SCREW DESIGN BASICS

The Processor Point Of View

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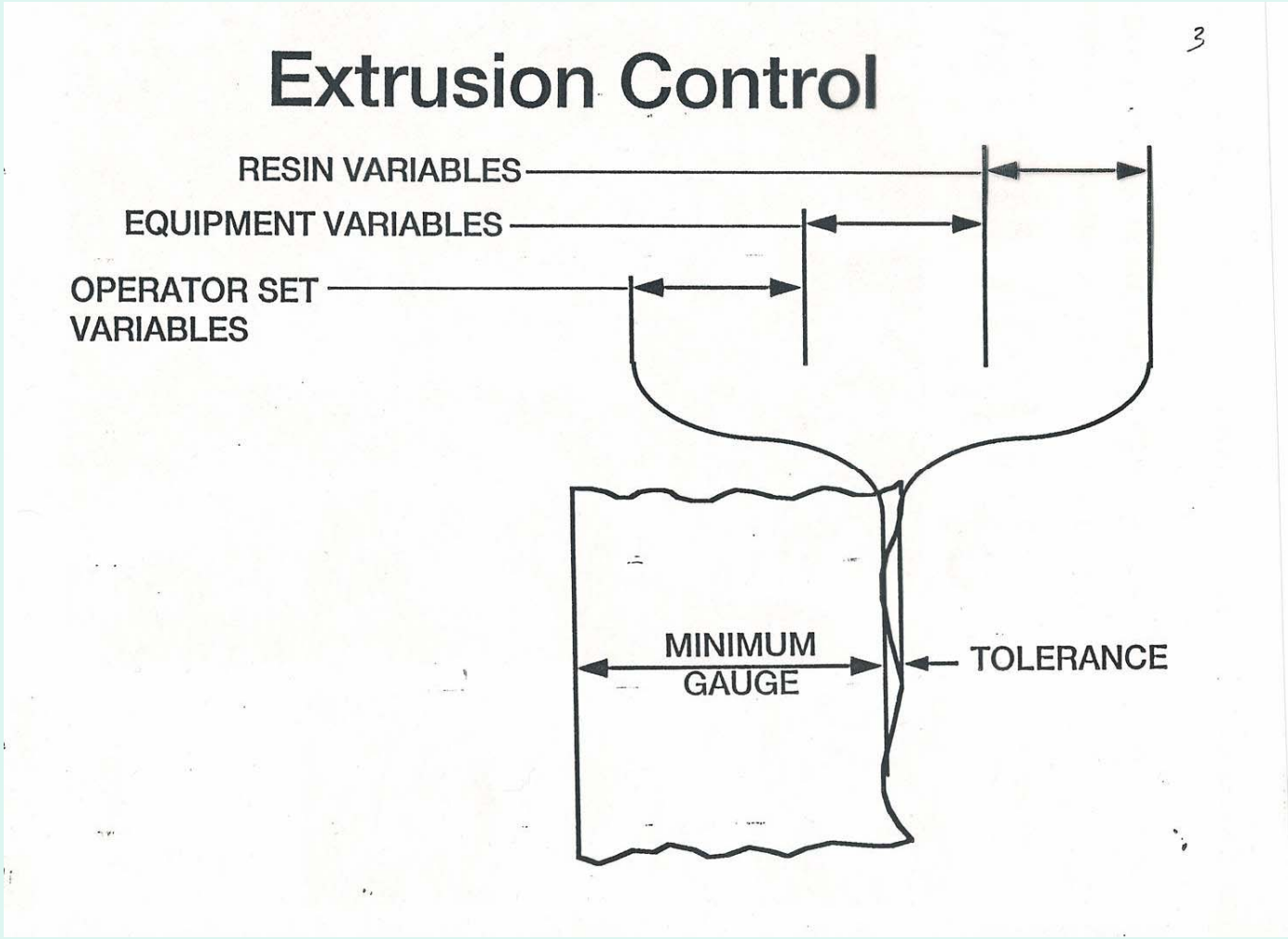
Outline

- Define the goal
- Review basic extruder components
- Discuss process elements
- Look at basic screw design features
- Put the components together
- Review process function optimization
- Discuss operator control and assessment
- Wrap Up

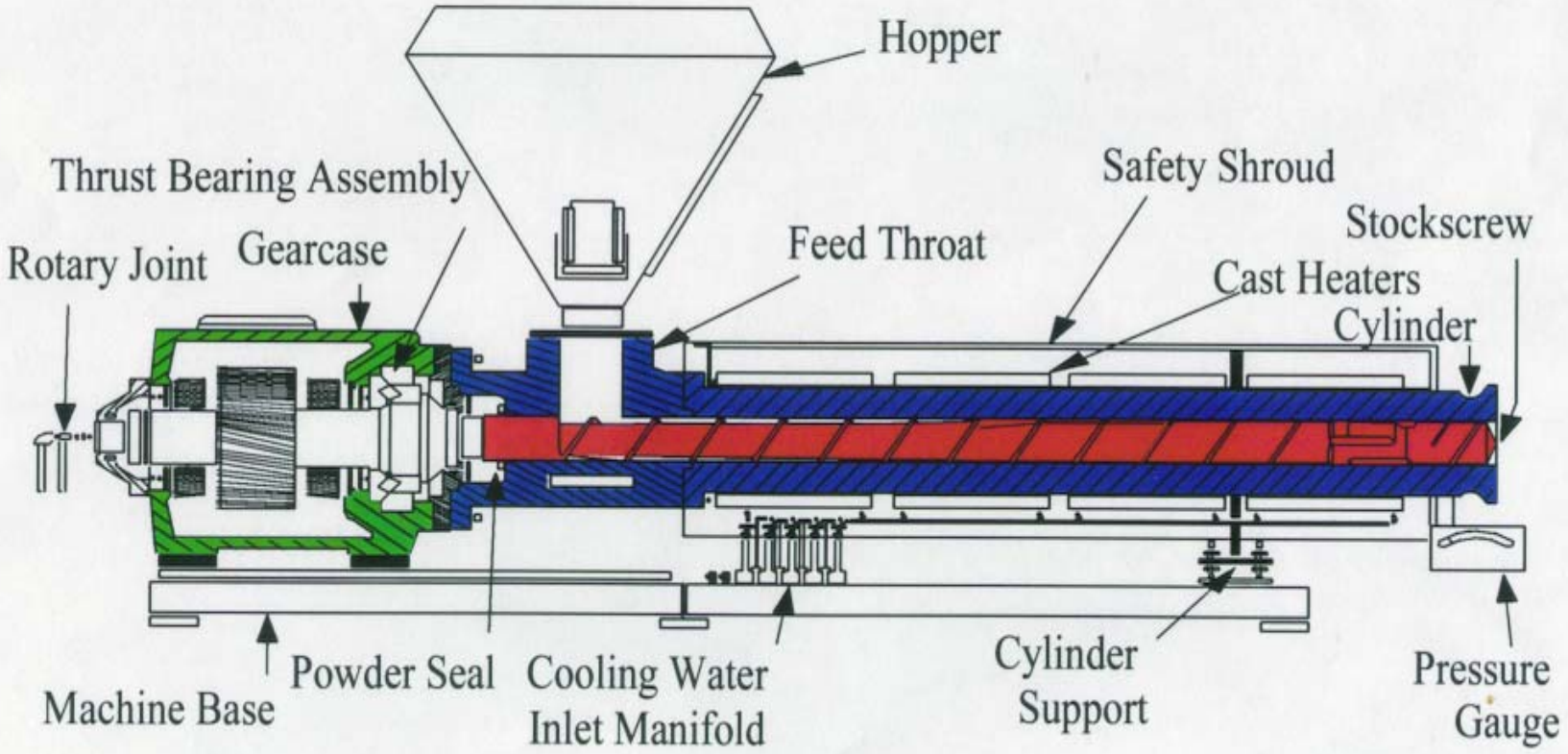
What is the goal?

Provide the melted polymer to the forming process at the desired rate, uniformity, and quality to produce the finished product within specifications.

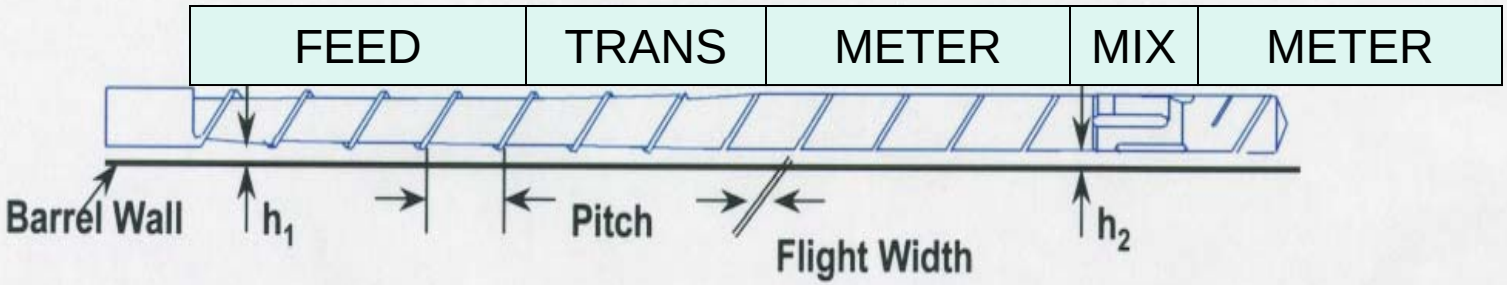
The Goal: Thin films & coatings



Extruder Components



Screw Nomenclature



Compression Ratio is h_1/h_2

Section	Depth	Function
Feed	Deep	Transport resin to next zone
Transition	Decreasing	Compress & melt polymer
Mixing	Shallow	Homogenize melt
Metering	Shallow	Deliver melt to die @ constant rate

Steps In The Process

- (Feeding to the extruder)
- Solids Conveying
- Melting
- Pumping
- Mixing

Take Note

The single screw extruder is basically a volumetric pump. It is not a positive displacement device. Variations in feeding result in variations in output. Solid conveying, melting, pumping and mixing occur simultaneously and are inter-dependent.

Resin Feeding

Feeding of the extruder is independent of screw design. For successful operation of any single screw extruder a consistent feed stream must be supplied. The feed stream must be of uniform composition and uniform weight.

