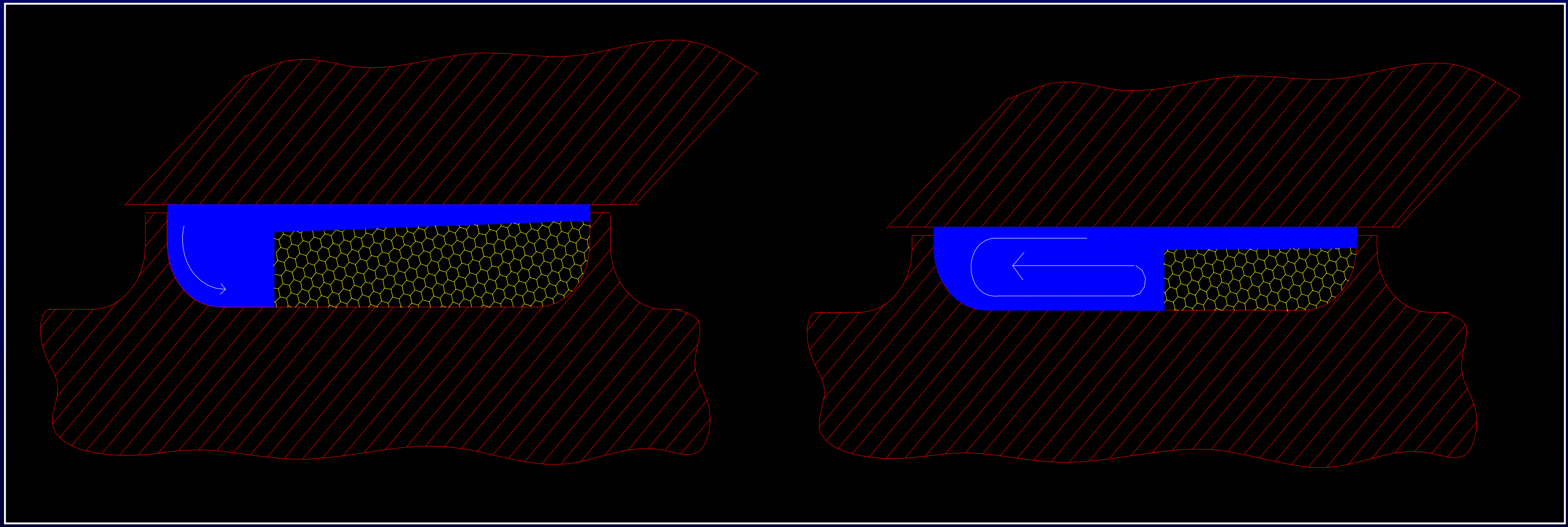
- Formation of a compacted solid bed
- Development of a melt film

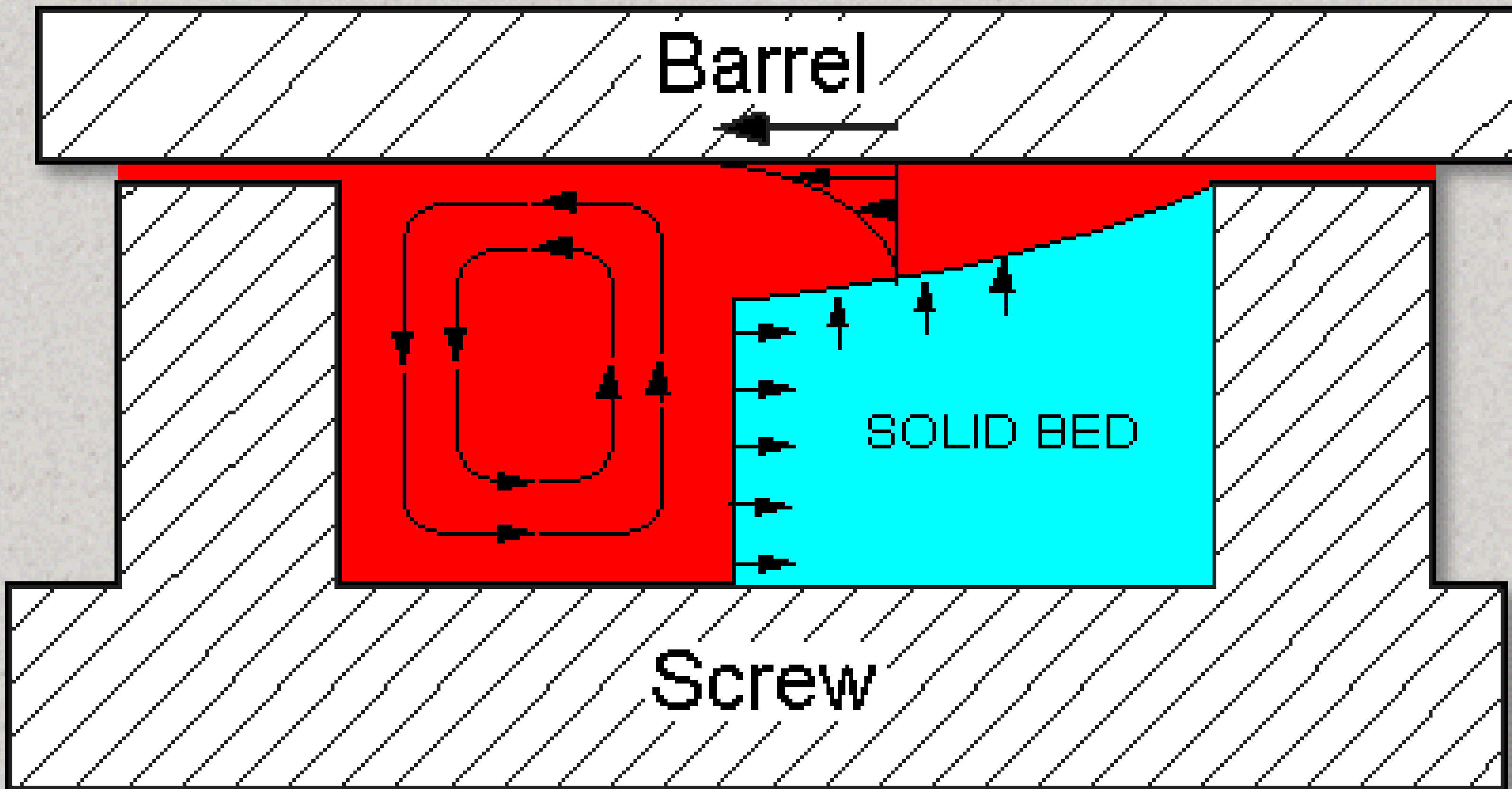



Mechanical
Deformation
Melt Film / Solid Bed
Interface
Melt Film / Barrel Wall
Interface
Conductive Melting
w/ Forced Melt Removal

Melting

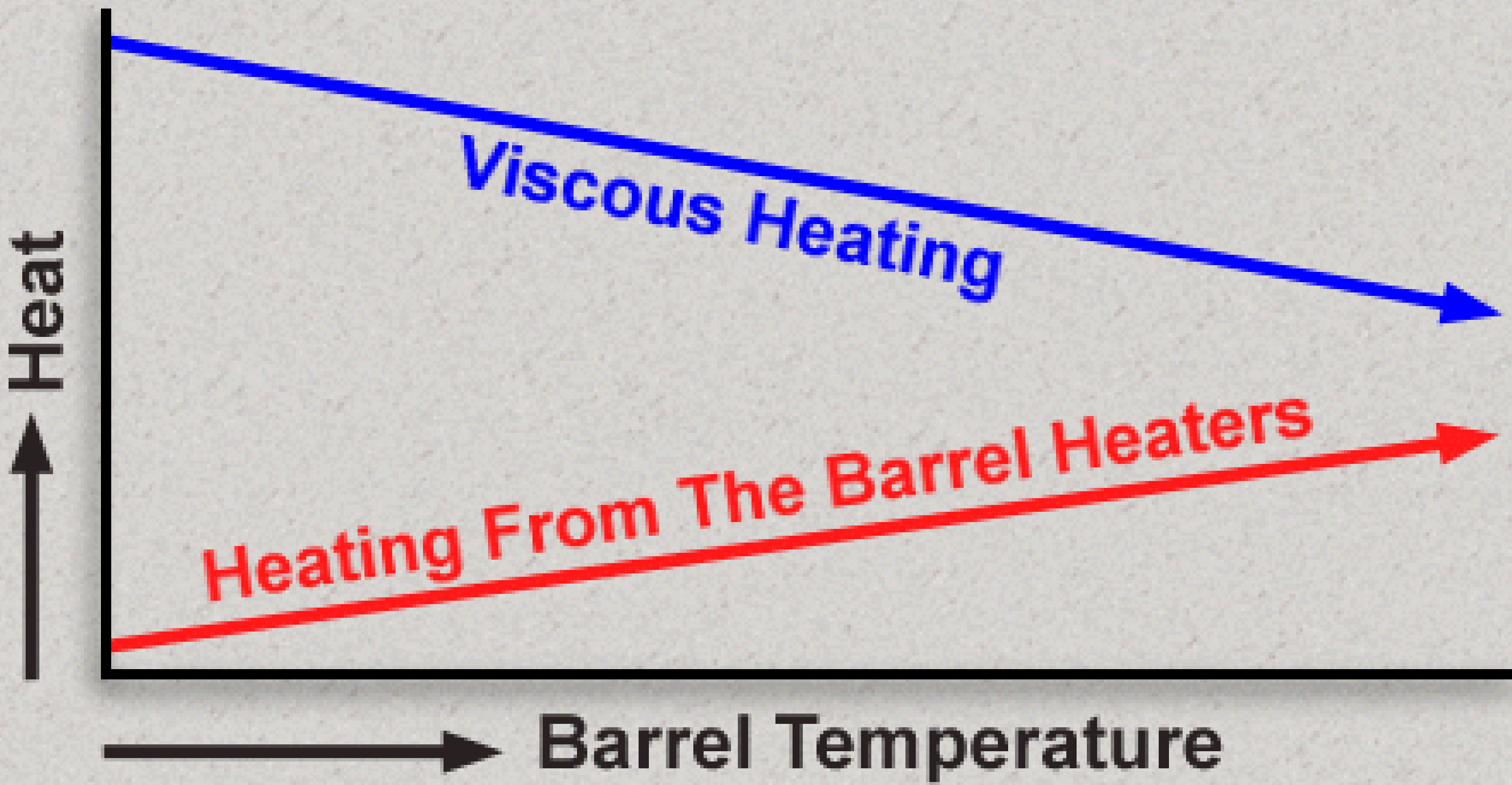
- Formation of a compacted solid bed
- Development of a melt film
- Removal of melt into an accumulating melt pool





