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Evolutions in Plastics™

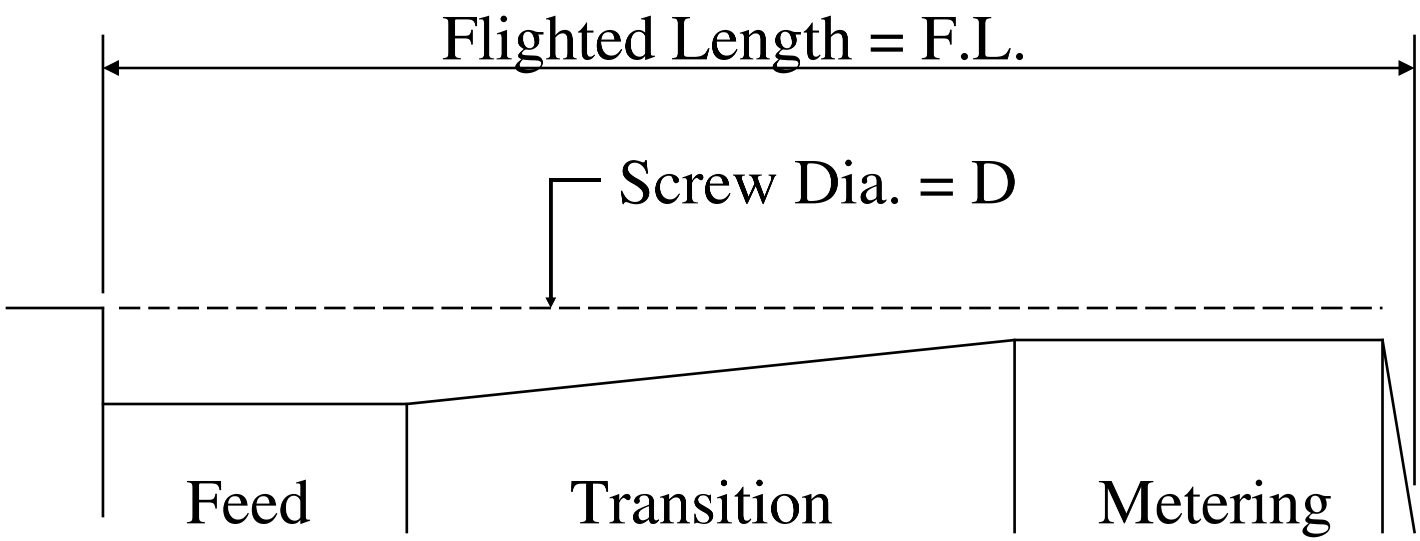
"Things Your Screw Designer Never Told You About Screws !!"

Presented by:

Tim Womer

1/25/2011

Common Nomenclature for Single Screws



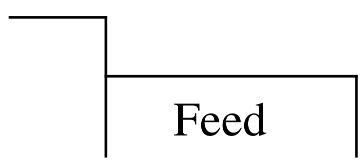
$$L/D = \frac{\text{Flighted Length (F.L.)}}{\text{Screw Diameter (D)}}$$

Length per Diameter of a Screw (L/D)

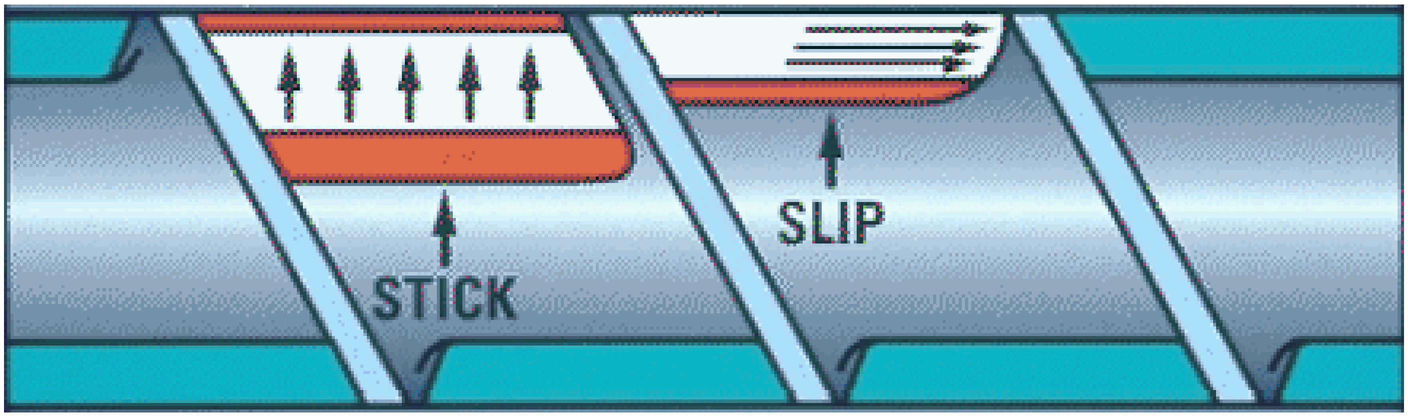
- Example:
  - Screw Diameter = 2.5”
  - Flighted Length = 63”
  - L/D = 63/2.5 = 25.2:1 L/D
  - OEMs refer to this as a 24:1 L/D
  - Typical L/Ds are 24:1, 30:1, 32:1, 36:1
- Machine manufacturers define L/D differently.
- Screw manufacturers sometimes price a screw based on the overall flighted length.

Section Lengths - Feed

- No feed section - old RPVC powder design
- 5 to 6 turns - typical
- 8 to 10 turns for poor feeding materials
- 10 to 12 turns when the material requires heat to be absorbed before it can be melted.