Resin Feeding

- Driven by Gravity
- Opposed by
  - Frictional forces
  - Escaping air from compaction
  - Centrifugal force due to screw rotation
- Optimum Conditions
  - Low COF – Pellets to Hopper
  - Low COF – Pellet to Pellet
  - Large Volume to Surface Ratio of Pellets
  - Large Opening

Remember the process steps

- (Feeding to the extruder)
- Solids Conveying
- Melting
- Pumping
- Mixing

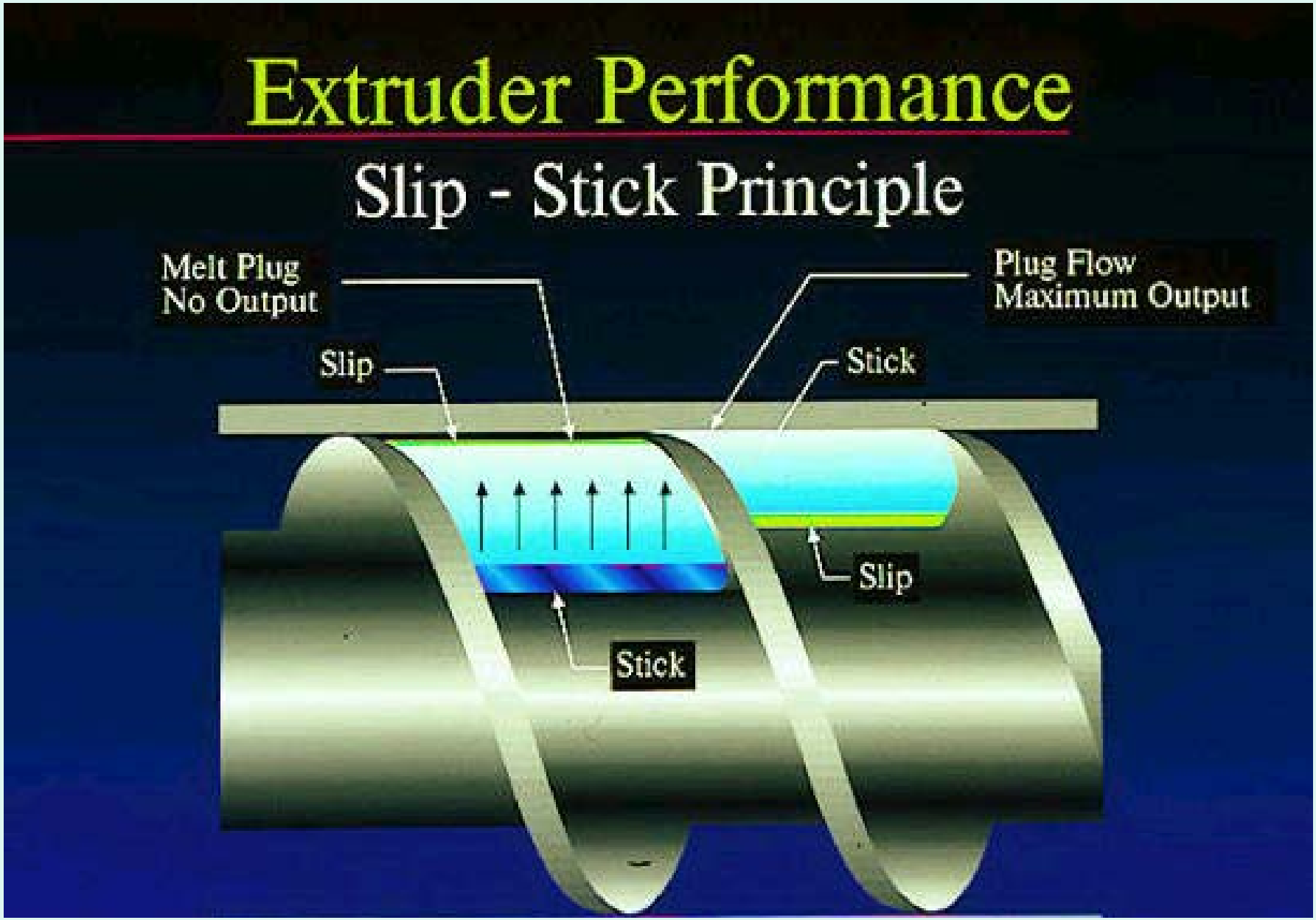
Process steps relate to design features

Solids Conveying

- Driven by Sliding Force Pellet to Barrel
- Opposed by Sliding Force Pellet to Screw

Extruder Performance

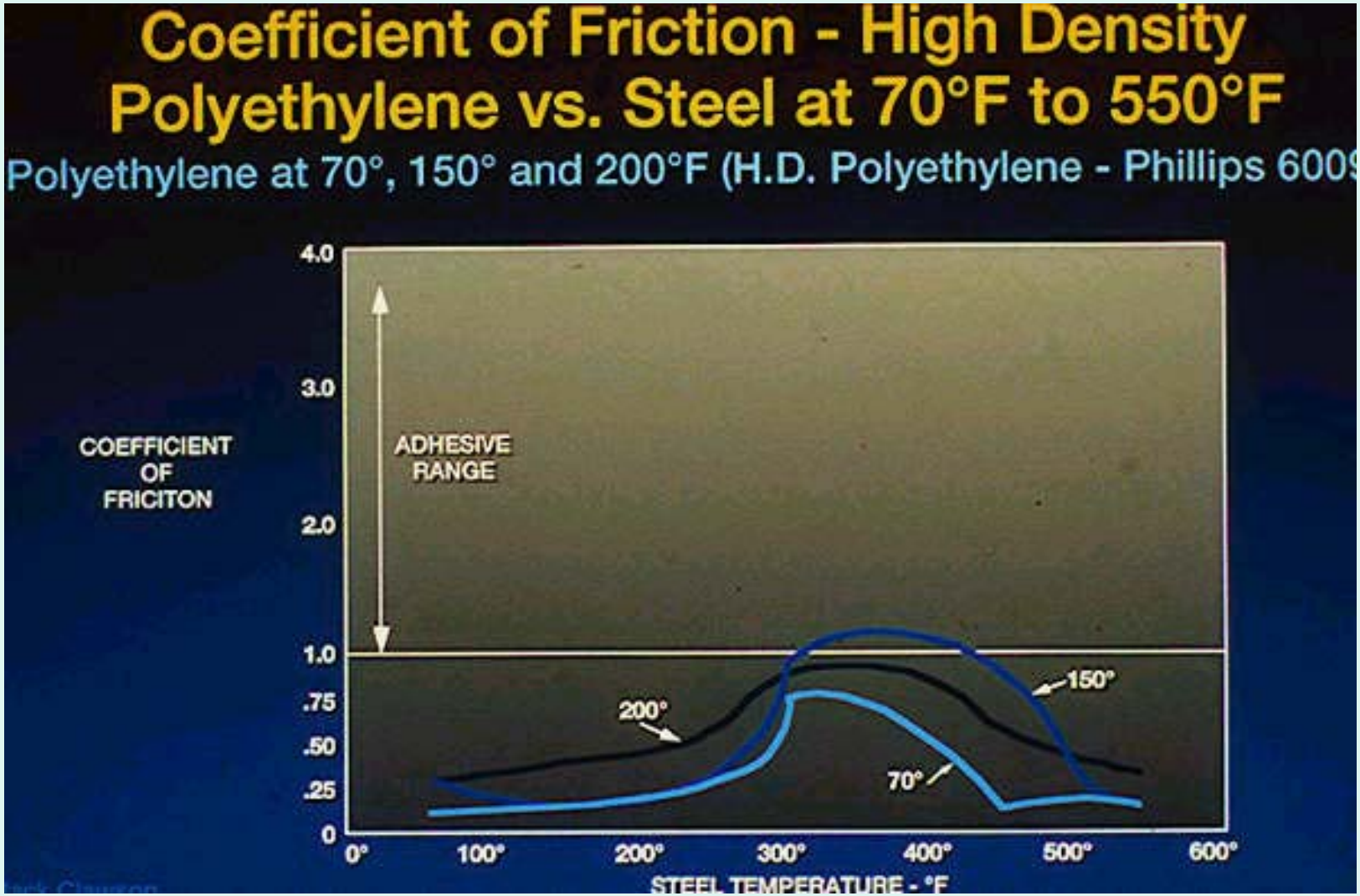
Slip - Stick Principle



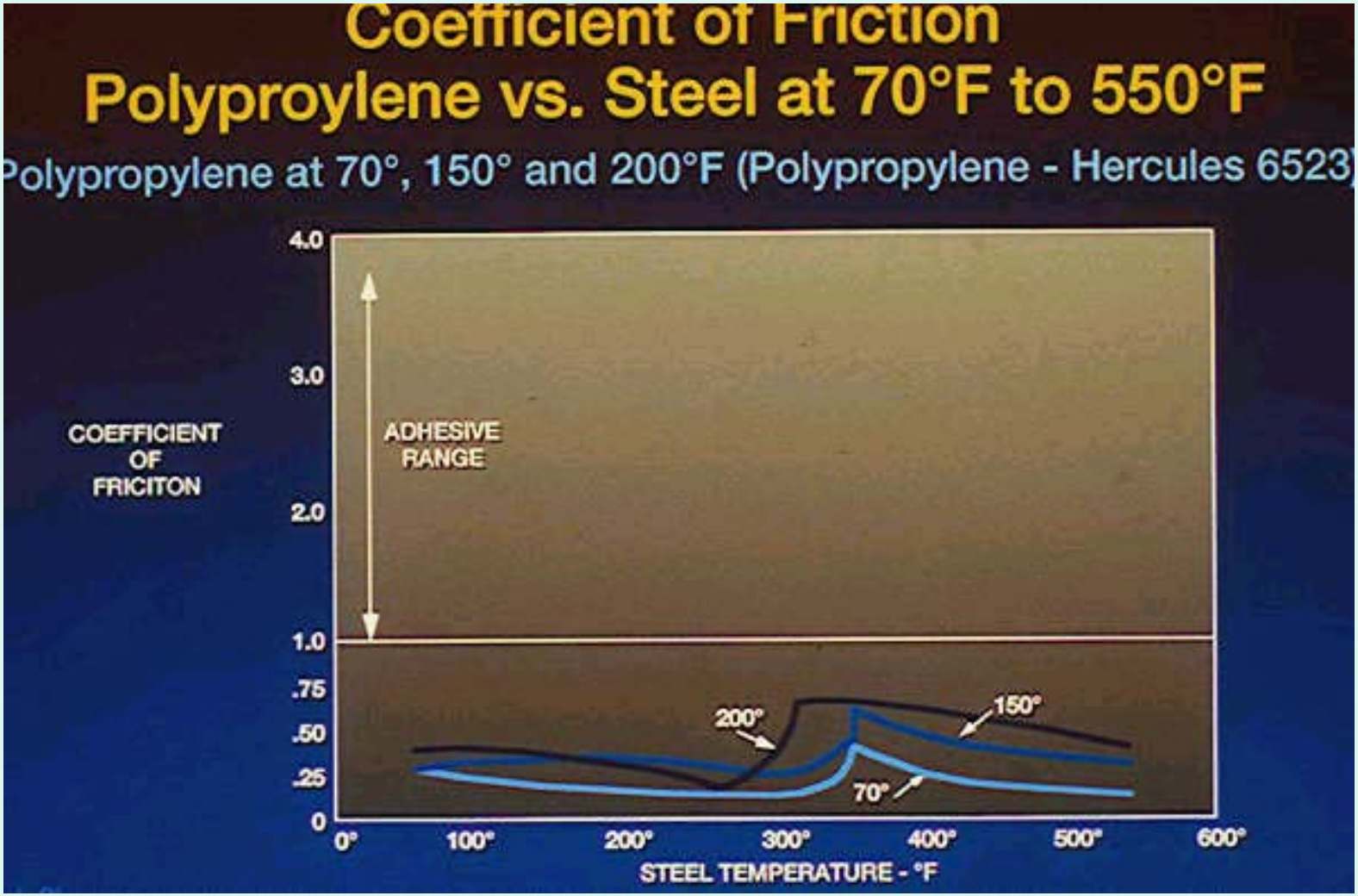
Solids Conveying

- Optimum Conditions
  - High COF – Pellets to Barrel
  - Low COF – Pellets to Screw Channel
  - High COF – Pellet to Pellet
  - Soft for Easy Compression
    - All temperature dependent
  - Low Surface to Volume Ratio of Pellets
    - Material dependent
  - High Channel Width to Depth Ratio
    - Screw design dependent