Contiguous Solids Melting

EFFECT OF BARREL TEMPERATURE

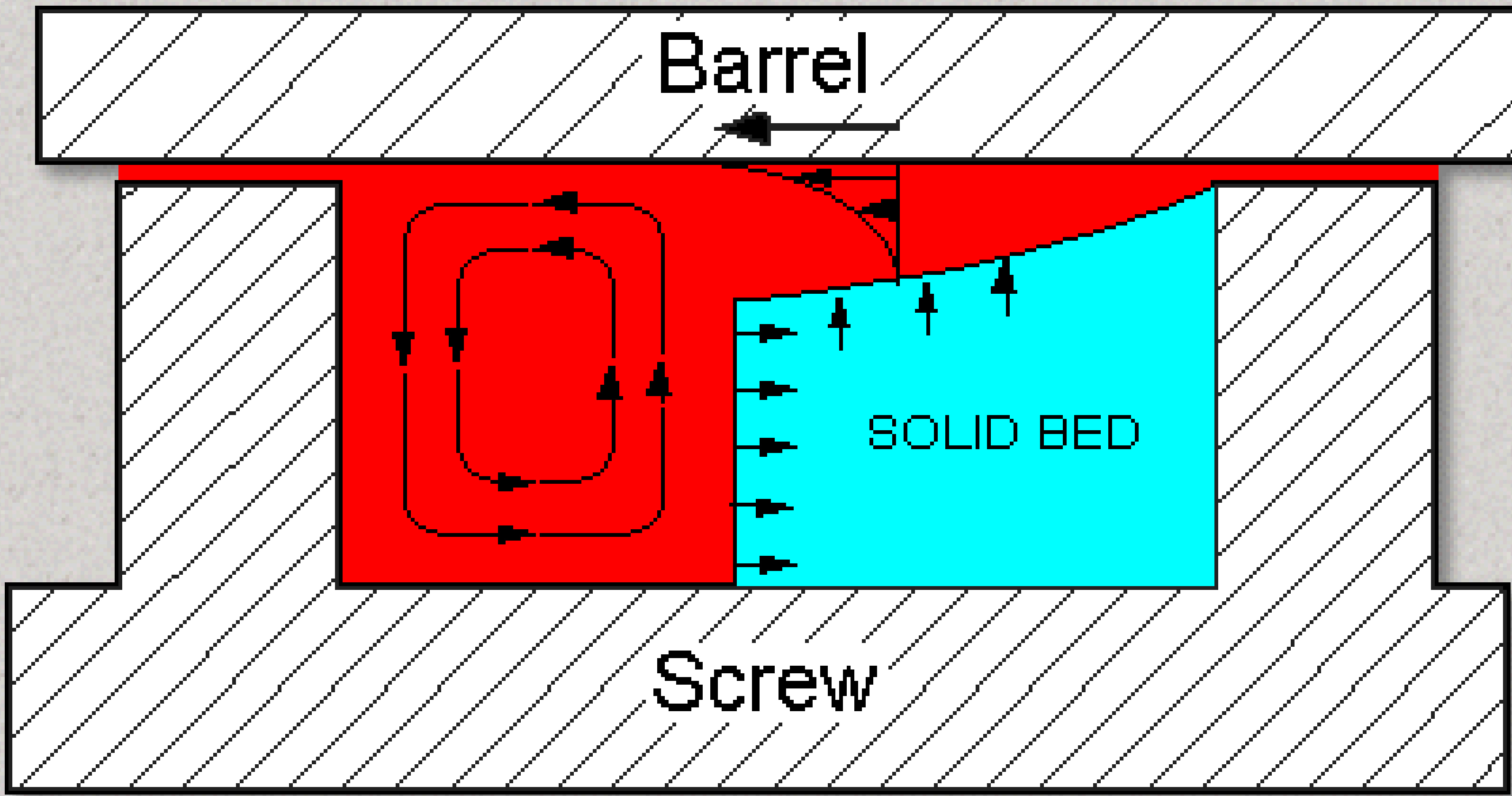


Viscous Heat Generation

$\text{Heat} = \text{Viscosity} \times \text{Shear Rate}^2$

Factors that effect the melt rate

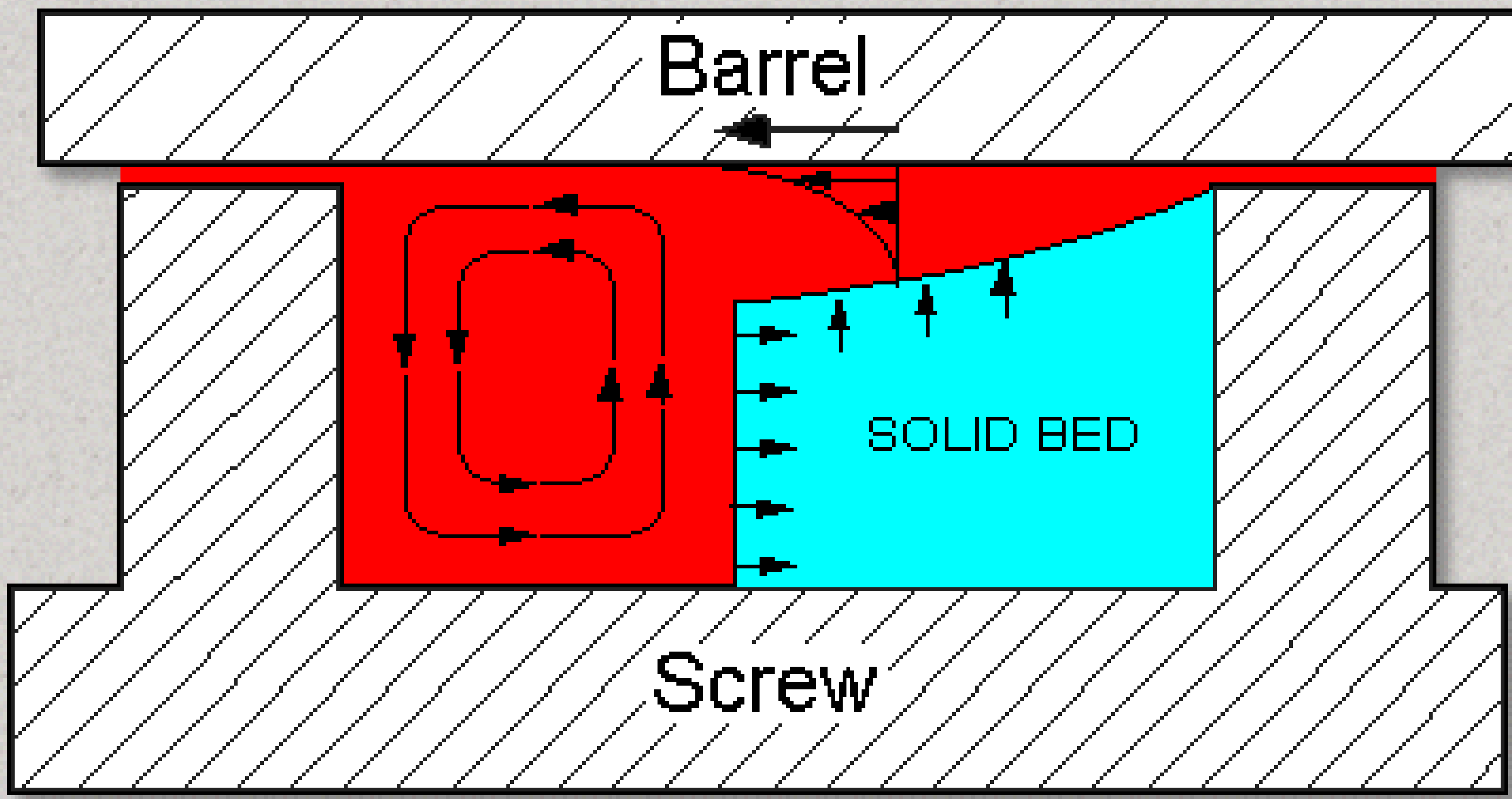
- Melt Film Thickness