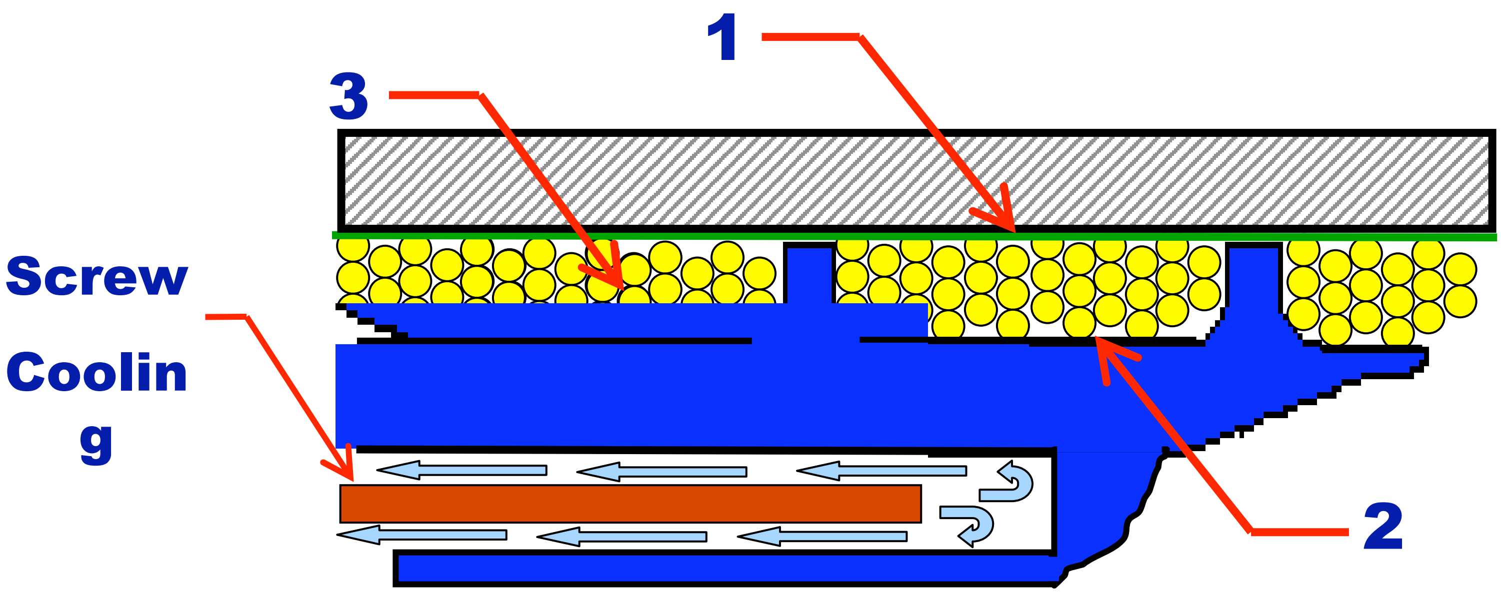
Basic Theory of Solids Conveying



- In order for the plastic pellet to move forward:
  - Stick to the barrel
  - Slip on the screw
- If the plastic sticks to the screw, we have a melt block
- If the plastic doesn't stick to the barrel we get “wind milling”

Coefficient of Friction

(in the feed section of the screw)



1. **Pellet to the barrel wall**
2. **Pellet to the root of the screw**
3. **Pellet to Pellet**

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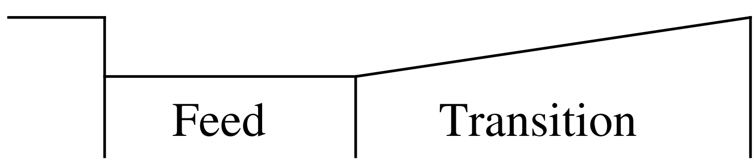
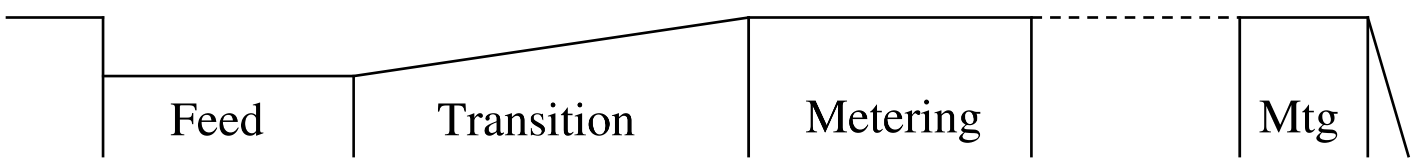
Transition Section for a Single Stage Screw

- Length should match melting rate of polymer of resin being processed
- This is where all of the work is done and more generally the most amount of screw and barrel wear is seen.
- Typically 5 to 10 turns long



Section Length - Metering

- Melting is completed and polymer pumping takes place.
- Minimum of 5 to 6 turns before mixer, even if a mixer is being used, to help insure stable output and pumping.
- 2 Turns after mixer for re-orienting the melt.
- Longer Metering Section typically for Non-barrier type screws.