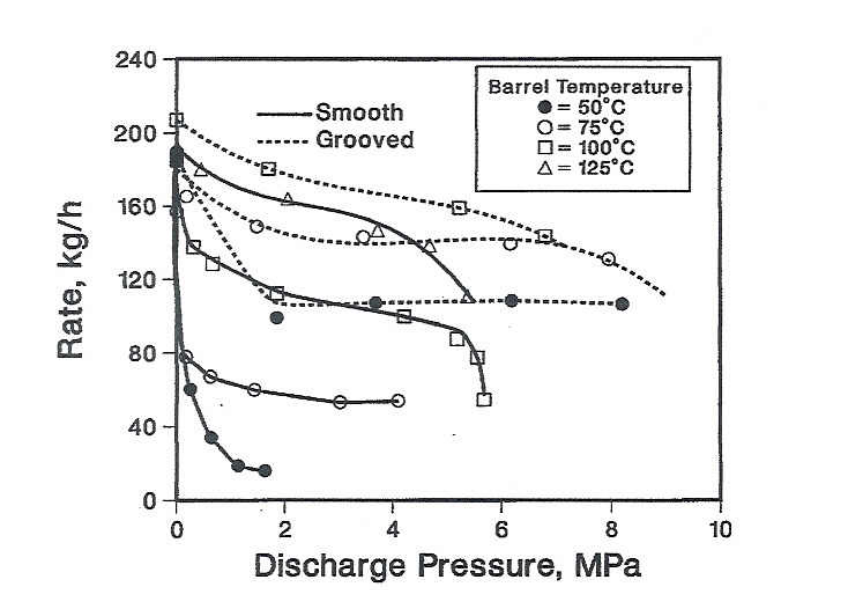
Static COF Data - Gregory

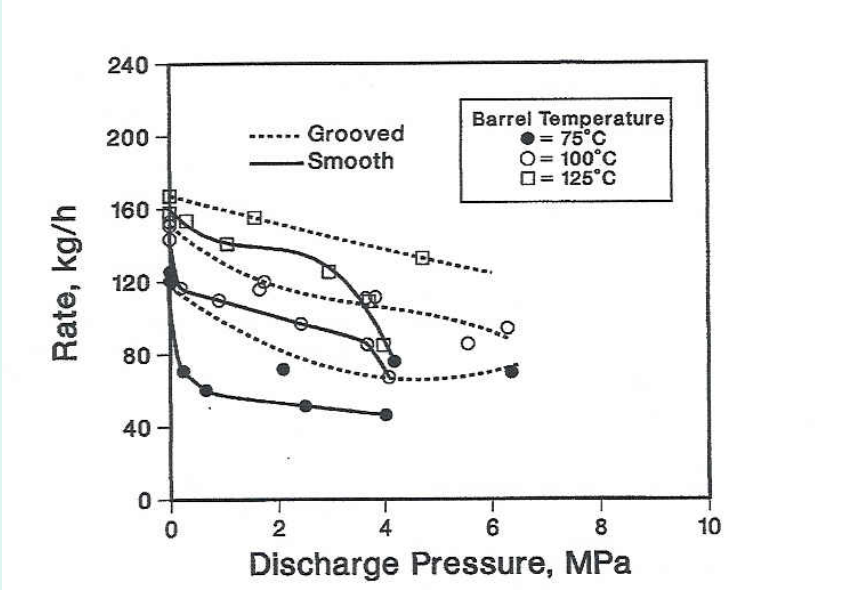


Static COF Data - Gregory



LDPE Solids Conveying





- Screw RPM = 80
- Root Temperature = 50 C
- Screw Diameter = 63.5 mm
- Channel Depth = 11.1 mm

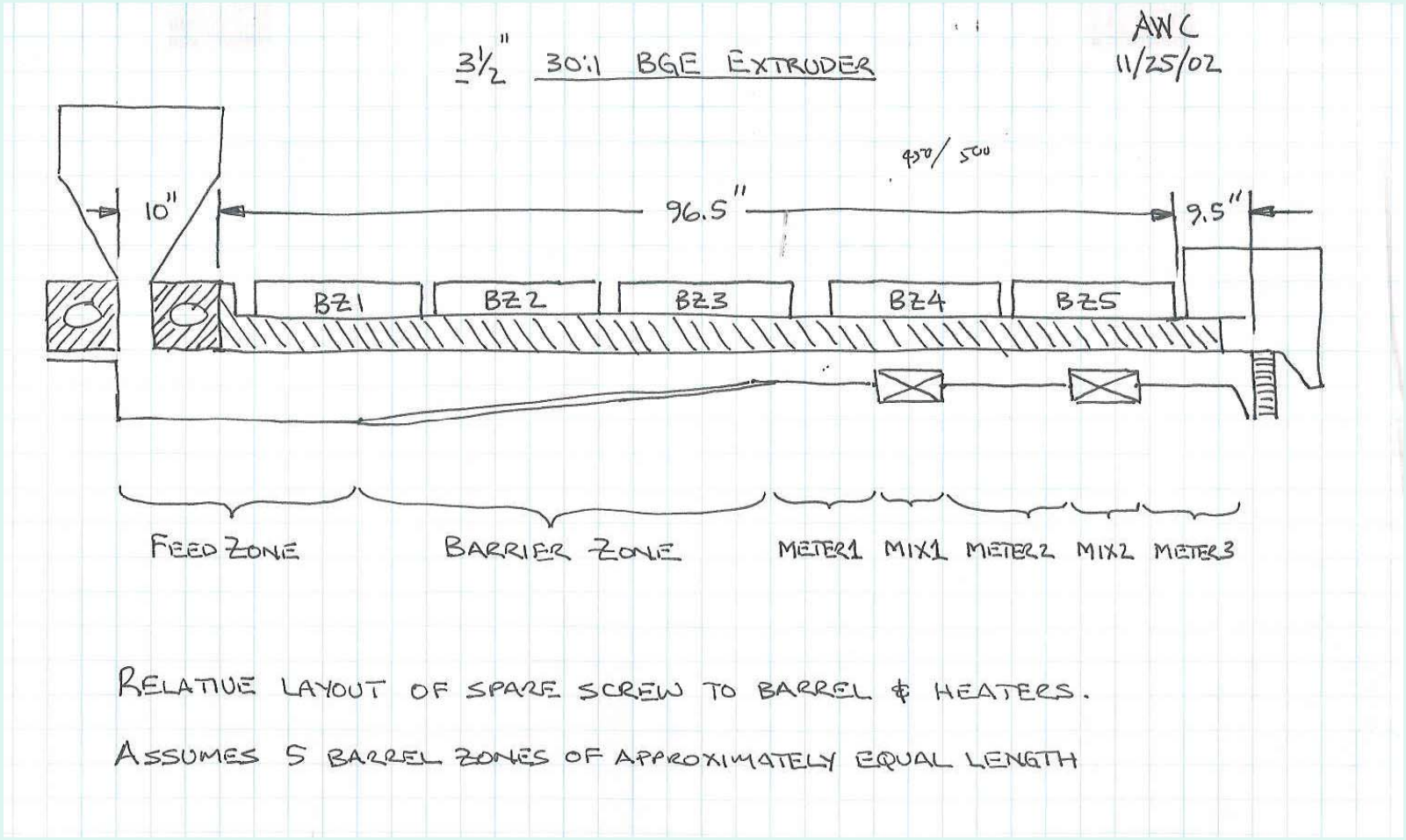
- Screw RPM = 80
- Root Temperature = 100 C
- Screw Diameter = 63.5 mm
- Channel Depth = 11.1 mm

"An Experimental Investigation of Solids Conveying in Smooth and Grooved Barrel Single Screw Plasticating Extruders", Conf. Proceedings, ANTEC 98, pp 136-141

Rate is Solids Conveying

- Output rate has a direct correlation to solids conveying
- The operator can impact solids conveying through temperature control in the solids conveying zone
  - Screw Root Temperature
  - Feed Cylinder Temperature
  - Barrel Zone Temperature (s) [over solids]
- Pressure variation indicates rate variation
  - Correct with stable solids conveying