Contiguous Solids Melting

Factors that effect the melt rate

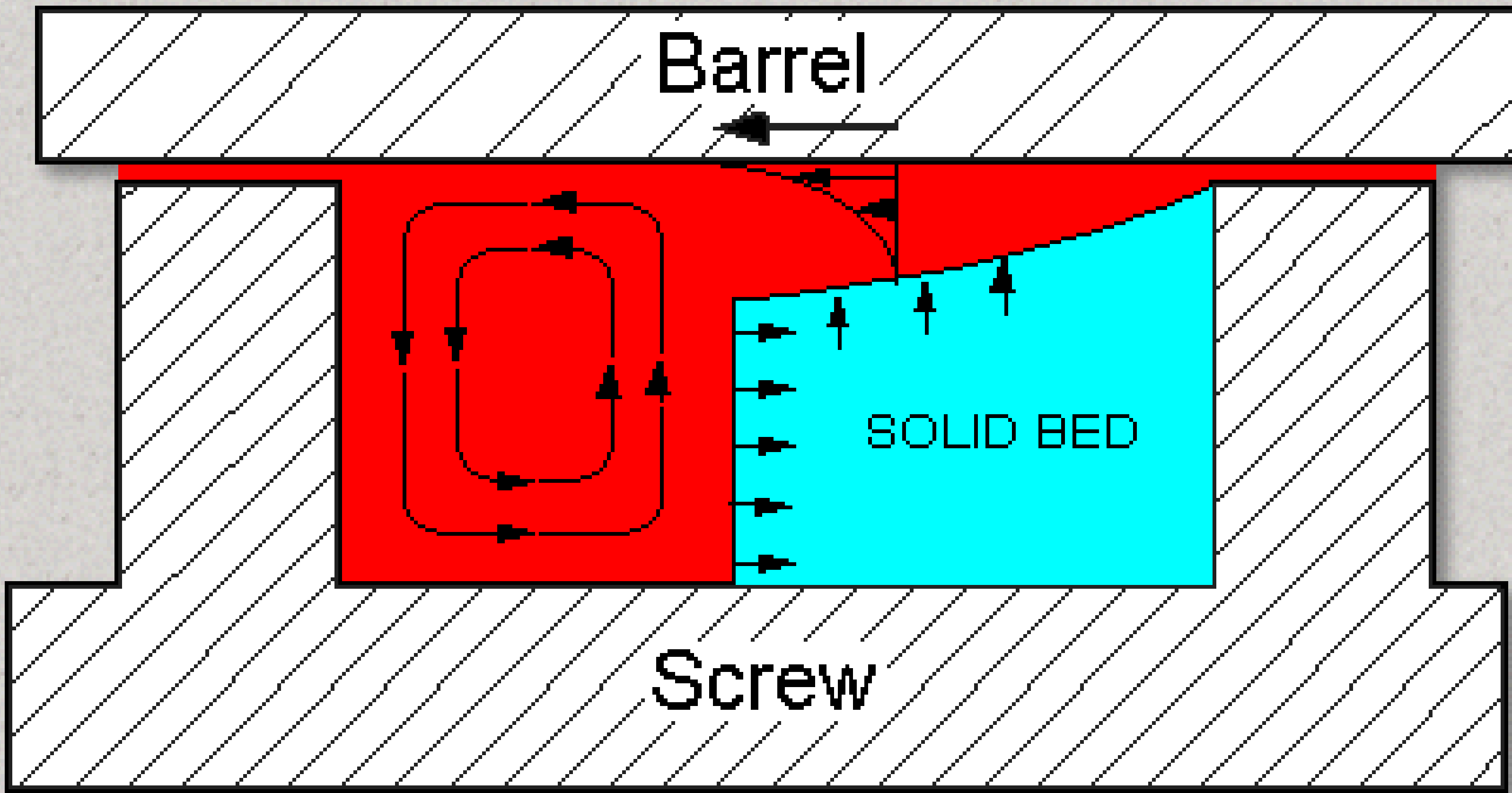
- Melt Film Thickness
- Barrel Temperatures



Contiguous Solids Melting

Factors that effect the melt rate

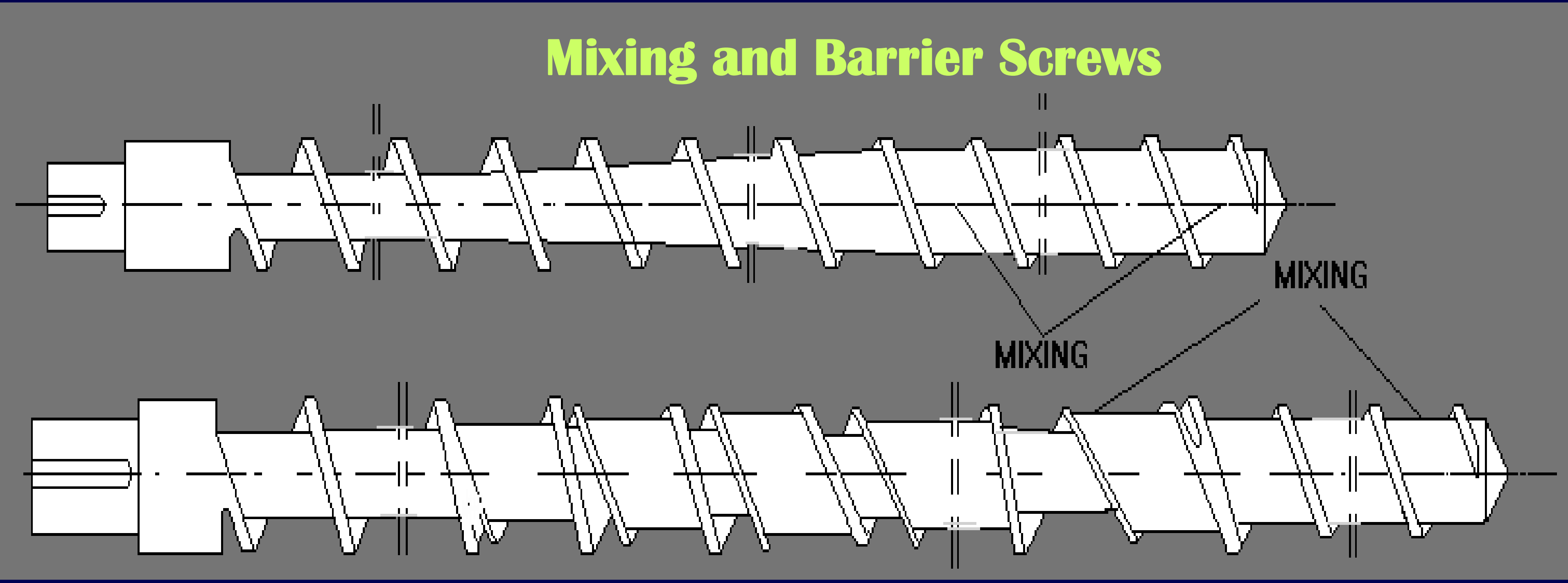
- Melt Film Thickness
- Barrel Temperatures
- Screw Speed