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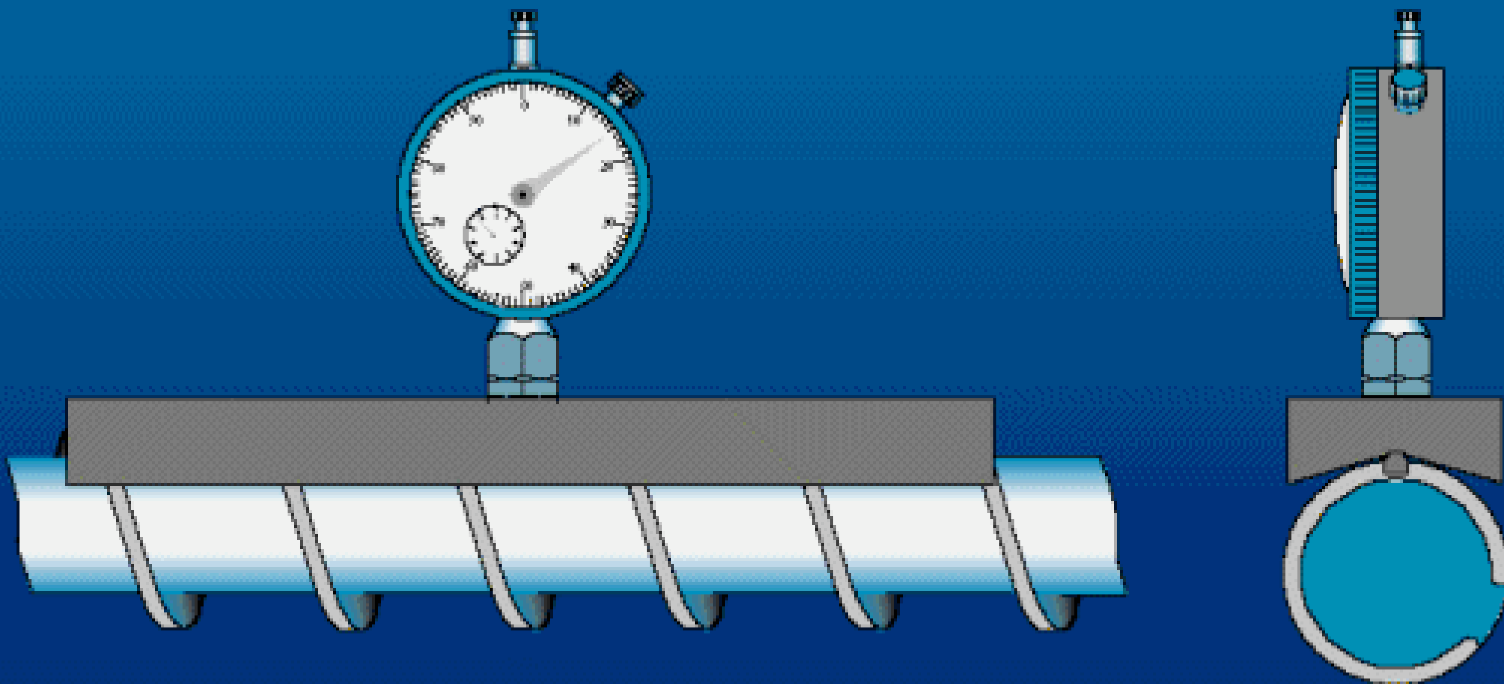
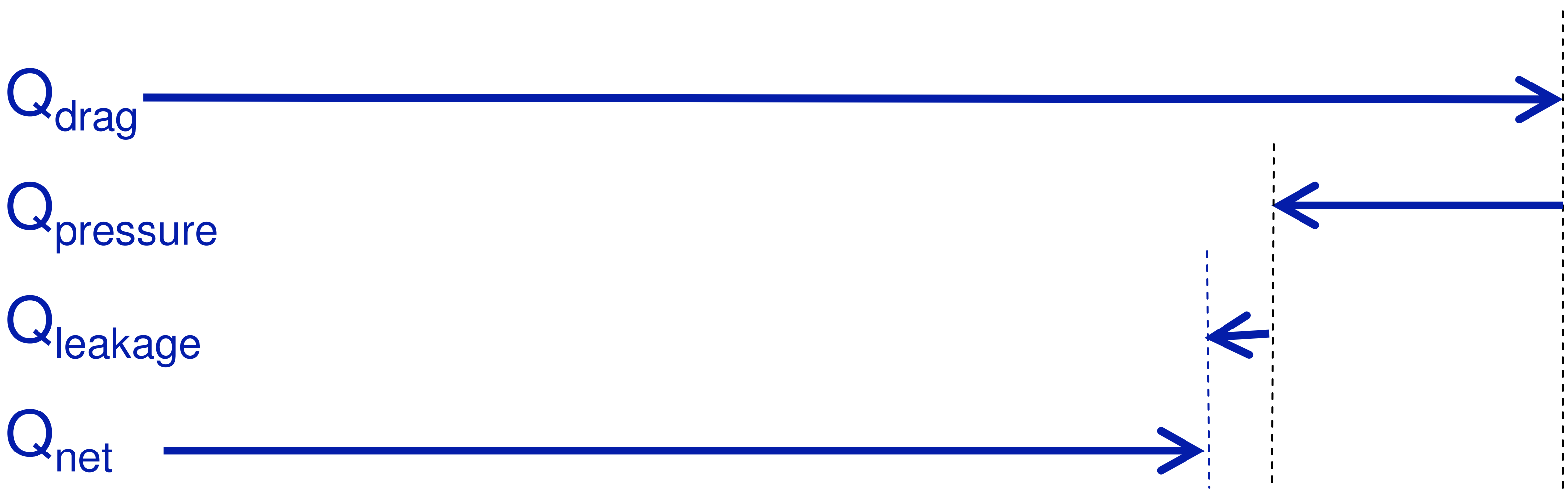
CHANNEL DEPTH GAUGE



Pumping in the Metering

$$Q_{net} = Q_{drag} - Q_{Pressure} - Q_{leakage}$$



- Pressure Flow must never be greater than 33% of Drag Flow
- On a new screw Leakage Flow is typically less than 1%

Drag Flow / Pressure Flow Equation

$$Q_n = \frac{F_d^{'} \cdot \pi^2 \cdot D^2 \cdot N \cdot h \cdot \left(1 - \frac{n \cdot e}{t}\right) \cdot \sin\phi \cdot \cos\phi}{2} - \frac{F_p^{'} \cdot \pi \cdot D \cdot h^3 \cdot \left(1 - \frac{n \cdot e}{t}\right) \cdot \sin^2\phi}{12 \cdot \quad \cdot L} \cdot \Delta p$$