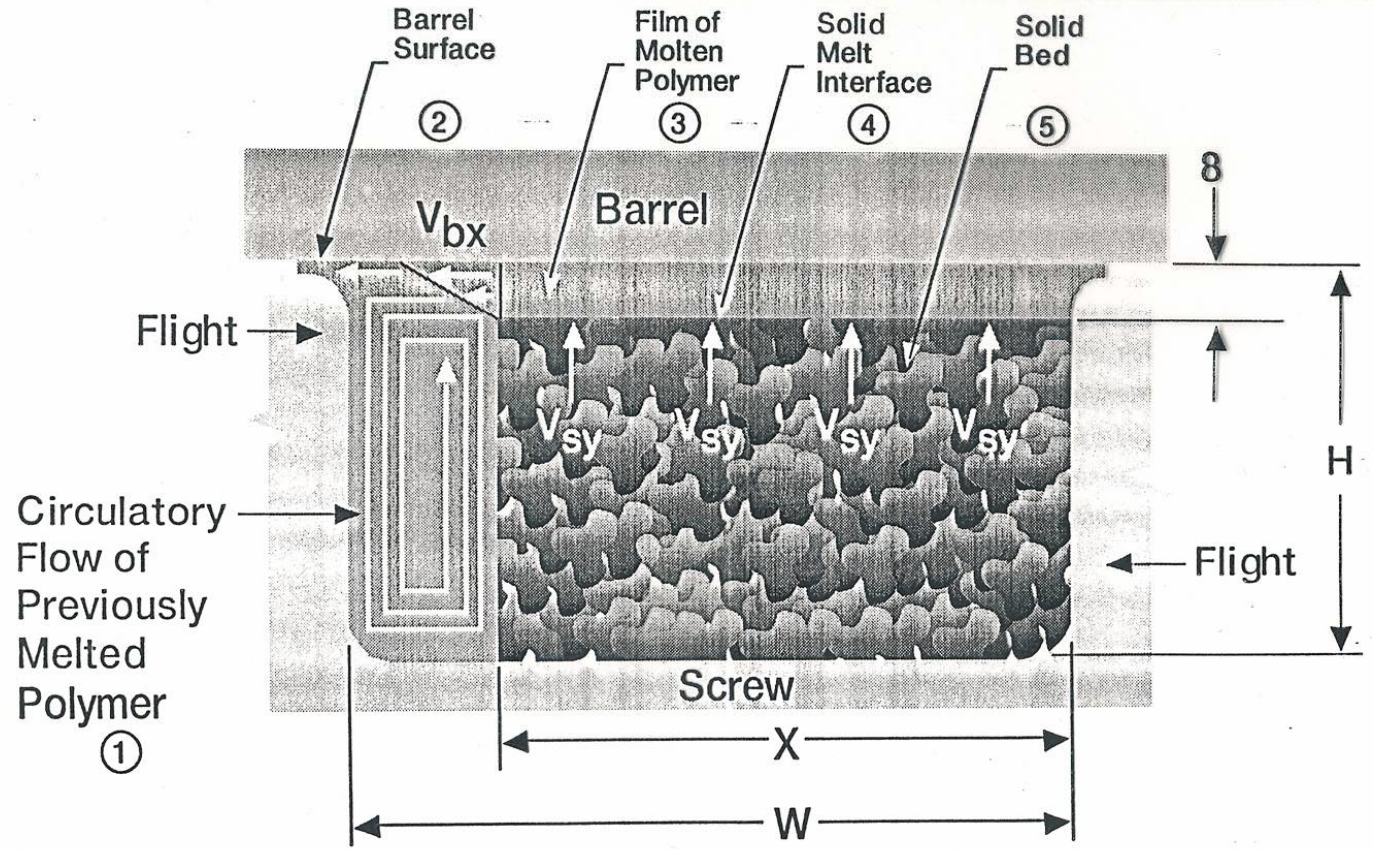
Put the screw in the system!



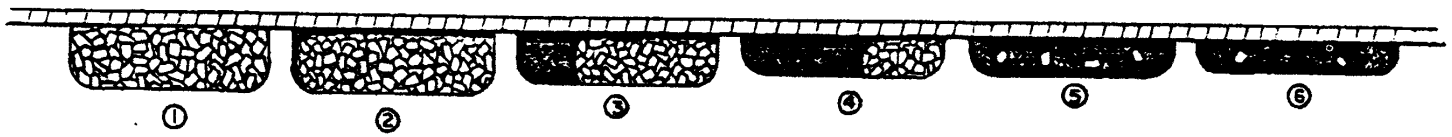
Melting

- Driven by
  - Viscous Heat due to Shearing
  - Heat Conduction from Adjacent Poly
  - Heat Conduction from Barrel & Screw
- Opposed by Heat Removal

Tadmor's Melting Model



EXTRUDER SCREW



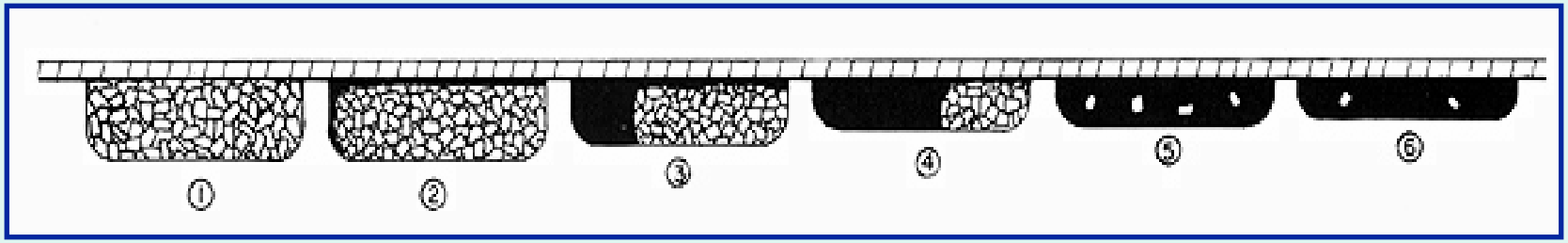
Melt Model Single Flight

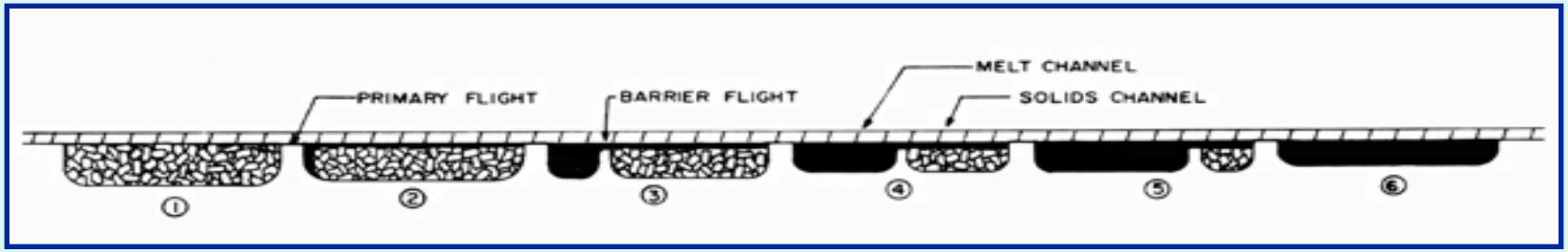
1. Solid Resin Pellets
2. Compression starts - Some melting on barrel walls at the back of the flight
3. Melt pool starts to form - welting and compaction continues
4. Channel depth is decreasing - melt continues
5. Solid pellets are mostly melted
6. Mixing and melting are complete

Melting

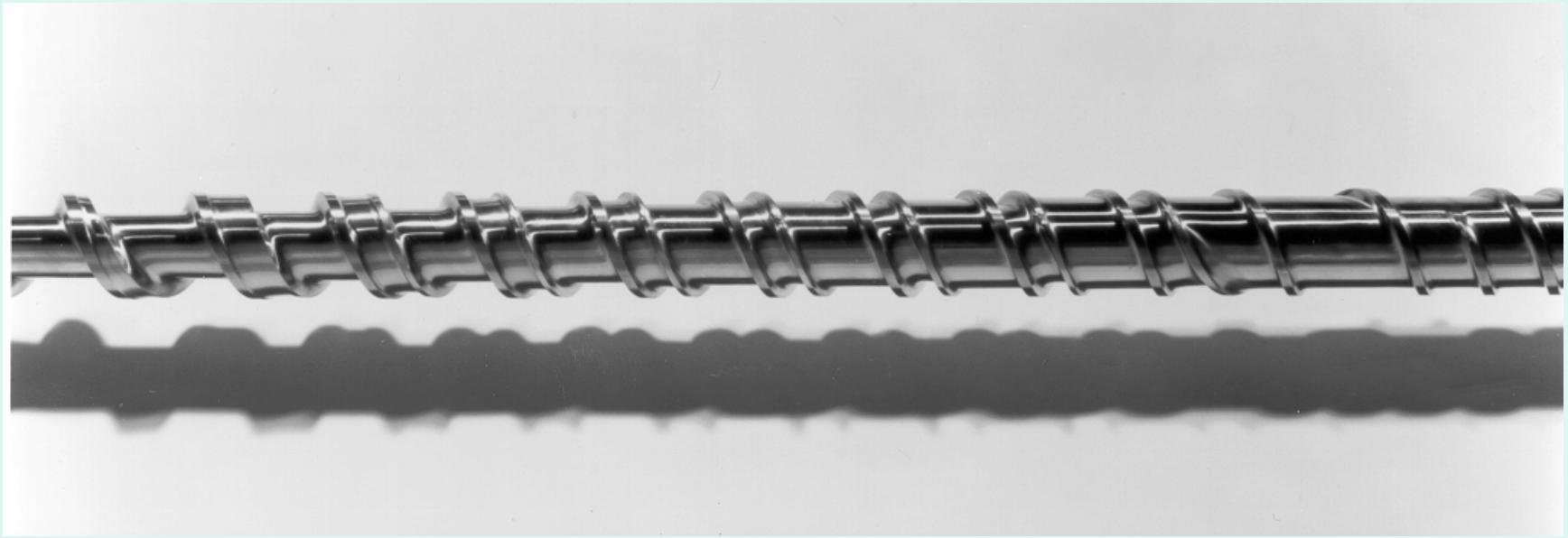
- Optimum Conditions
  - High Viscosity & Shear Rate
  - Large Solid Interface with Barrel
  - Small Channel Width