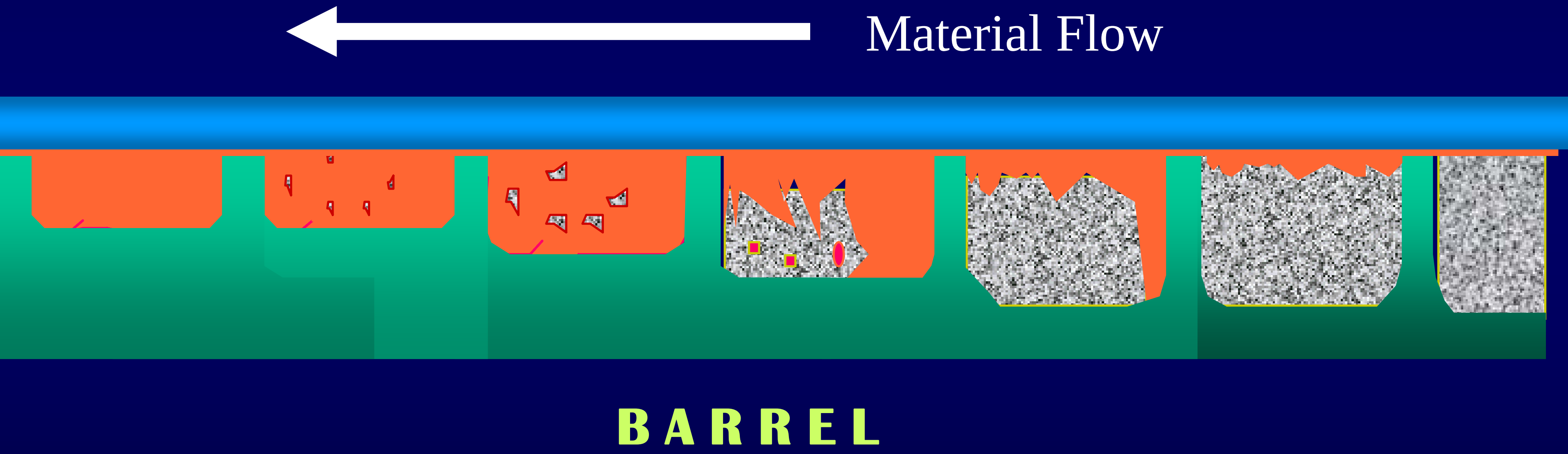
Contiguous Solids Melting

Barrier vs. Single Screw Melting

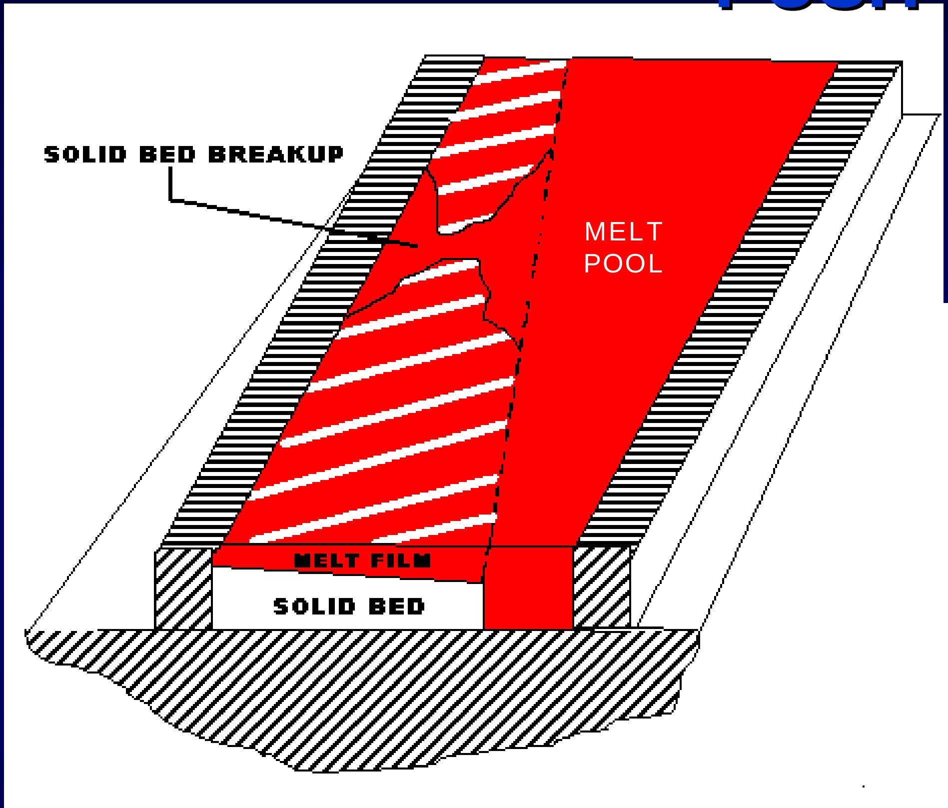
Single Stage Mixing Screw vs. Barrier Screw