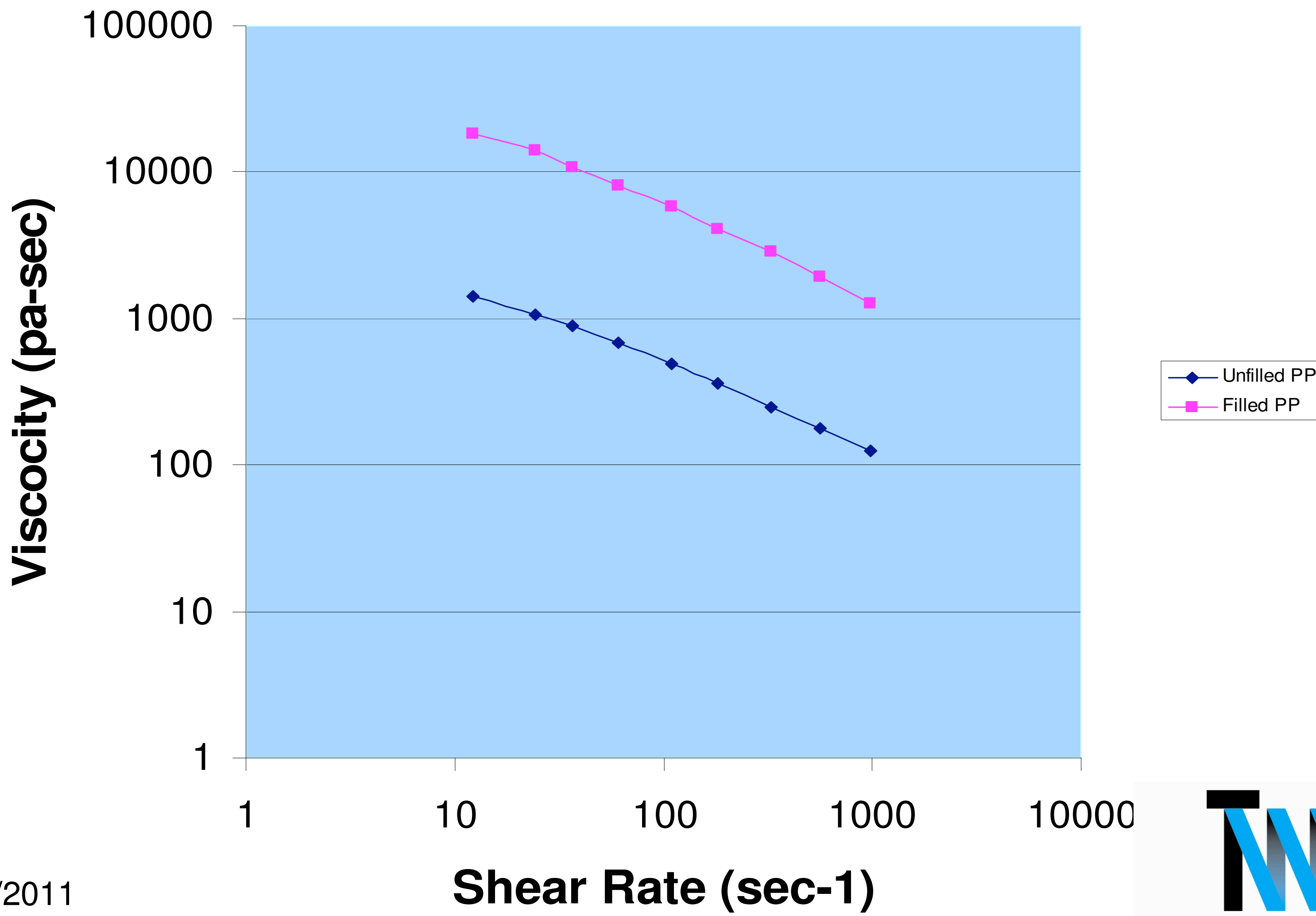
- Pure pumping capacity of the metering section
- Leakage Flow is disregarded on new screws because it is < .1%
- Result if done in unified units is in^3/sec.

Drag Flow Equation

$$Q_d = \frac{F_d' \cdot \pi^2 \cdot D^2 \cdot N \cdot h \cdot \left(1 - \frac{n \cdot e}{t}\right) \cdot \sin\phi \cdot \cos\phi}{2}$$

- F'_d = Shape factor of the channel
- Pure displace based on the geometry of the screw.
- Rate is directly related to screw speed
- The helix angle (Φ) of the flight in the metering section does have an effect on the pumping capacity of the screw

Differences in Viscosity



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Pressure Flow Equation

$$Q_{\mathrm{Pr}ess} = \left(\frac{F_p^{'} \cdot \pi \cdot D \cdot h^3 \cdot \left(1 - \frac{n \cdot e}{t}\right) \cdot Sin^2 \phi}{12 \cdot \quad \cdot L} \cdot \Delta p \right)$$

- *"µ"* is the viscosity of the polymer
- It has an inverse relationship to the Pressure Flow
- The greater the viscosity the lesser the Pressure Flow
- The higher the % of filler, typically the higher the viscosity

Simple Calculation for Rate

$$Rate = 2.3 \times D^2 \times h_m \times MD \times N$$

Where:

D = Screw Diameter (inches)

h_m = Metering Depth (inches)

MD = Melt Density of the resin (gm/cc)

N = Screw Speed (rpm)

Example Problem

$$Rate = 2.3 \times D^2 \times h_m \times MD \times N$$

Where:

D = 2.5”

h_m= .150”

MD = LDPE (.76 gm/cc)

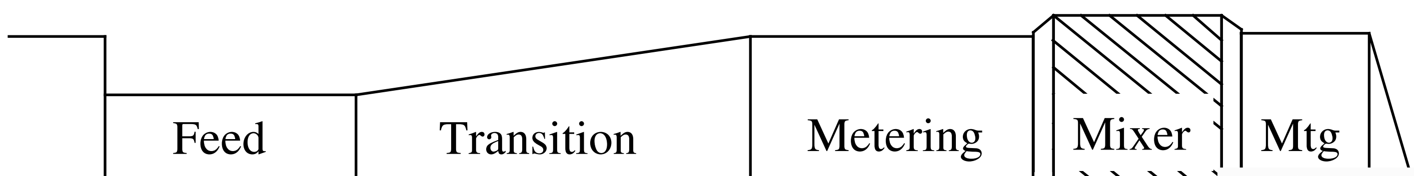
N = 120 rpm

$$Rate = 2.3 \times D^2 \times h_m \times MD \times N$$

$$Rate = 245.8\ lb/hr$$

Section Lengths - Mixers

- Two types of Mixing - Distributive and Dispersionary Mixing
- Most mixers are 2 turns long
- Some of the more intense dispersionary mixers are 3+ turns long.
- Mixers should be located back from the tip of the screw approximately 2 turns to help in re-orienting the melt.