Melt Separation Barrier





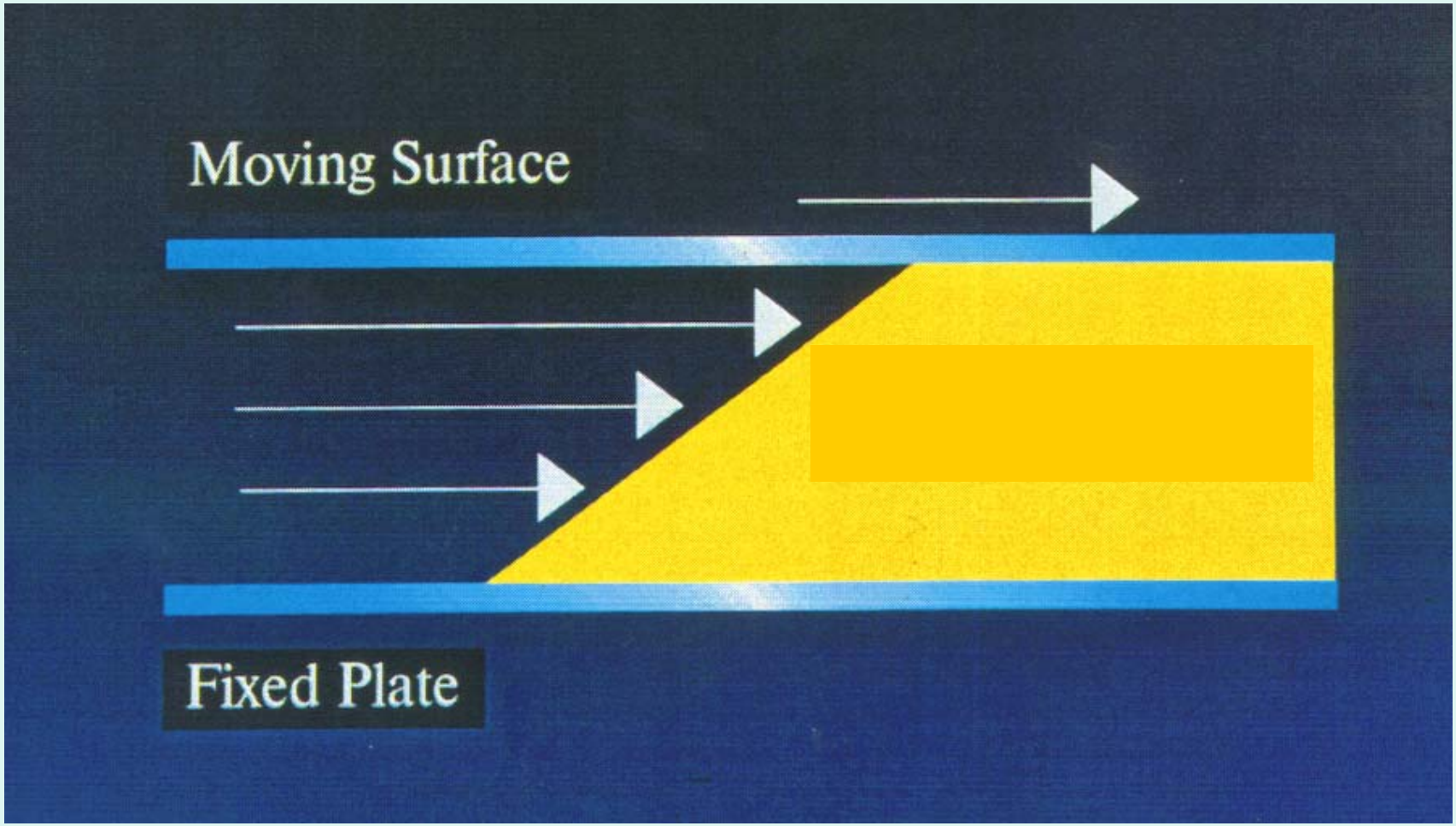
Melt Separation Barrier



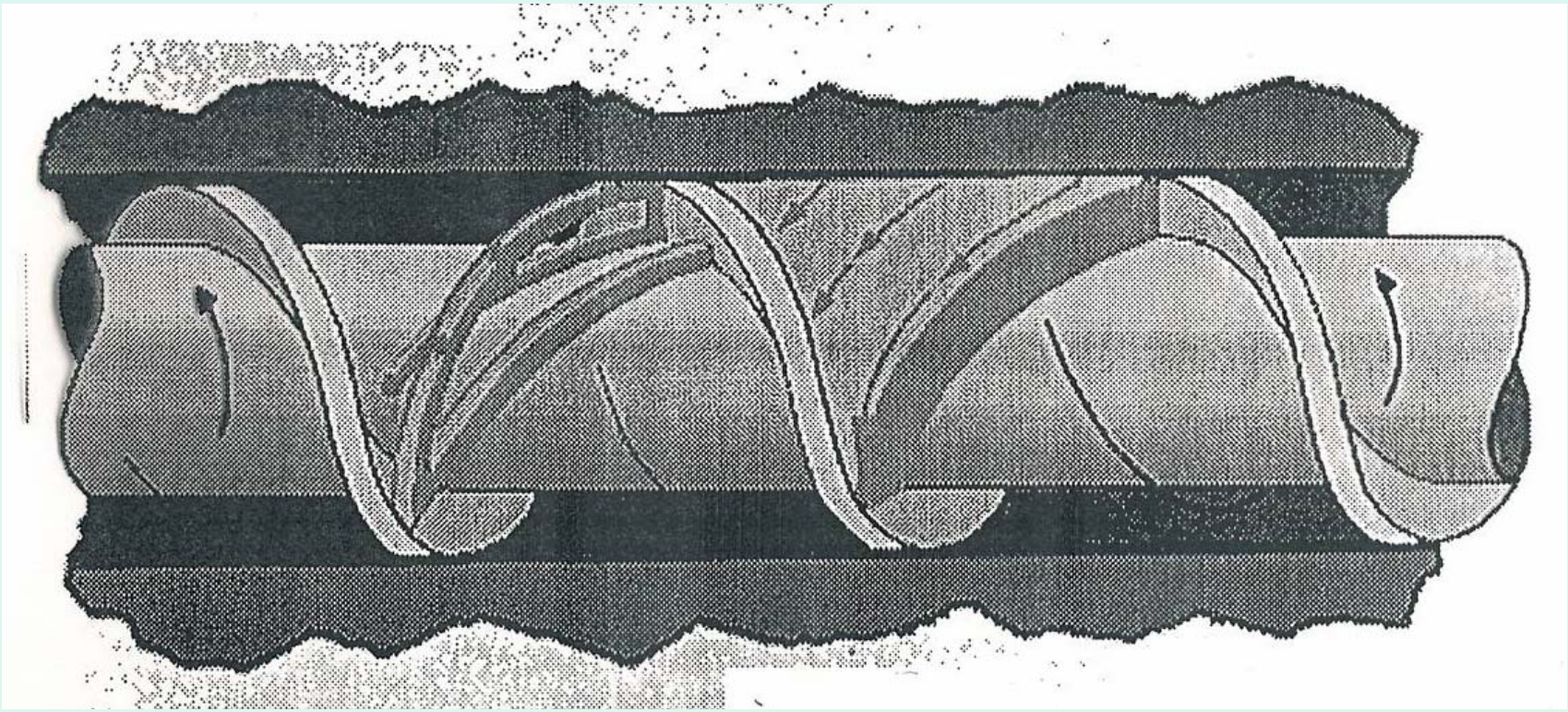
Pumping

- Driven by Drag Flow
- Opposed by Pressure Flow

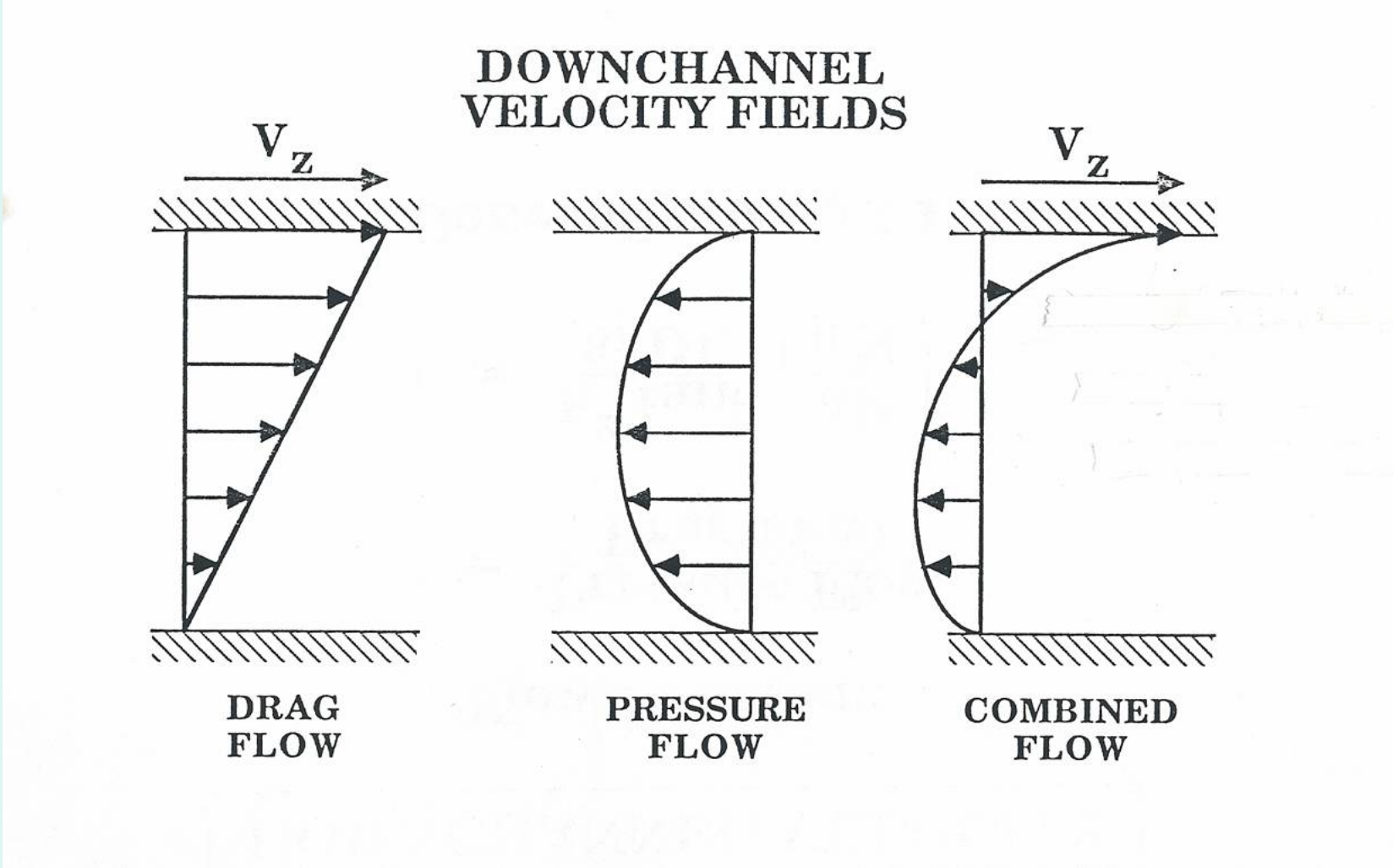
Drag Flow



Flow Path Along A Channel



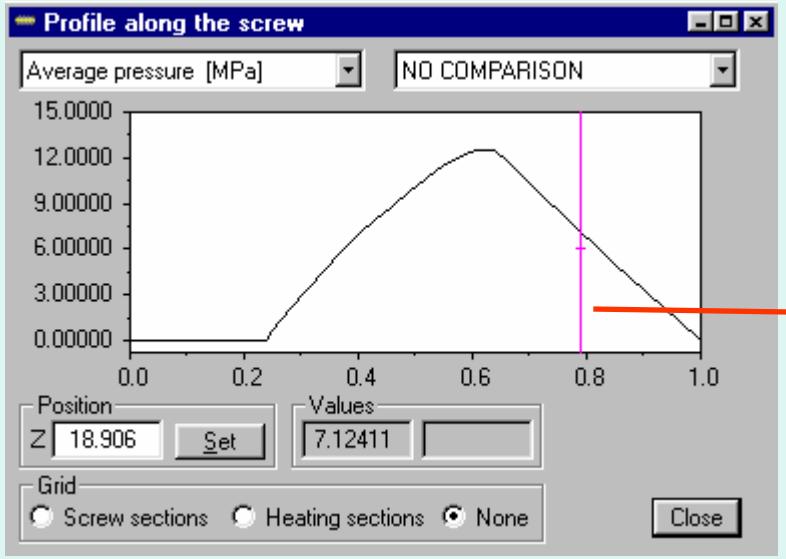
Flow Velocity Components

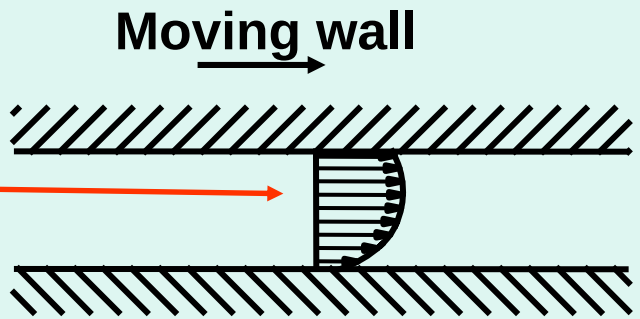


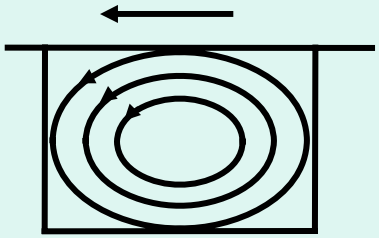
Pumping

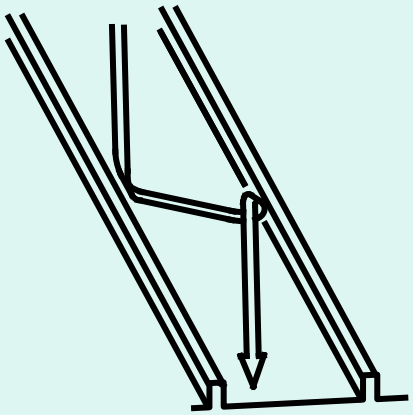
- Optimum Conditions
  - Low Head Pressure
  - High Entrance Pressure
  - High Screw Speed
  - High Melt Viscosity

Velocity inside the screw channel

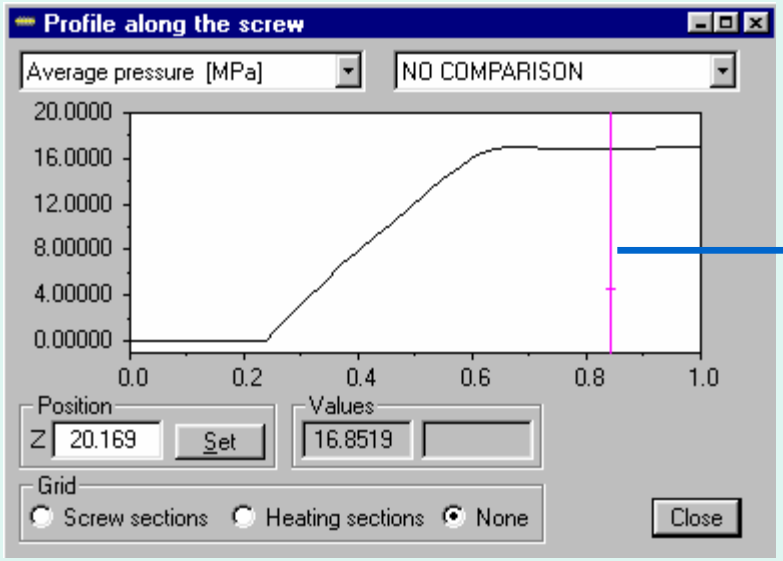


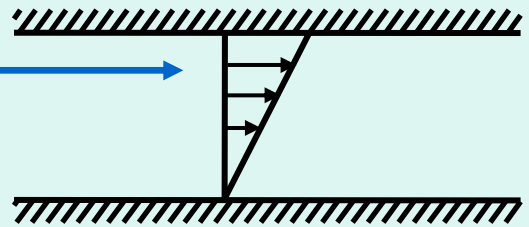


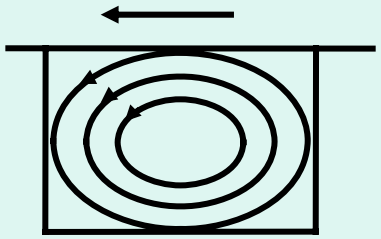


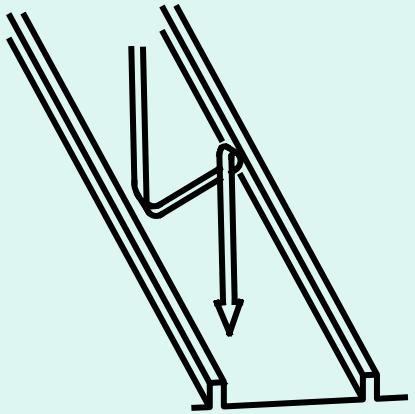


Velocity inside the screw channel

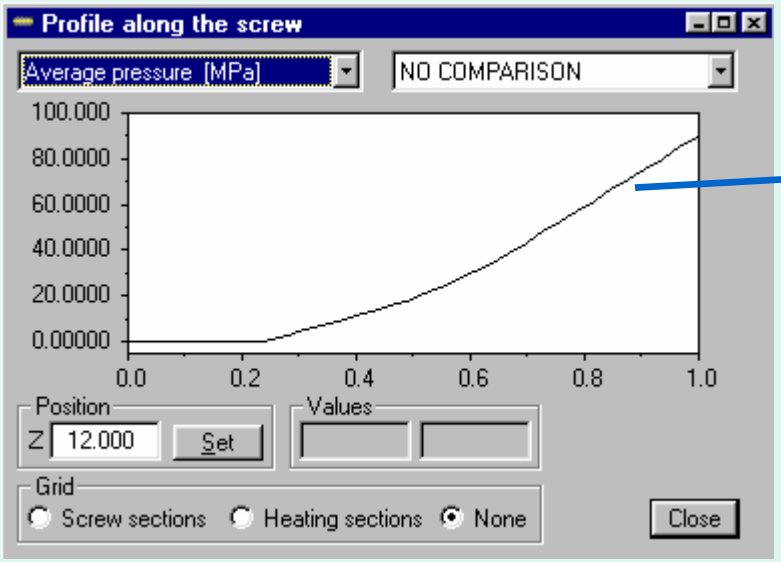


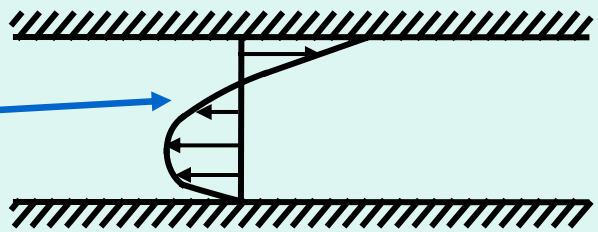


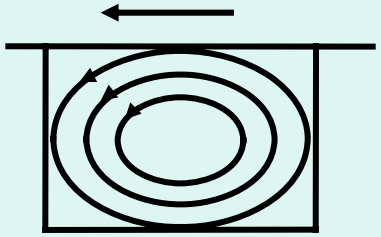


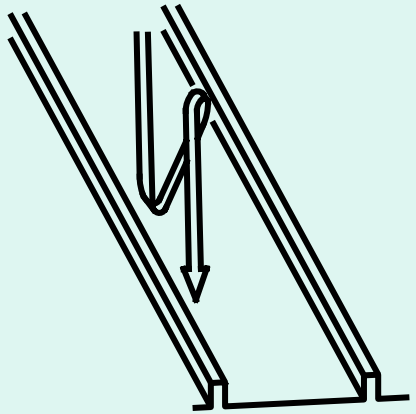