Melting Model – Single Flighted Screw

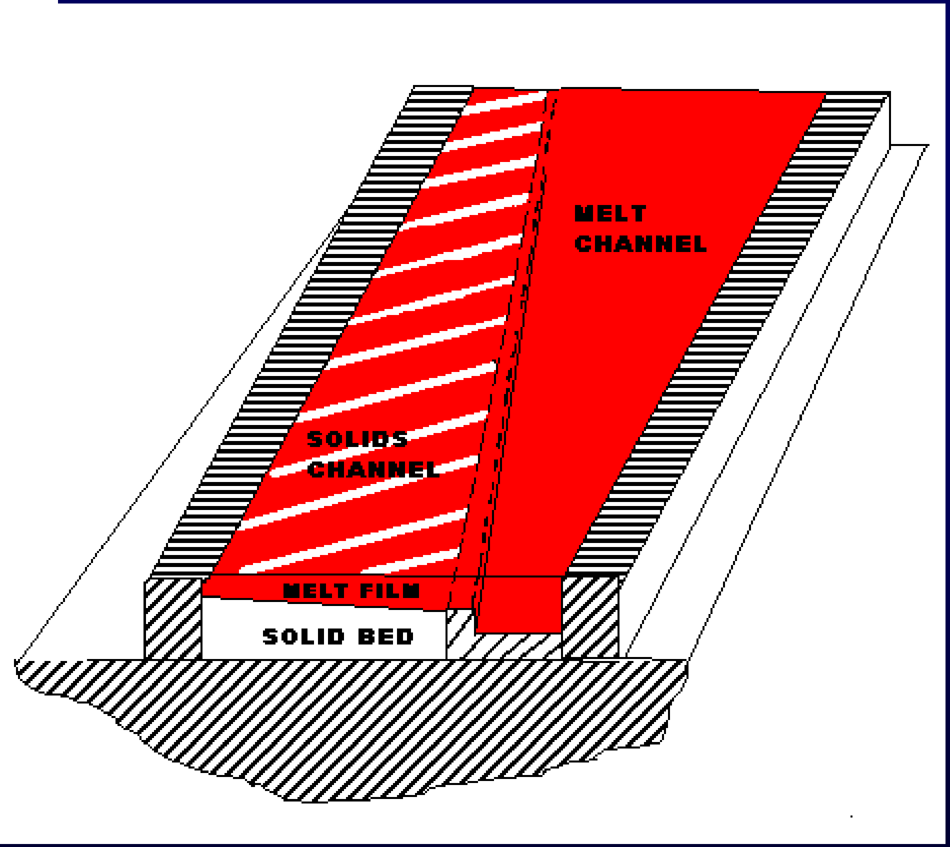


MELTING MECHANISM SEEN IN SCREW PUSH-OUTS

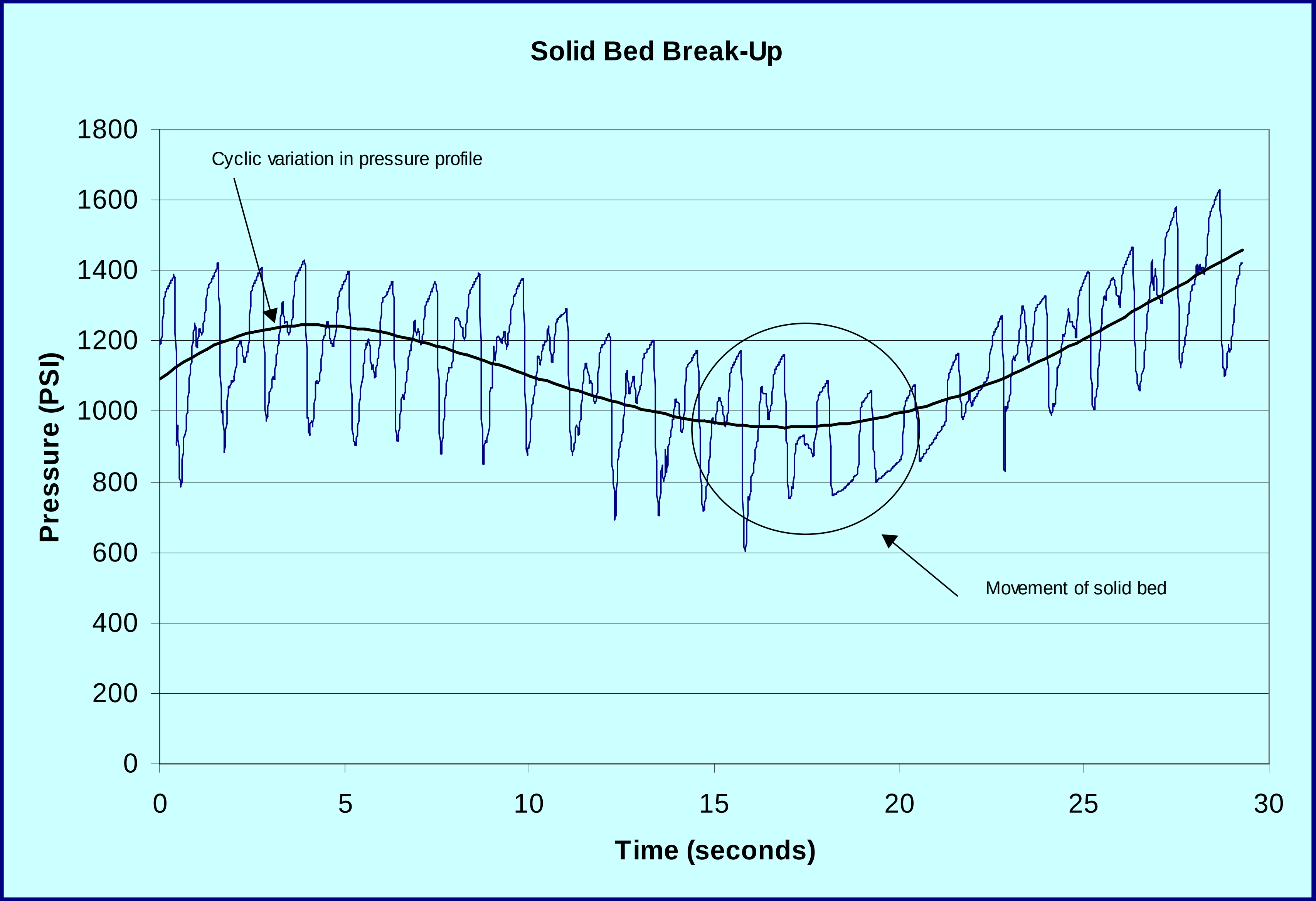


CONVENTIONAL SCREW

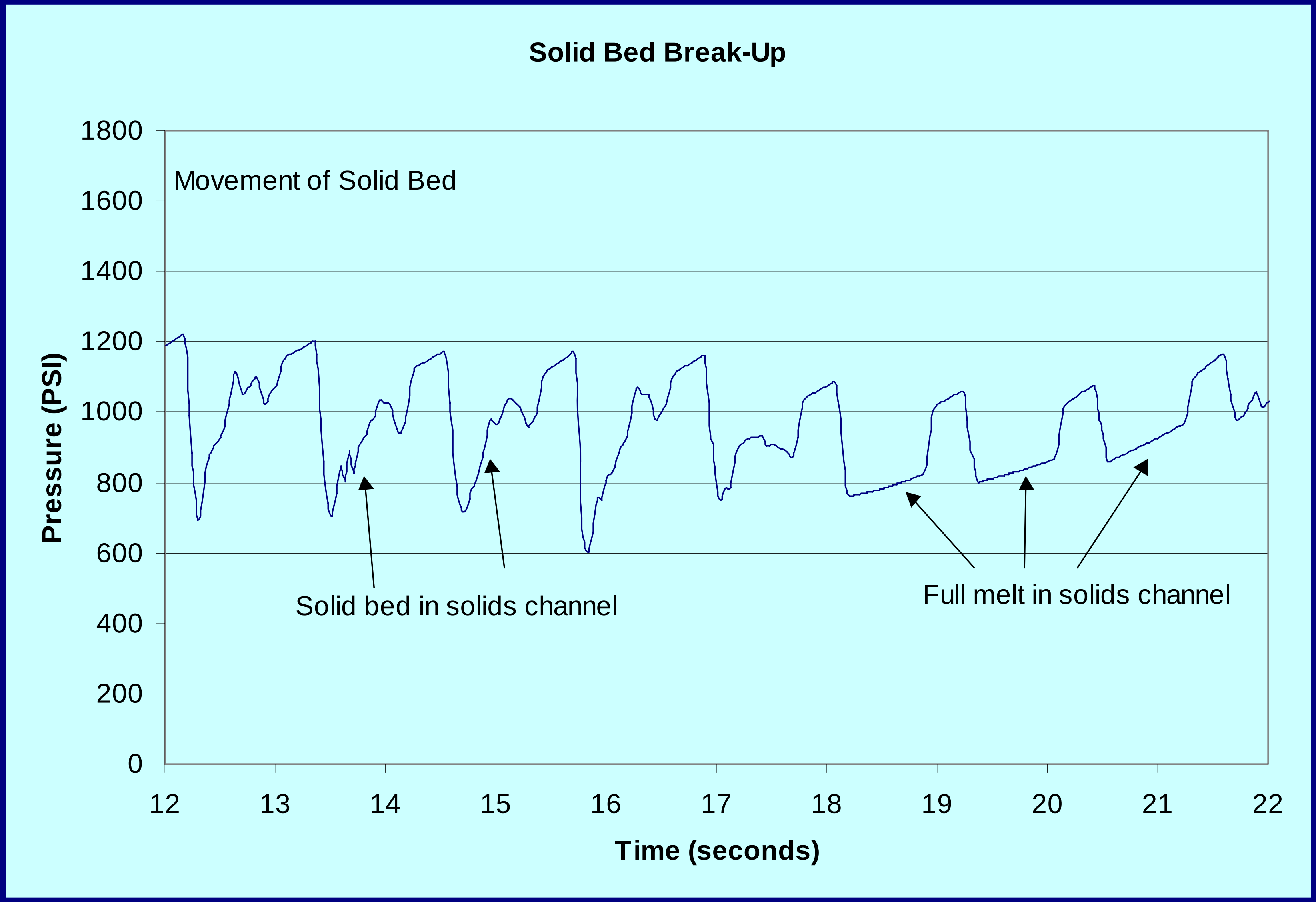
BARRIER SCREW



Solid Bed Break-Up



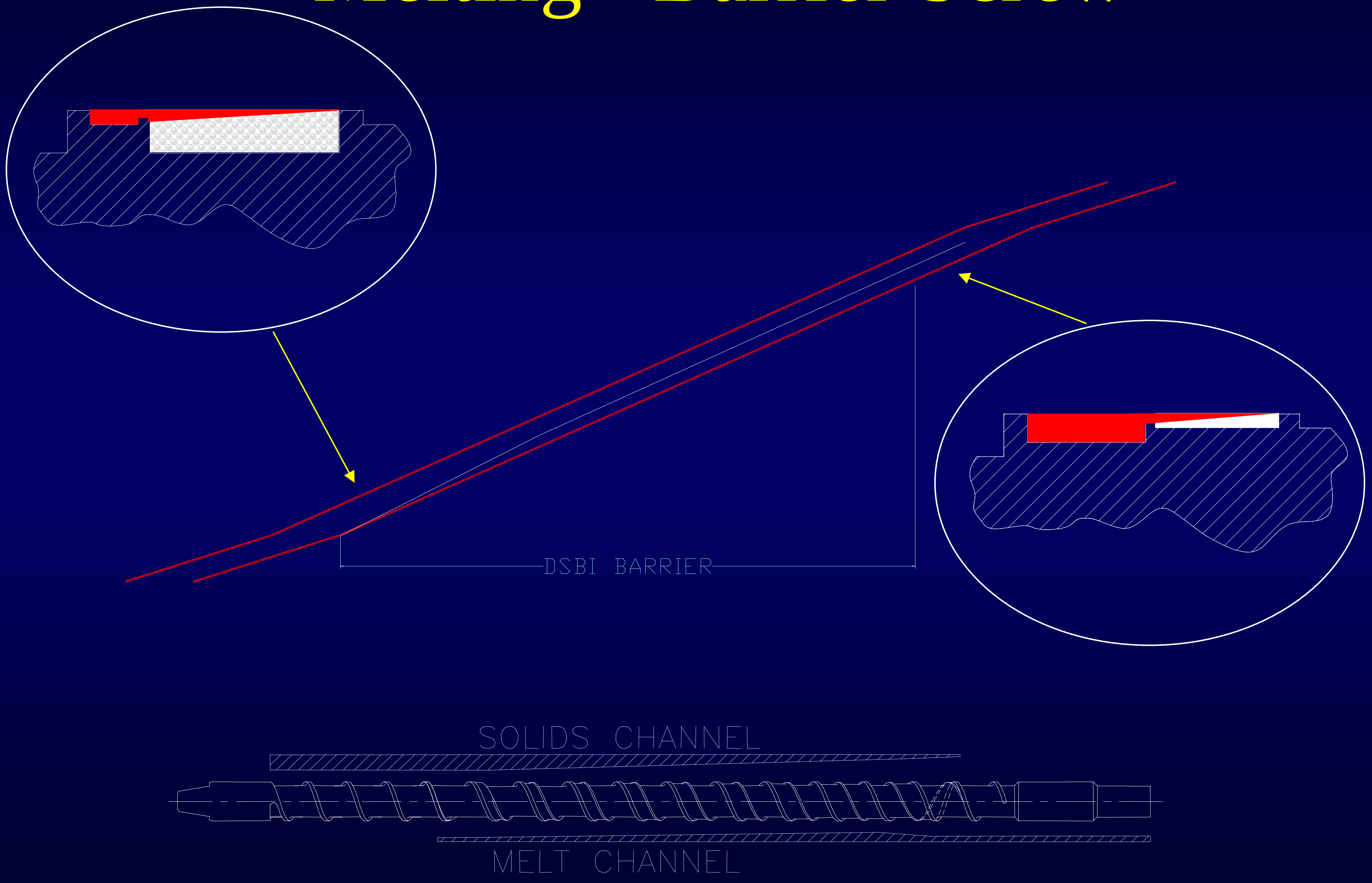
Solid Bed Break-Up

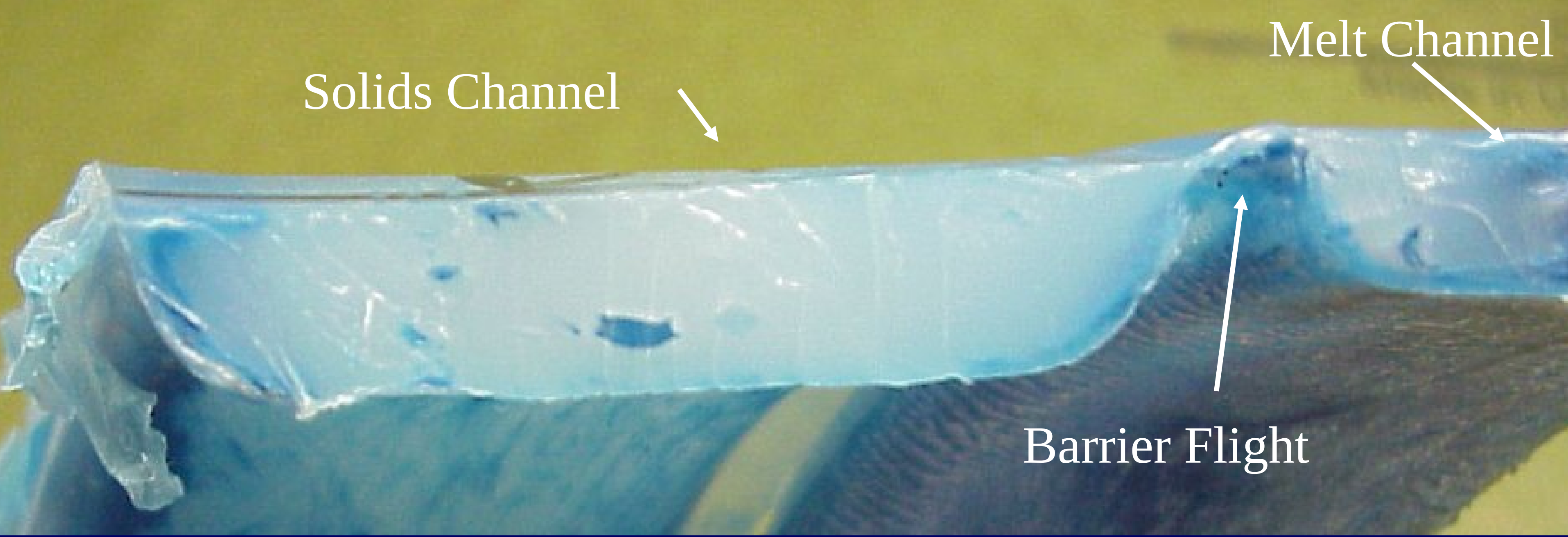


Melting
Barrier Screw

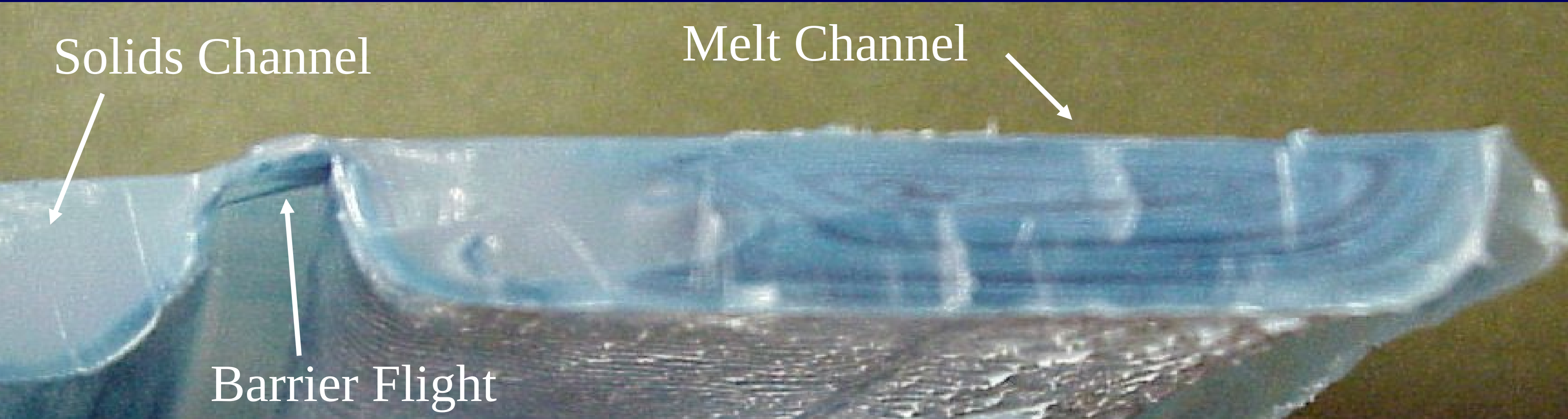
- Barrier flight isolates solid bed from melt pool
- Solids and melt channel depths vary independently to accommodate accumulating melt pool and diminishing solid bed
- Critical design variables:
  - Solids channel compression
  - Barrier flight undercut

Melting - Barrier Screw





Mid Barrier Cross-Sectional Photos



Melt Temperature

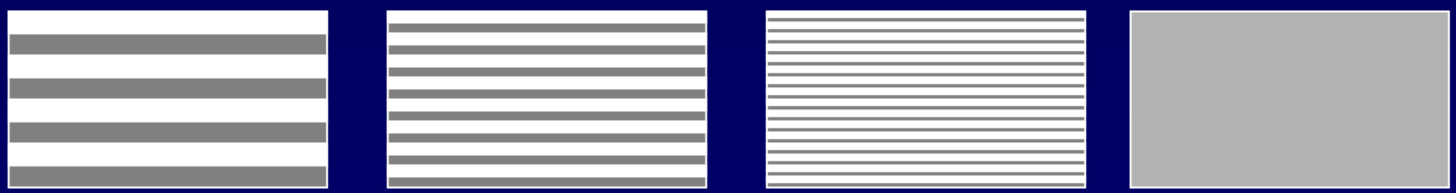
Influenced primarily by two factors:

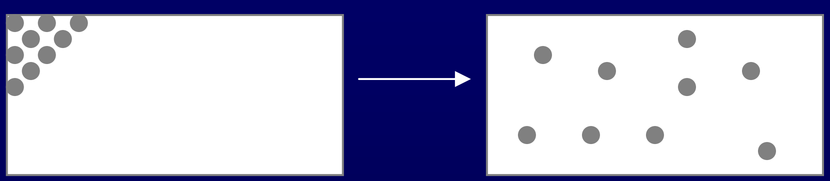
- Conduction
  - = f (residence time, barrel set-points, limitations of heating/cooling units...)
- Viscous Energy Dissipation (VED)
  - = f (viscosity, shear rate...)

Mixing in
Single Screw Extrusion

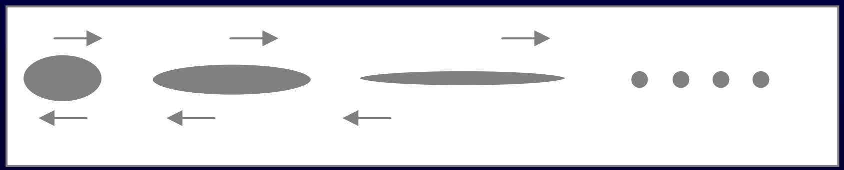
Mixing

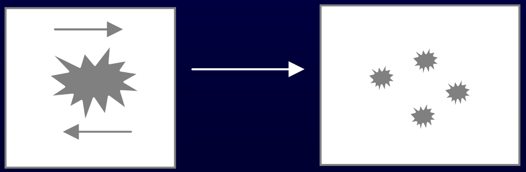
- DISTRIBUTIVE
  - Increase of interfacial area between two miscible components
  - Splitting and recombination of flow streams



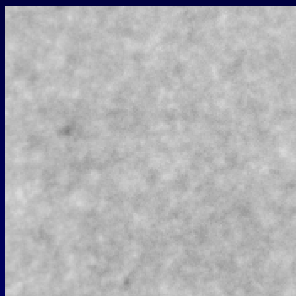


- DISPERSIVE
  - Shear induced particle size reduction of immiscible components

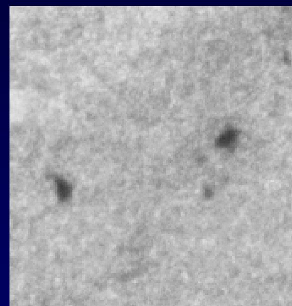




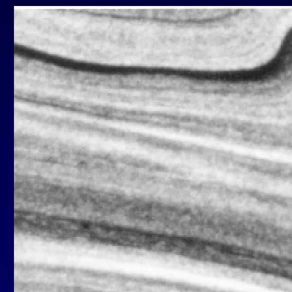
Mixing and Quality



Excellent



Poor
Dispersive



Poor
Distributive

Poor
Dispersive &
Distributive

- Poor mixing can effect:
  - Physical properties
  - Product Uniformity
  - Aesthetics