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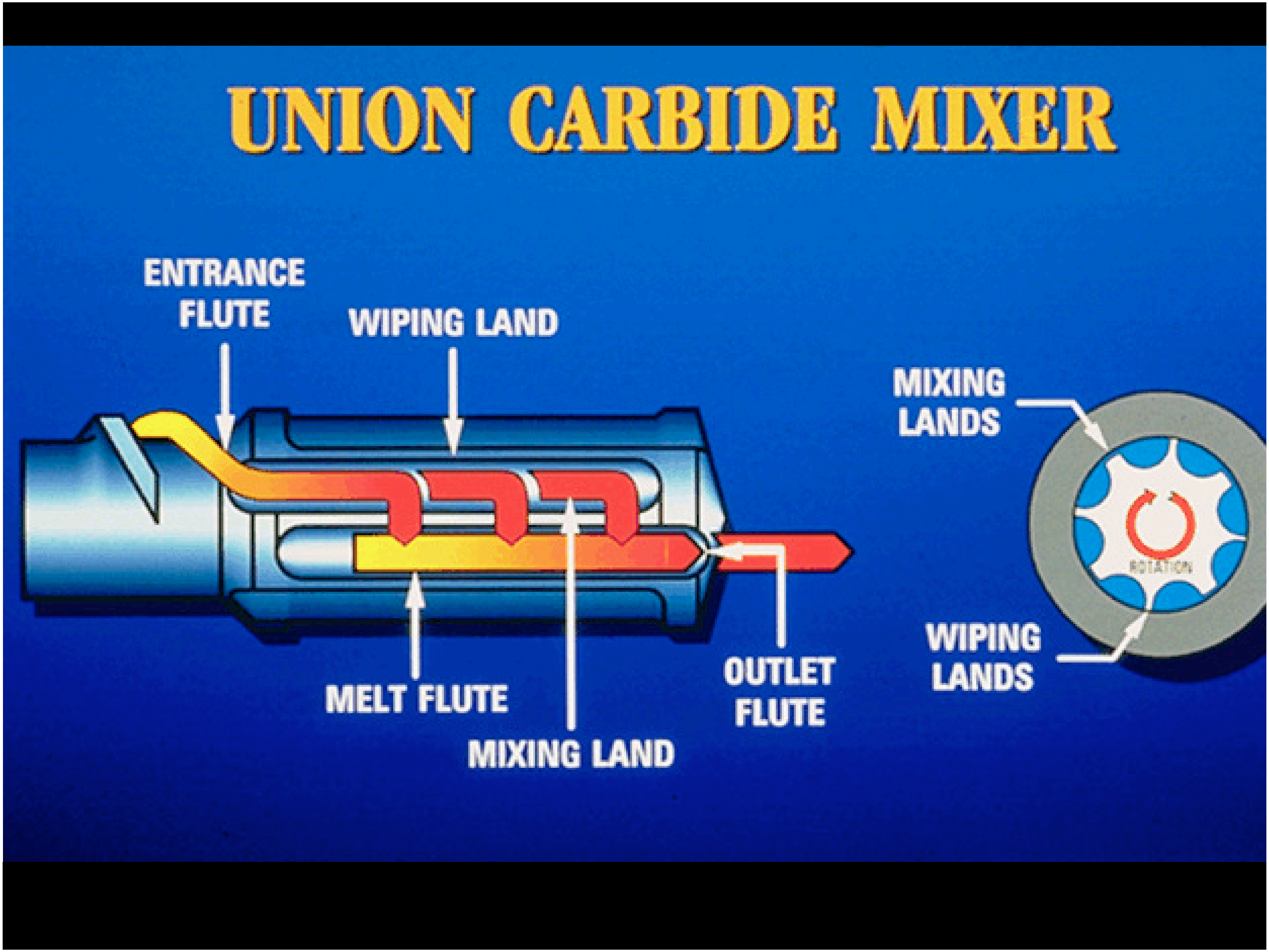
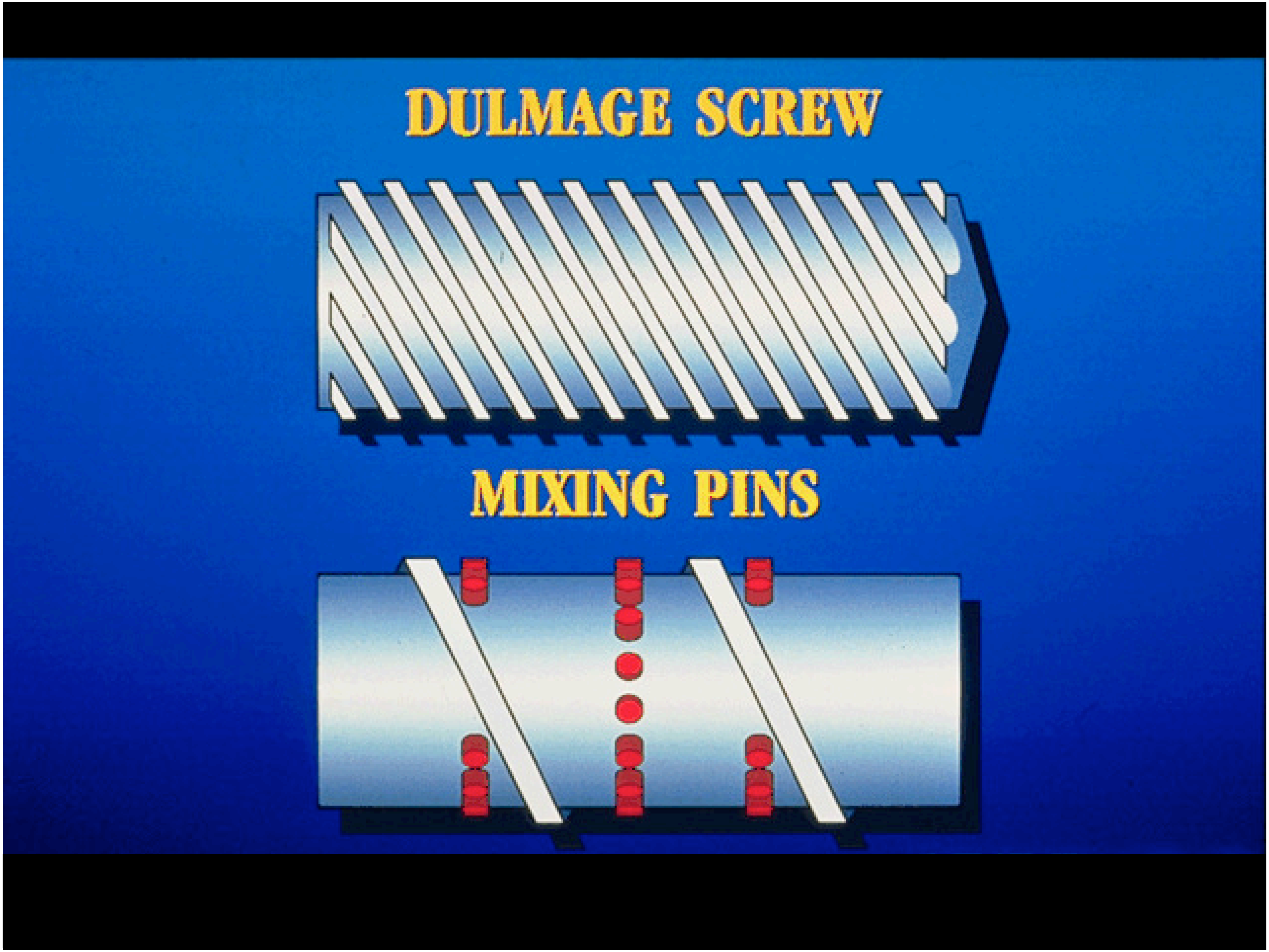