Velocity inside the screw channel









Mixing & Mixtures

- Two types of mixtures
  - Solid in liquid
  - Liquid in liquid
- Two types of mixing
  - Dispersive
  - Distributive

Dispersive Mixing

Deformation of the comingled components resulting in a reduced component size and increased interfacial area. The deformation being accomplished through shear, elongation, or compression or in combination.

Distributive Mixing

A repetitive random or ordered bulk rearrangement of the comingled components. Does not require continuous deformation of the material.

Mixtures

- Polymer Melts with Liquids
  - One polymer with large bulk temperature gradients
  - Alloys of two or more polymers
  - A polymer with minor components
    - Plasticizers
    - Stabilizers
    - Liquid Colorant
    - Lubricant

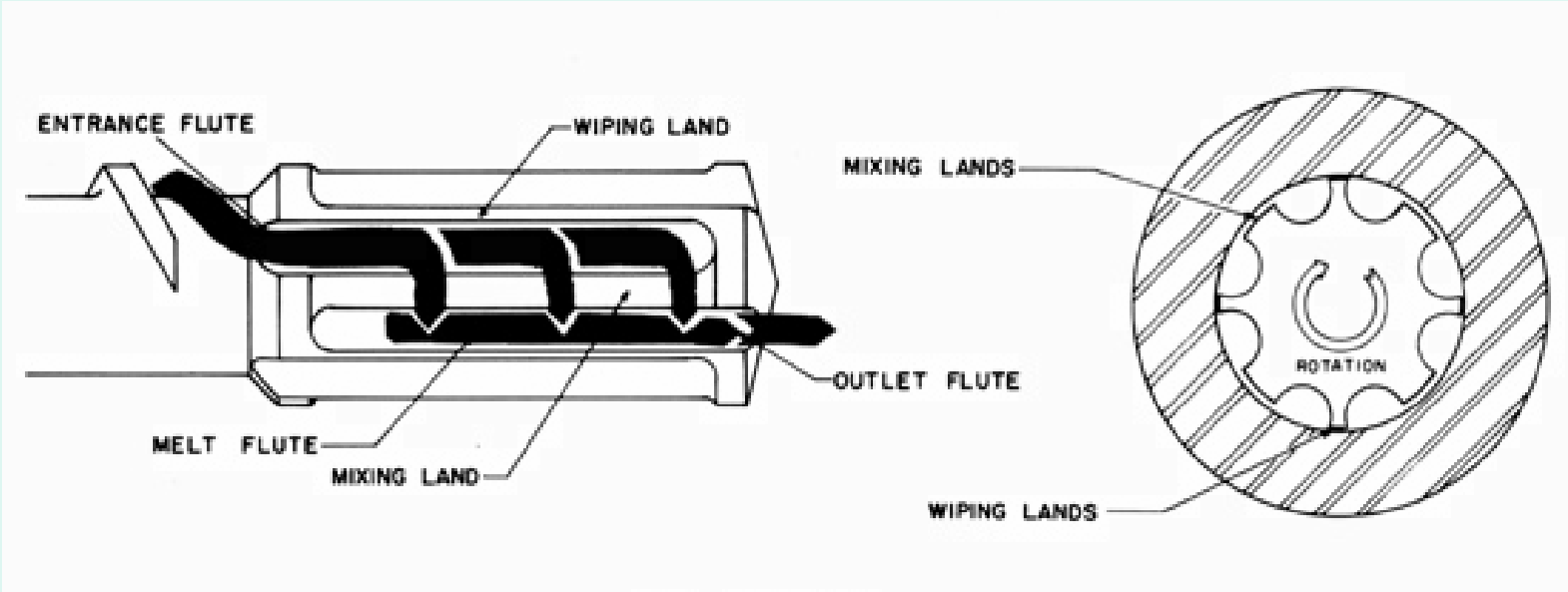
Mixtures

- Polymer Melts with Solids
  - Polymer melt with unmelted polymer
  - Polymer melt with other solids
    - Pigments
    - Flame Retardants
    - Nucleating Agents
    - Contaminants