Micro-graphs 100X 0.15 MI HDPE+5% CBMB

Mixing Sections

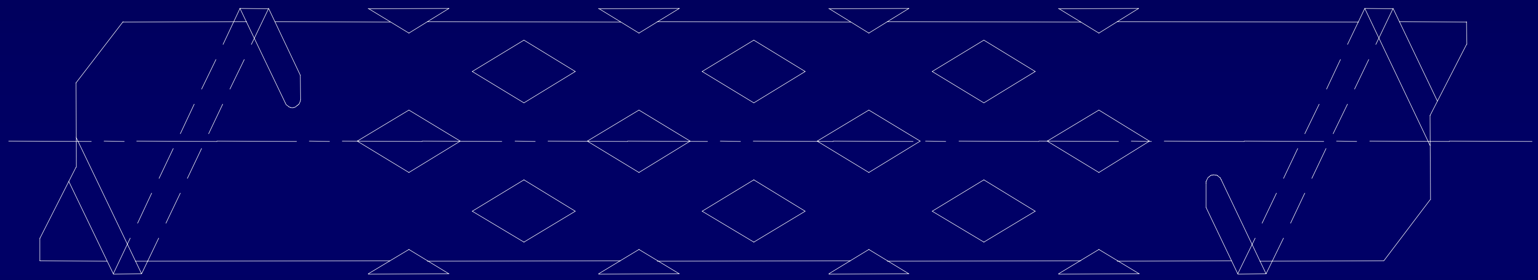
DISTRIBUTIVE

- Pineapple Mixer
- Saxton Mixer
- Dulmage Mixer

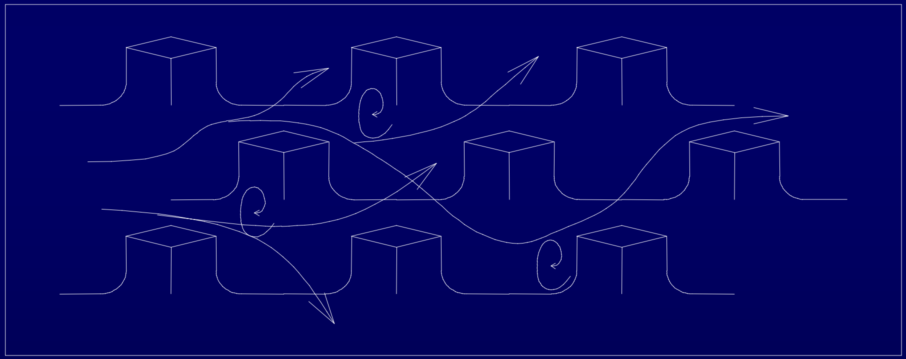
DISPERSIVE

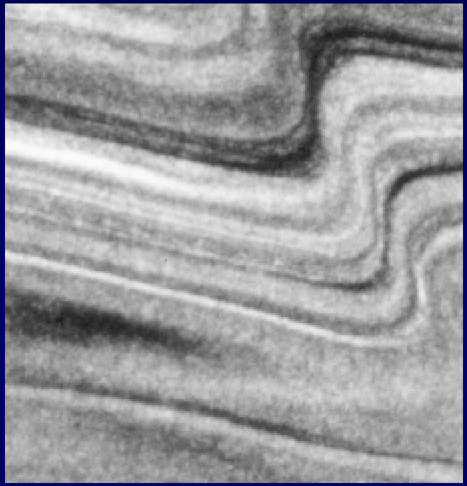
- Union Carbide Mixer
- Helical UCC
- Cavity Transfer Mixer

Pineapple Mixing Section



Pineapple Mixing Section

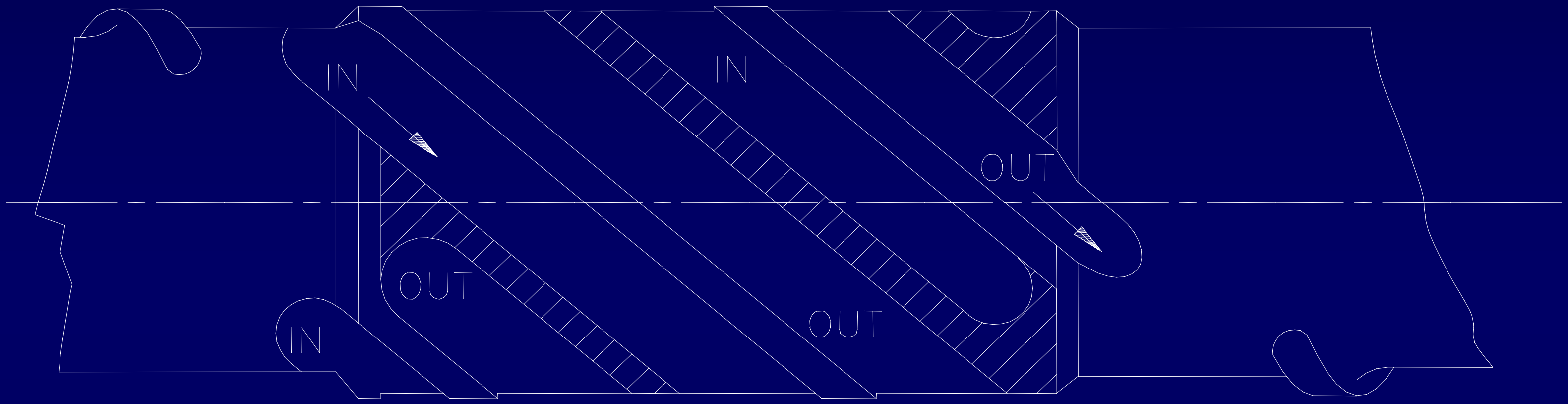




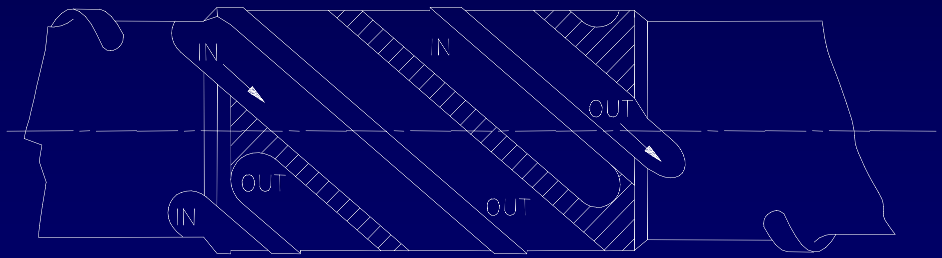
100X HDPE+5% CBMB

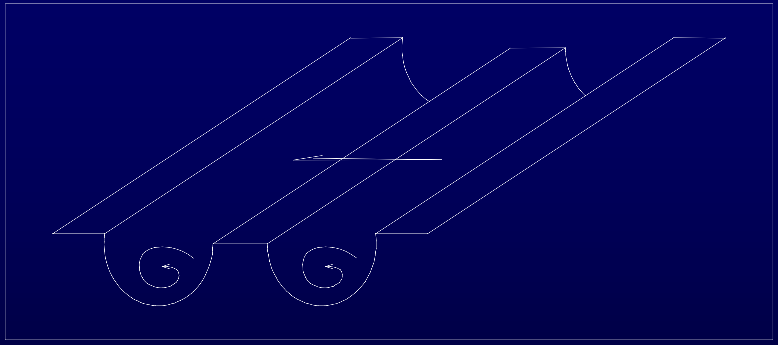
Streamlines Showing Distributive Mixing

Helical Union Carbide Mixing Section (UCC-T)

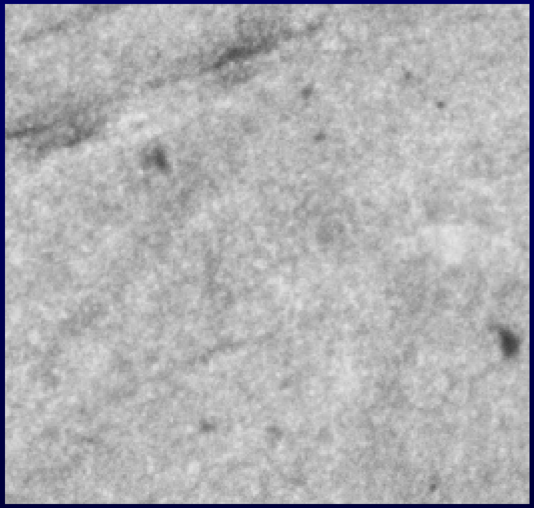


Helical Union Carbide Mixing Flow Pattern





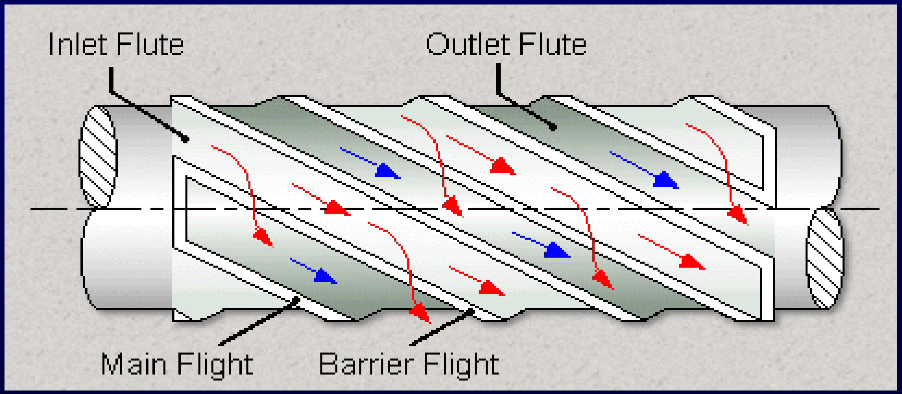
Channel Cross Section



100X HDPE+5%CBMB

EGAN Mixer

- Similar to UCC mixer
- Higher pressure drop
- Intensive shearing
- Surface of barrel not wiped by flight (completely under-cut)

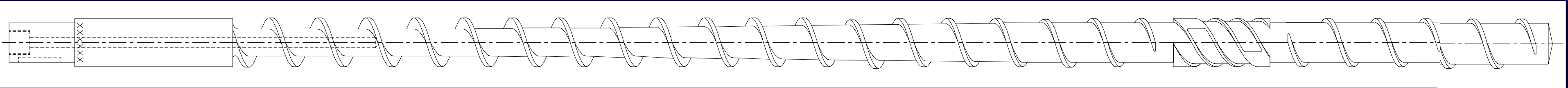


Screw Designs for Extrusion Coating Applications

Conventional Mixing Screws

- Workhorse design for processing extrusion coating resins since the 1960's
- Typical Design
  - 28:1 - 32:1 L/D
  - Shallow Metering Depth
  - 4:1 Compression Ratio (CR)
  - Single mixing section (Egan or UCC)