UNION CARBIDE MIXER
ENTRANCE FLUTE
WIPING LAND
MIXING LANDS
ROTATION
WIPING LANDS
OUTLET FLUTE
MELT FLUTE
MIXING LAND


DULMAGE SCREW
MIXING PINS

Nano™-Mixer

US Patent 6,497,508

- Dispersionary Mixing
- Self-cleaning
- Multi-Pass Mixing
- Injection and Extrusion

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StrataBlend® II Mixer

US Patent 6,488,399

- Distributive Mixing
- Chaotic Mixing
- Low Shear (PVC, ABS, PC, etc.)
- Injection and Extrusion

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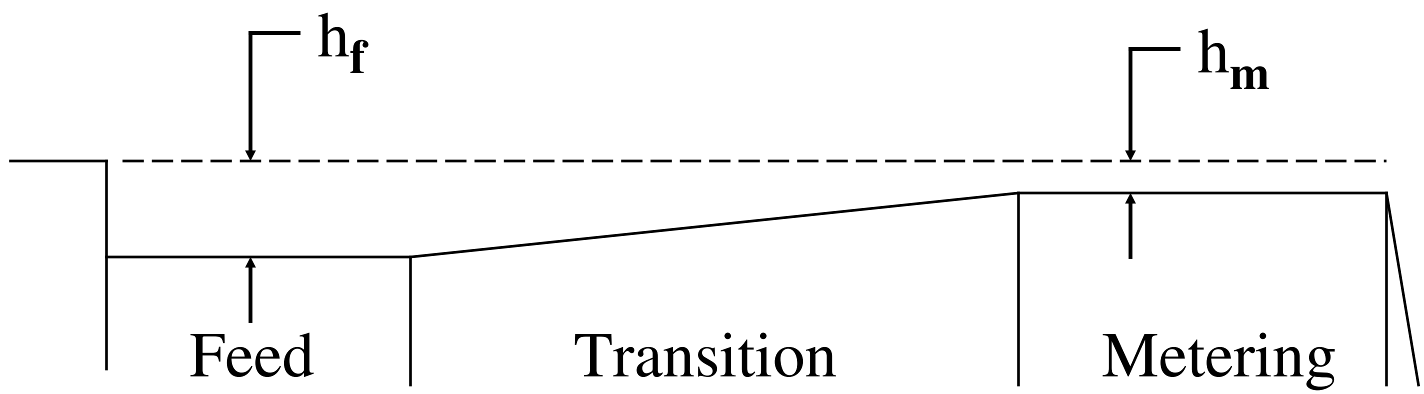
Mixing Experiment

Depth to Depth Compression Ratio



$$\text{Compression Ratio (C.R.)} = \frac{h_f}{h_m}$$

Compression Ratio = C/R

- Feed Depth / Metering Depth
- Examples for a 2.5” screw:

$$\frac{h_{\mathbf{f}}}{h_{\mathbf{m}}} = \frac{.300''}{.100''} = 3:1$$

and

$$\frac{h_{\mathbf{f}}}{h_{\mathbf{m}}} = \frac{.450''}{.150''} = 3:1$$

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Barrier Screw Technology

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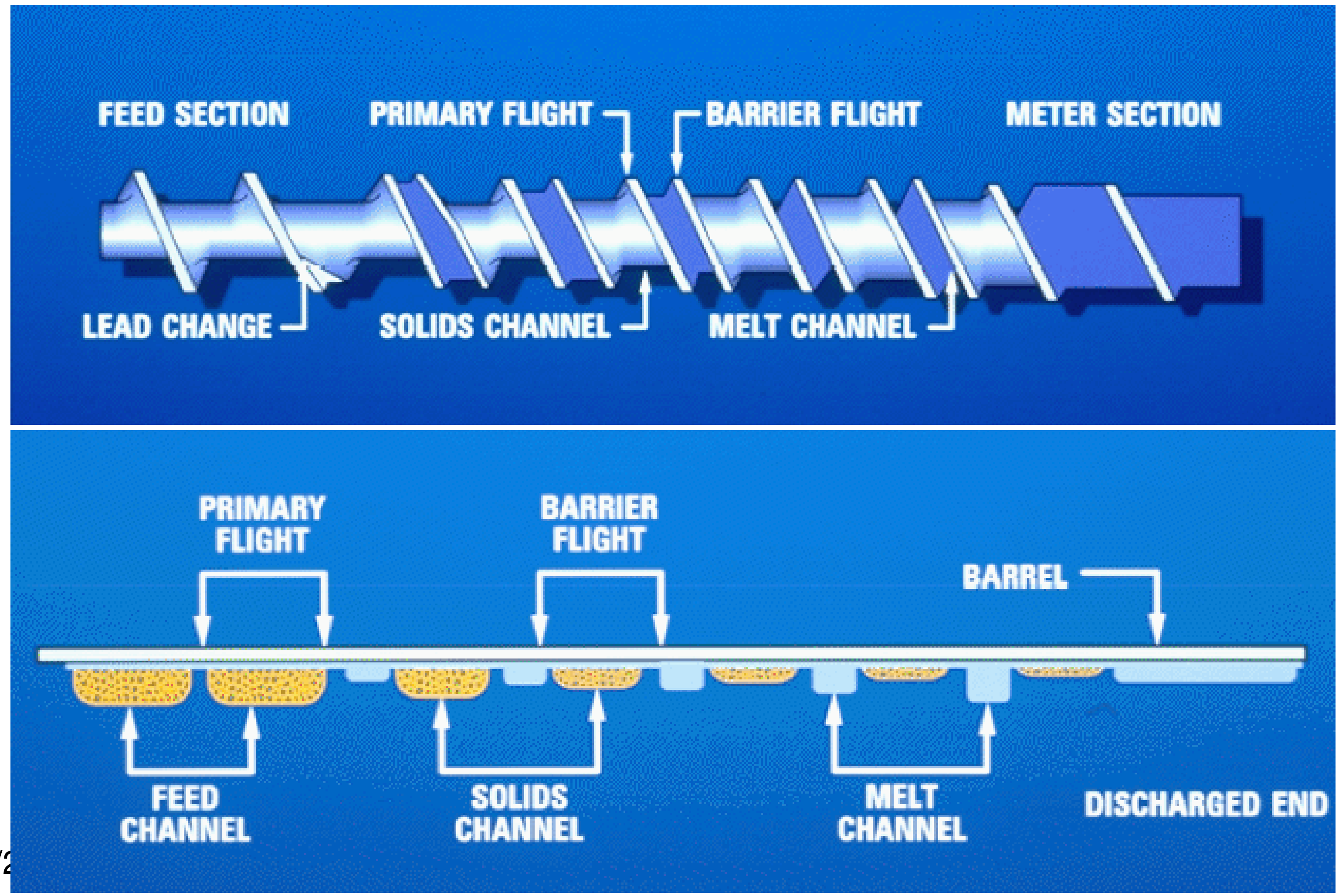
Barrier Screws

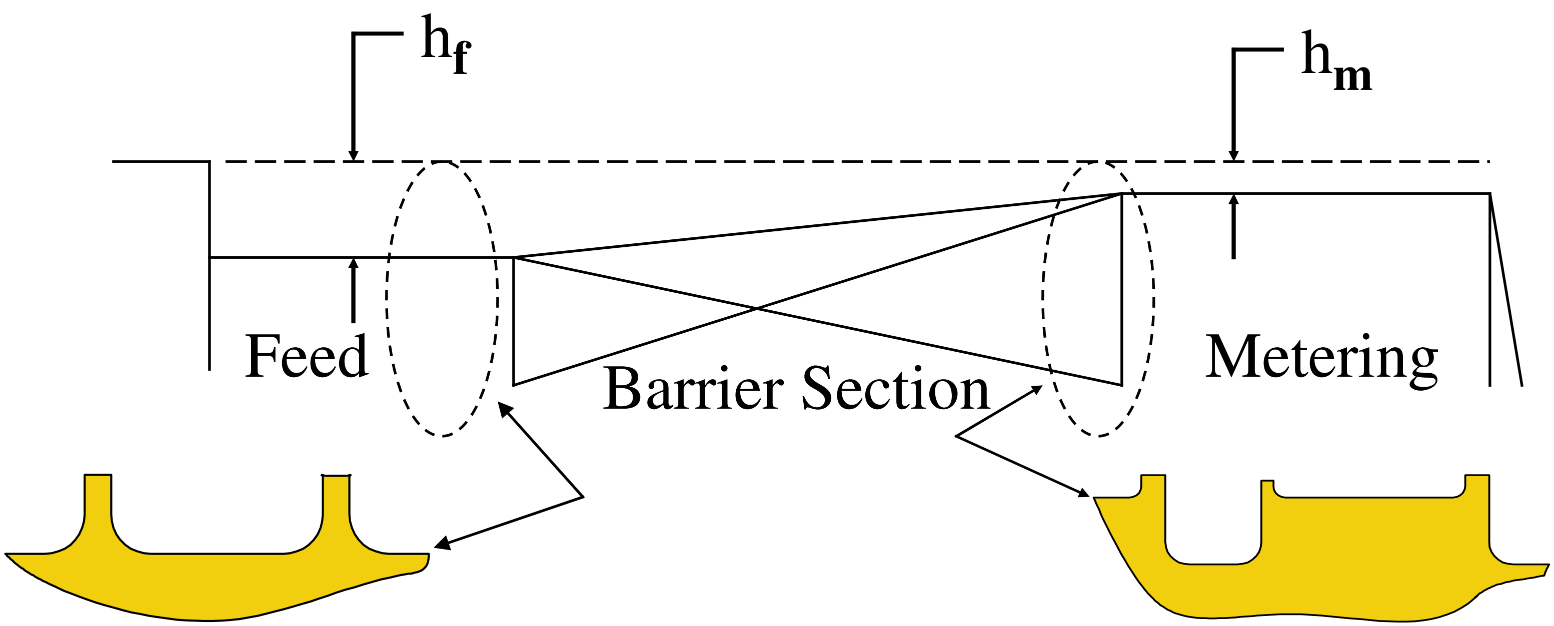
- High performance technology
  - Separates the melt pool from the solids bed
  - Lower overall melt temperature