Mixer Performance

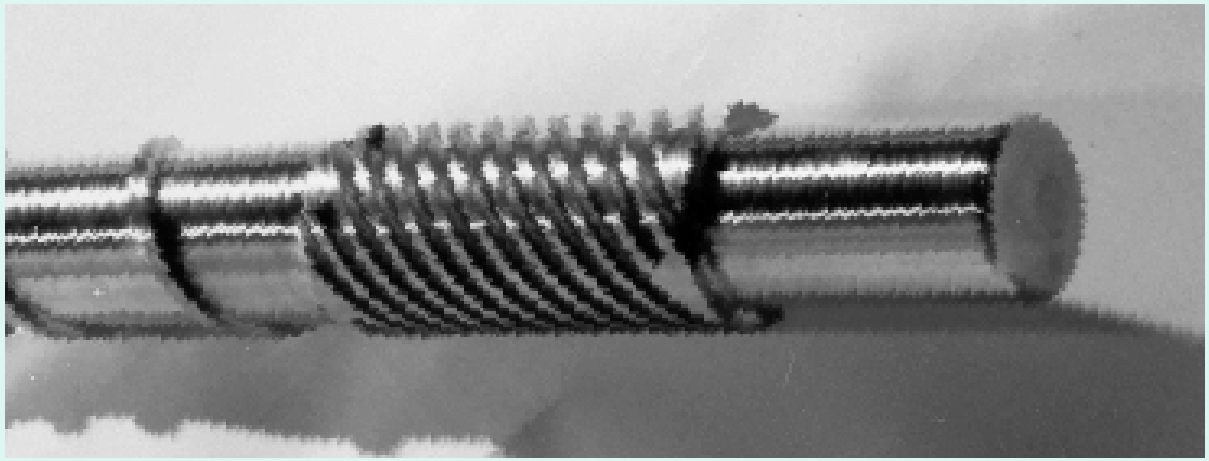
- Dispersion
- Distribution
- Efficiency
  - Pressure Drop
  - Streamlining
  - Relative Surface Area

Maddock's (UCC) Mixer



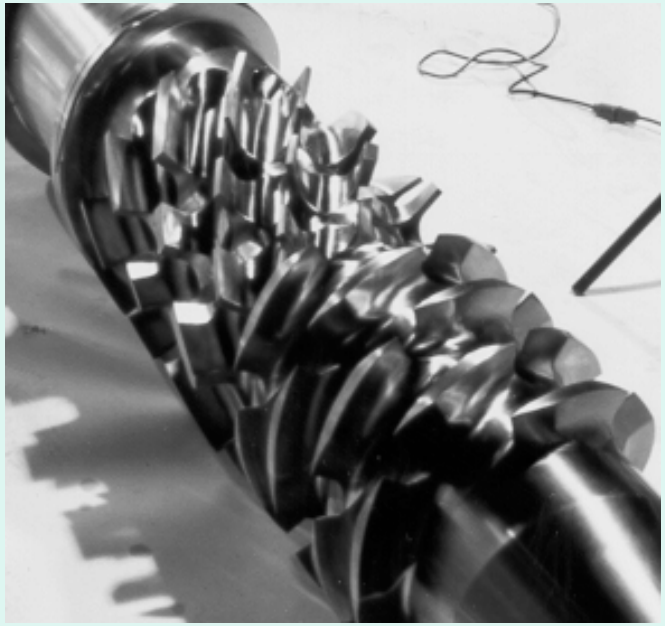
- Dispersion – high shear over barrier
- Distribution – splits & recombines flow
- Depends on pressure for flow
- Dead ended channels

Gregory (Egan) Mixer



- Dispersive – high shear over barrier
- Distribution – splits & recombines flow
- Helical channels pump at all speeds
- Dead ended channels

Pineapple Mixer



- Dispersive – No high shear path
- Distributive – Multiple flow rearrangements
- Minimum pumping due to flight cuts
- Very large wetted surface area

Remember the goal

Provide the melted polymer to the forming process at the desired rate, uniformity, and quality to produce the finished product within specifications.

Understand Your System

- Resin Feed System
  - Hopper
  - Volumetric Feeder
  - Gravimetric Feeder
- Root Cooling
  - Depth
  - Temperature Control
- Feed Cylinder Cooling
  - Length
  - Temperature Control
- Barrel Heating
  - Zone Lengths
  - Number of Zones
  - Type of Heating / Cooling
- Screw Design
  - Type of Screw Design
  - Original Design Specification (Specific Mat'l Rate Verification)
  - Relationship of Screw Design Features to System Components

Extruder Performance

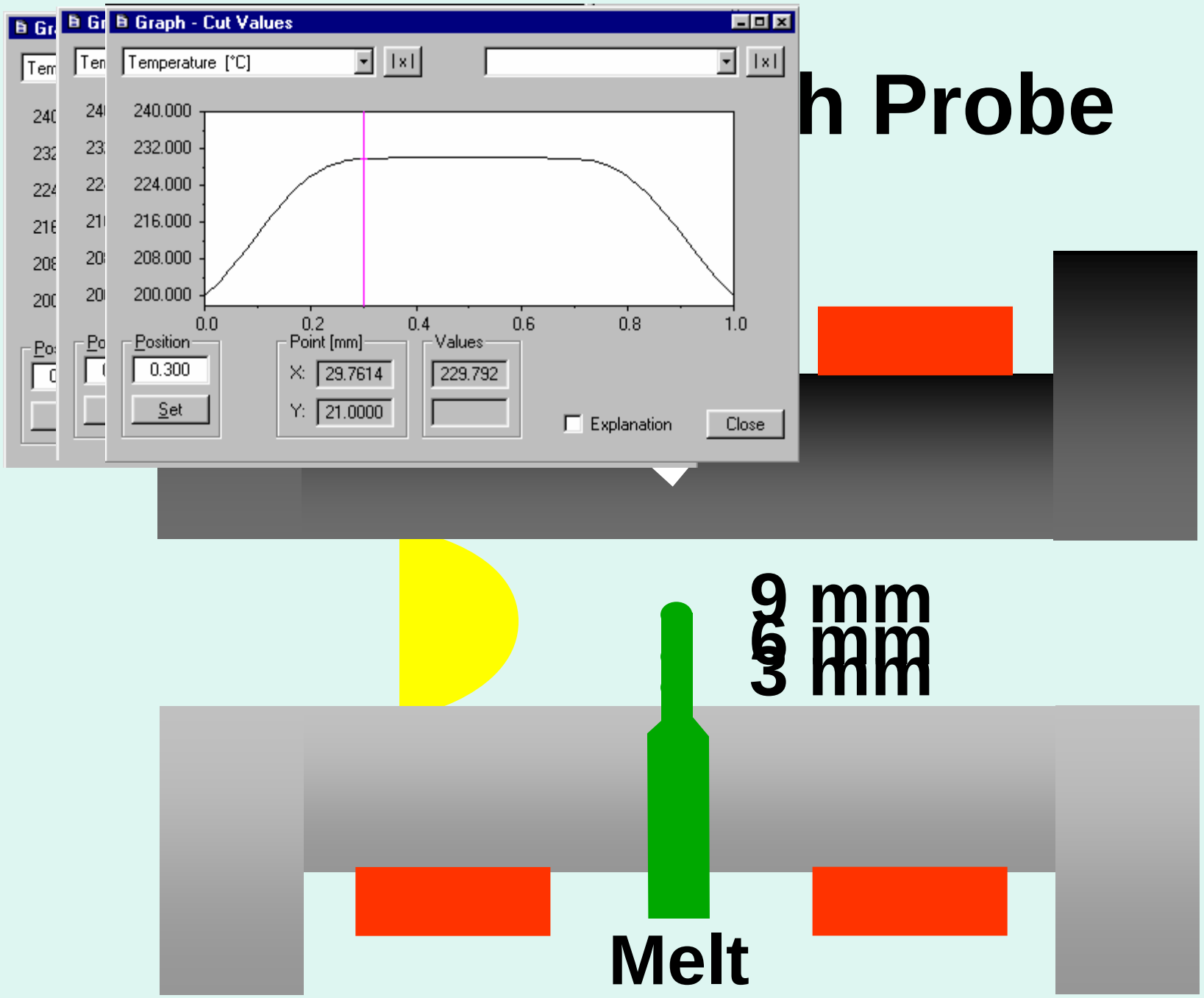
There is only one measure of extruder performance and that is melt quality. This is reflected in quantitative on-line measures as well as product performance measures.