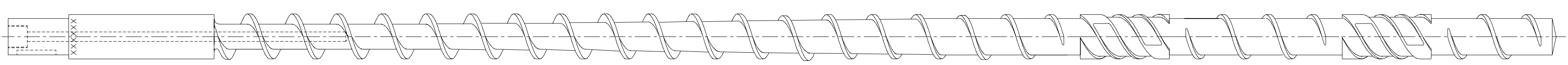
Feed Transition Meter Mix Meter



Double Mixing Screw

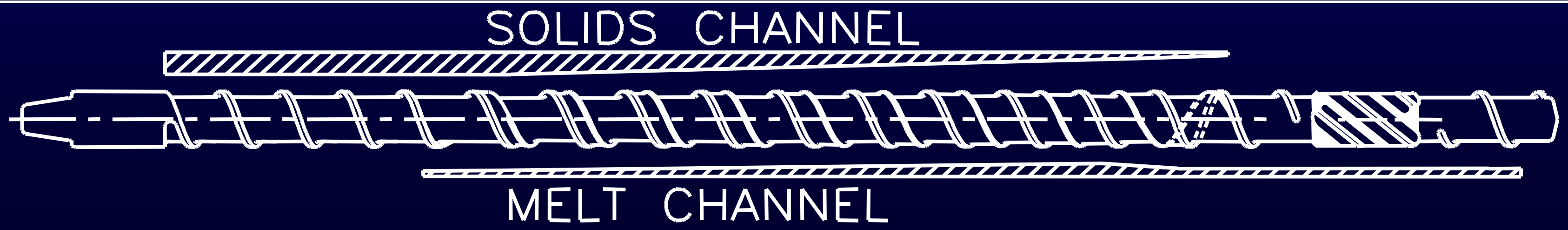
- A conventional screw with two barrier mixing sections introduced in the 1980's
  - Boost output rate (10-15%)
  - Improve reliability of adhesion at higher outputs
- Higher output applications necessitate the use of a static mixer to improve melt temperature homogeneity across the melt curtain

Feed Transition Meter Mix Meter Mix



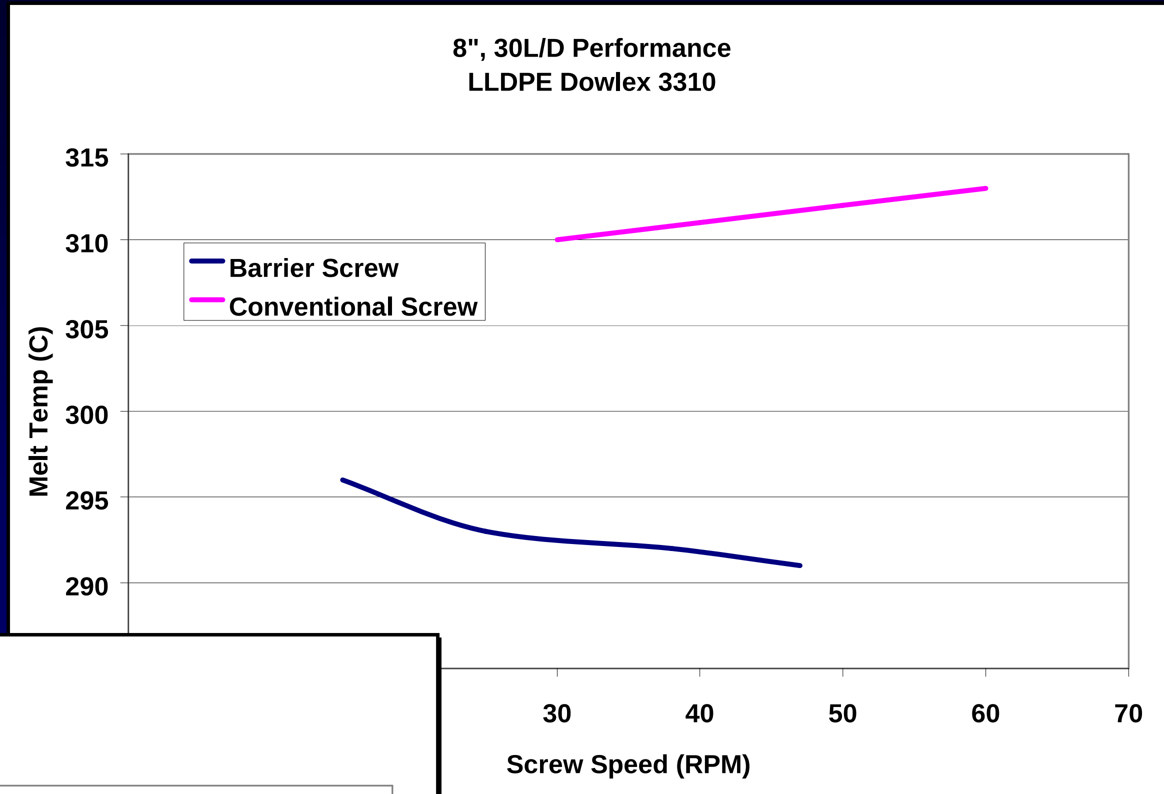
Barrier Screw Designs

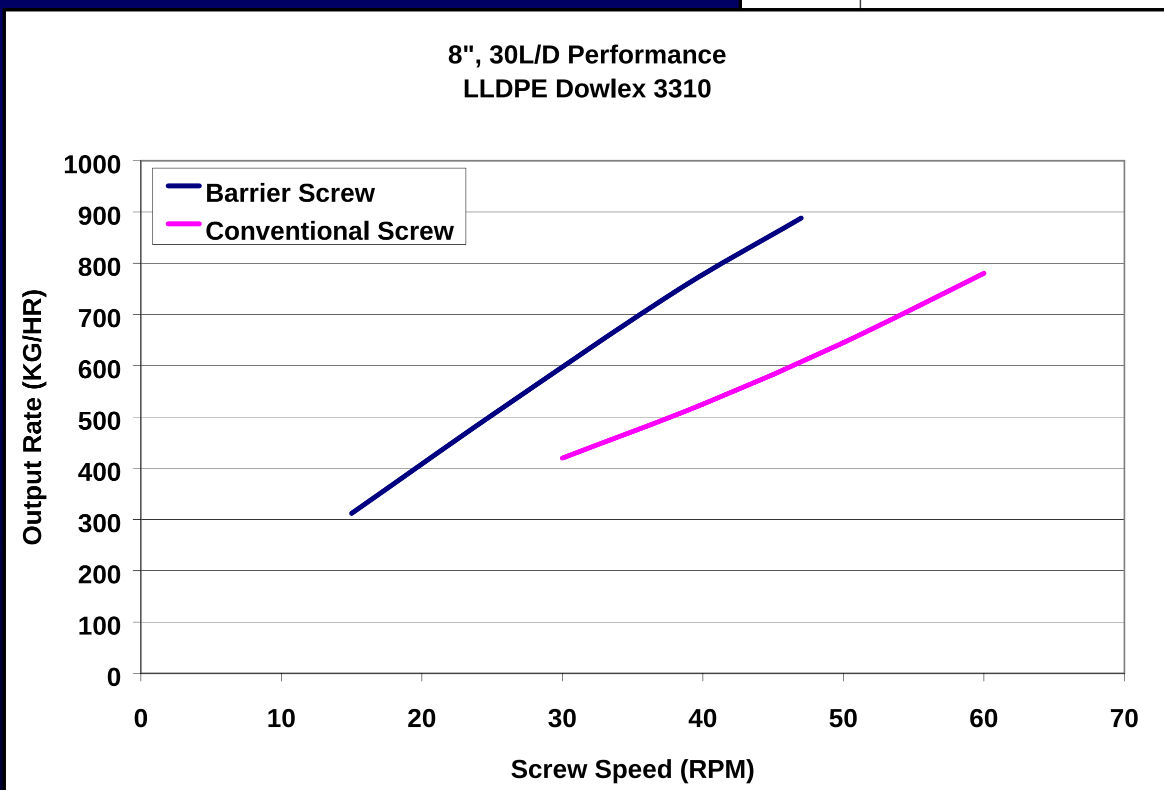
- Recommended for LLDPE and engineering resins in extrusion coating applications
- Also beneficial for lower temperature / higher output polyolefin applications
- Offers superior melting rates and process stability



Performance Comparison

8”, 30L/D Extruder
Resin: LLDPE Dowlex 3310
Conventional vs. Barrier





Barrier screw provides higher rate and lower melt temperatures

SCREW COMPARISON

What will I learn?

- Why can’t my screw run all resins?
- Why are barrel profiles unique to a screw design?
- Why can increased barrel temperature sometimes result in less output?
- What happens when my screw wears out?

LDPE VS PP COMPARISON

	LDPE	PP
Solid Density (kg/m^3)	920	907
Melt Density (kg/m^3)	750	735
Thermal Conductivity, Solid (J/s.m.°C)	0.28	0.22
Thermal Conductivity, Melt (J/s.m.°C)	0.24	0.15
Heat Capacity, Solid (J/kg.°C)	2300	1700
Heat Capacity, Melt (J/kg.°C)	2300	2100
Melting or Softening Temp, °C	110	163
Freezing or Hardening Temp, °C	90	138
Frictional Coefficient, f	0.3	0.22
Degree of Crystallinity	Low	High
Molecular Weight Distribution	Narrow	Broad

Solid Conveying - PP vs. LDPE

- PP more crystalline, pellets are harder and less elastic. Lower friction between PP and barrel.
- PP has higher melt temperature. Requires longer feed before compression starts.

Melt Conveying - PP vs. LDPE

- Melting rate is limiting factor for PP.
- Melt conveying rate is limiting factor in LDPE

General Screw Design - PP vs. LDPE

- LDPE screw would have shorter feed and faster transition.
- PP screw would have a shallower metering section to help in melting.

Thank You

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