Melt Quality

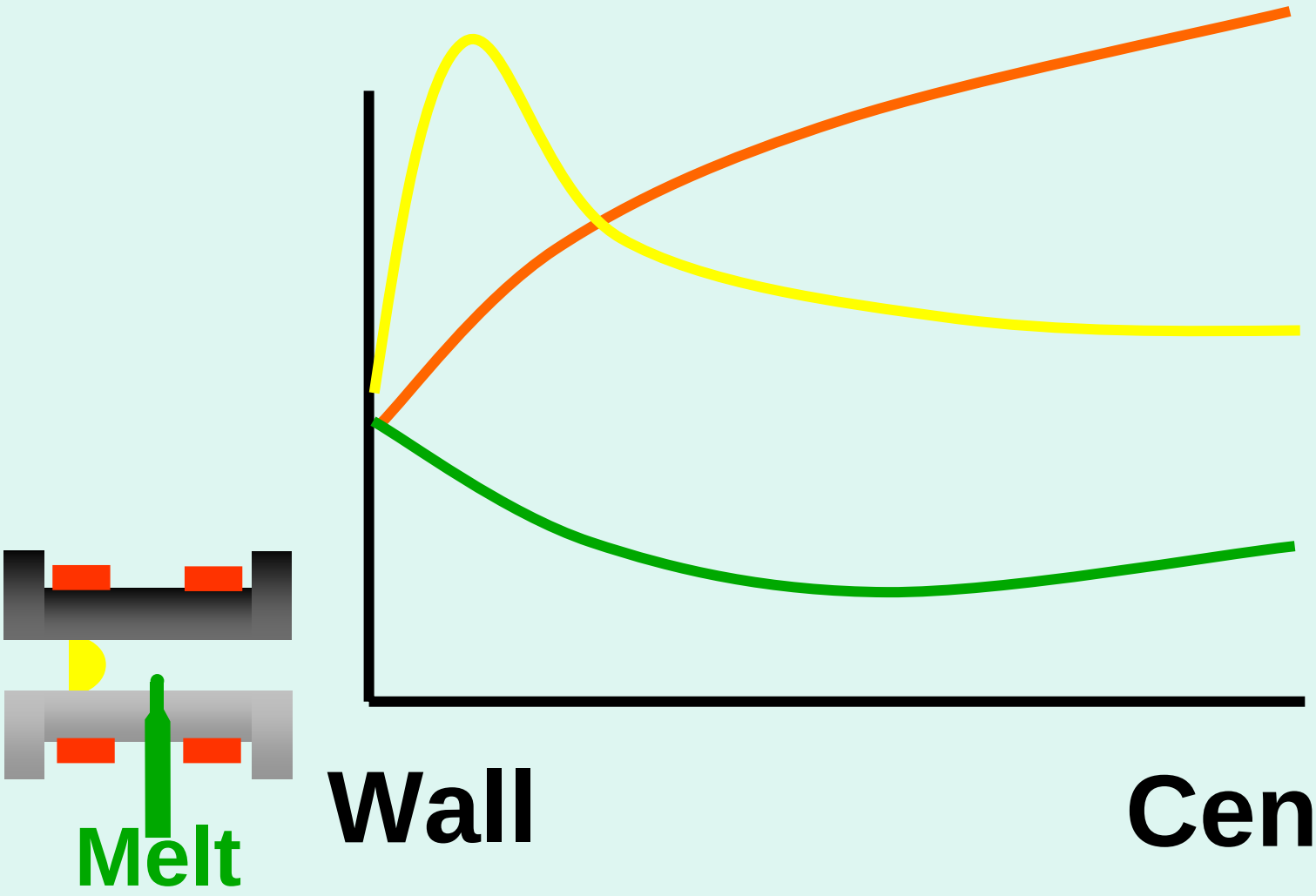
- Temperature Uniformity
- Pressure Uniformity
- Mixing and Dispersion
- Residence Time Distribution

Extruder thermocouples

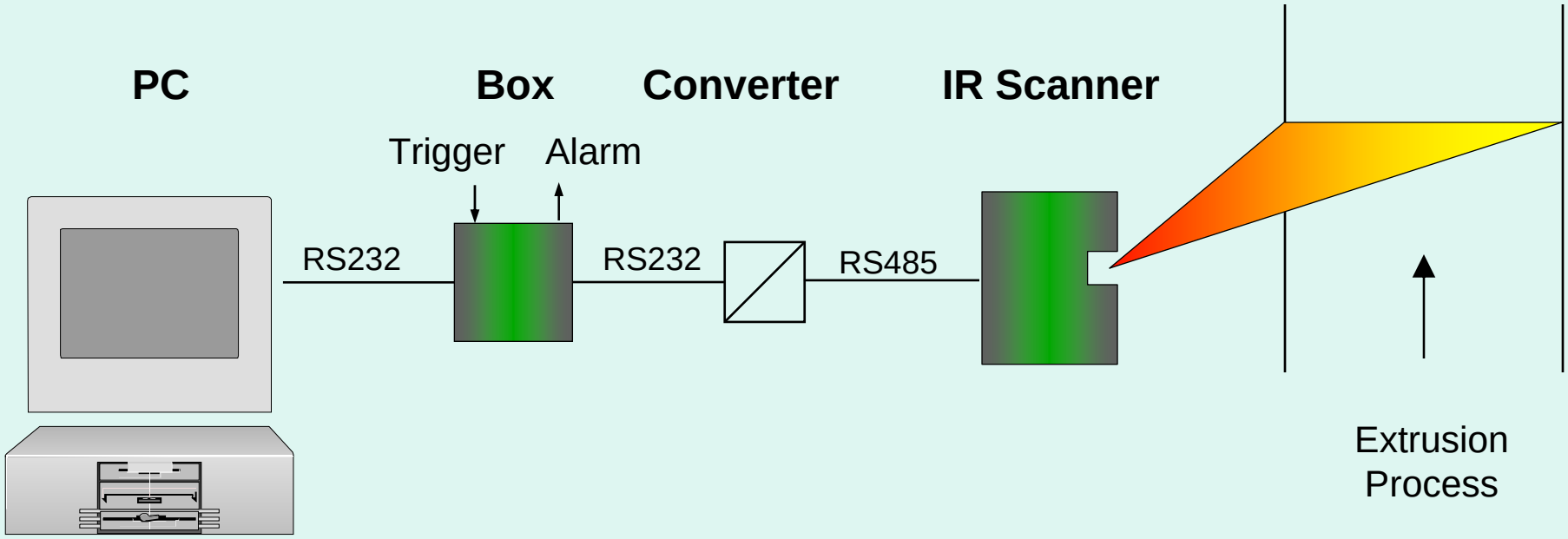
- Control Thermocouples
  - Mounted in extruder or component wall to provide feedback for heater control
- Melt Thermocouples
  - Flush with polymer flow surface (T&P)
  - Immersed into the polymer flow
    - Shielded junction
    - Exposed junction
  - Adjustable depth immersion
  - IR Probe


Graph - Cut Values
Temperature [°C]
240.000
232.000
224.000
216.000
208.000
200.000
0.0
0.2
0.4
0.6
0.8
1.0
Position
0.300
Set
Point [mm]
X: 29.7614
Y: 21.0000
Values
229.792
Explanation
Close
h Probe
9 mm
6 mm
3 mm
Melt

Possible Temperature Pattern

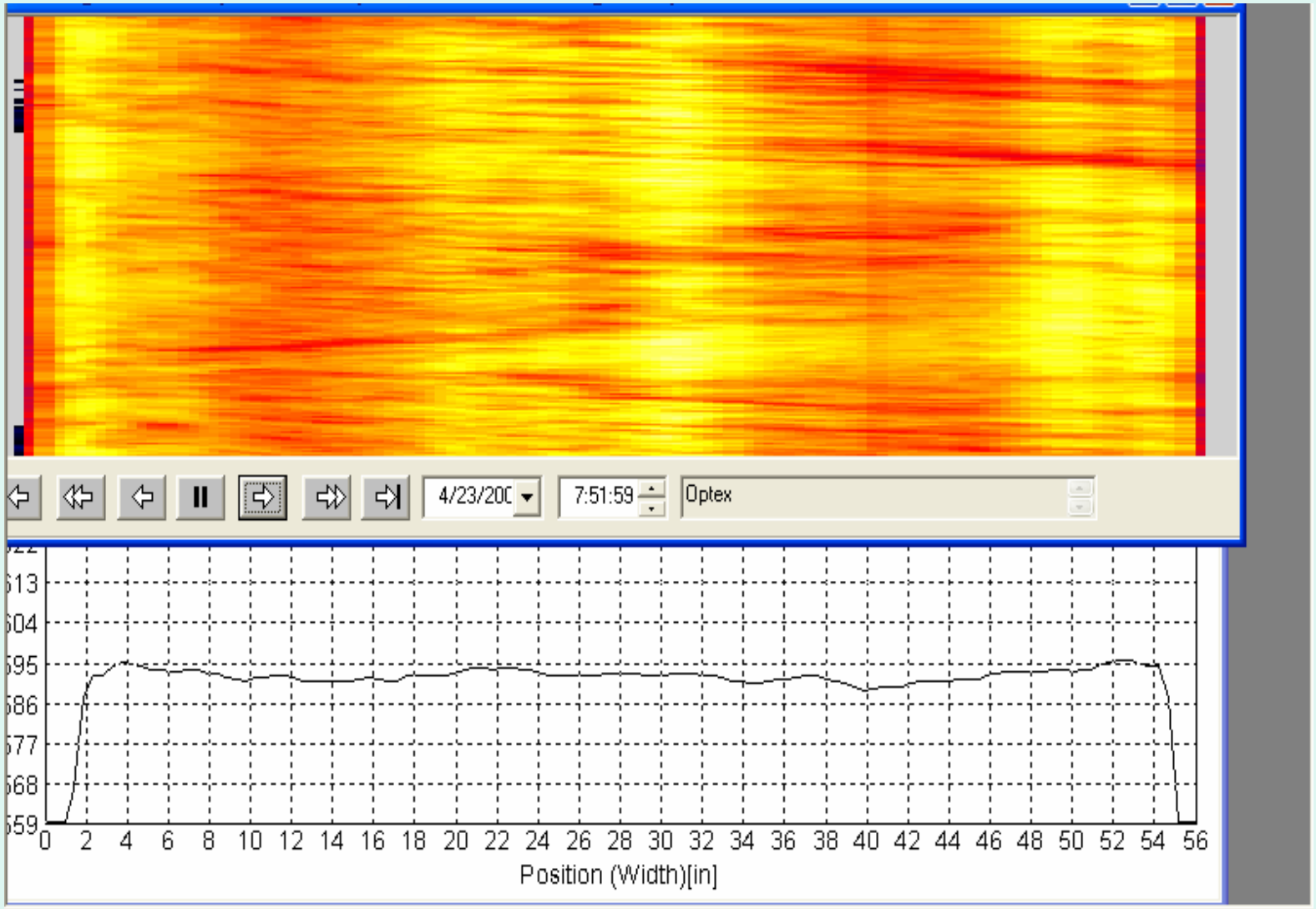


System Components



+ Laser
+ Adjustable Mounting Base
+ DataTemperature Software

IR Scan of Melt Curtain



Melt Quality

- Odor
- Gel Count
- Optics
- MVTR
- Physical Properties
- Heat Sealability
- Weatherability
- Wear Resistance
- Color

Summary

- The Goal is to produce an output and melt quality appropriate for your product
- In order to get the most from your system
  - Know the system component arrangement
  - Know the screw design – system component relationship
- Get quality real time feed back
  - Control temperatures / speeds
  - Gravimetric rate
  - Melt pressure
  - Melt temperature
    - Time dependent
    - Position dependent

Thank You

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