Barrier Basics



Volumetric Compression Ratio of Barrier Screws

Volumetric Compression Ratio = VCR



Cross-Section of Feed

Cross-Section at End of Barrier

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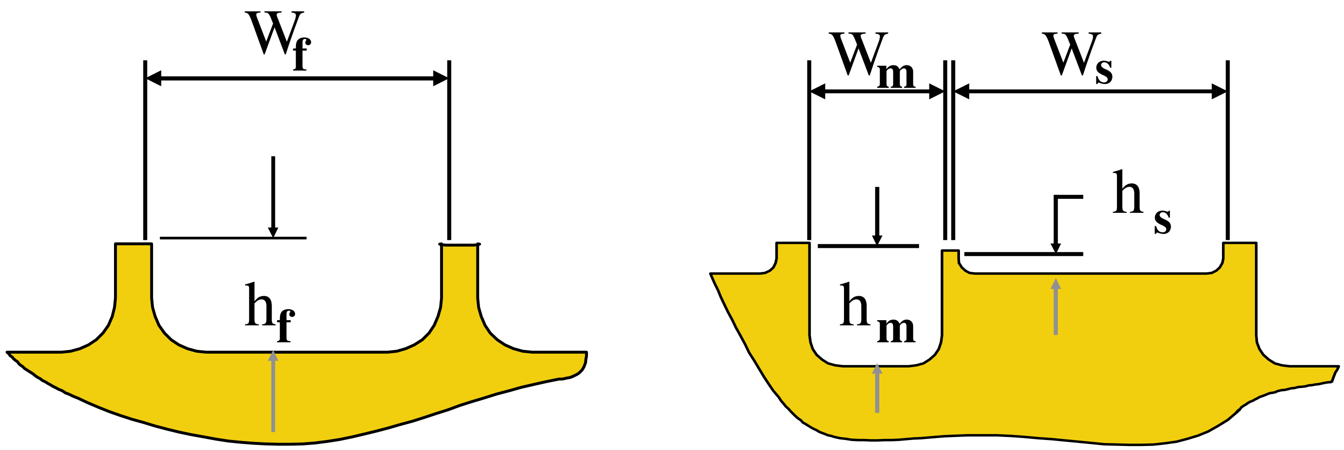
Volumetric Compression Ratio in Barrier Screws



Cross-Section of Feed

Cross-Section @ End of Barrier

$$\mathbf{VCR} = \frac{(W_f * h_f)}{(W_m * h_m) + (W_s * h_s)}$$

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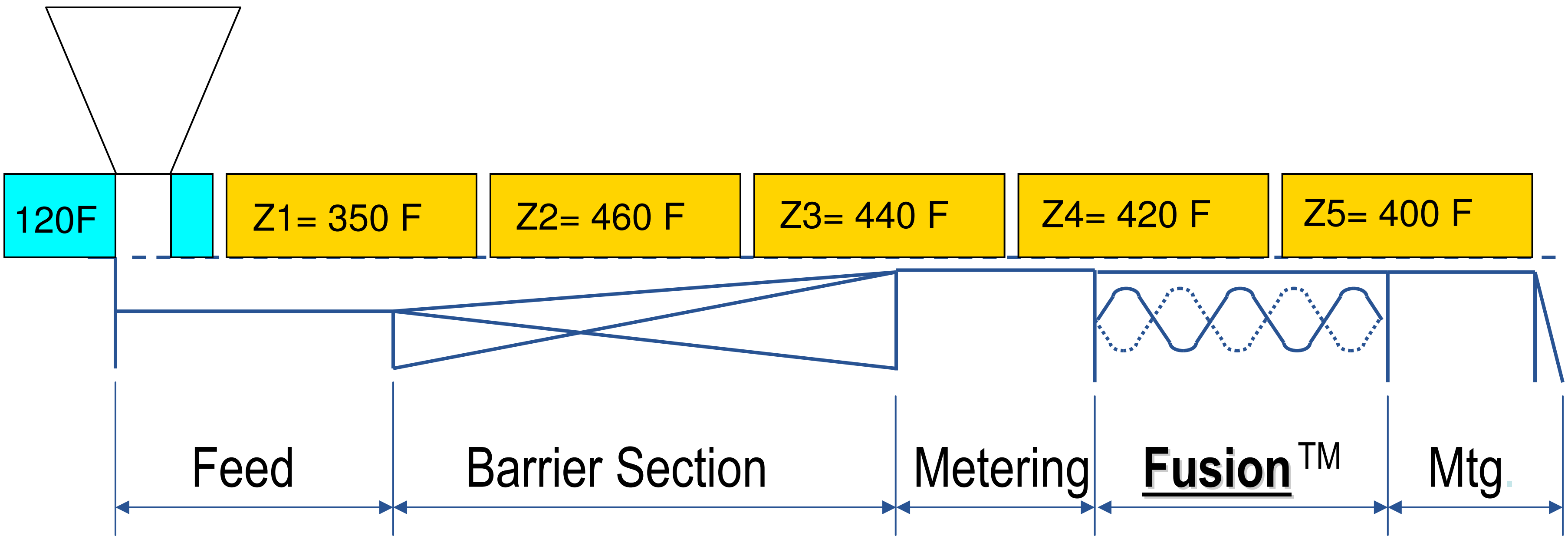
Temperature Profile

(for processing a .35MI HDPE)



NOTE: This profile typically will produce a 410-420F Melt against a 3500 PSI headpressure.

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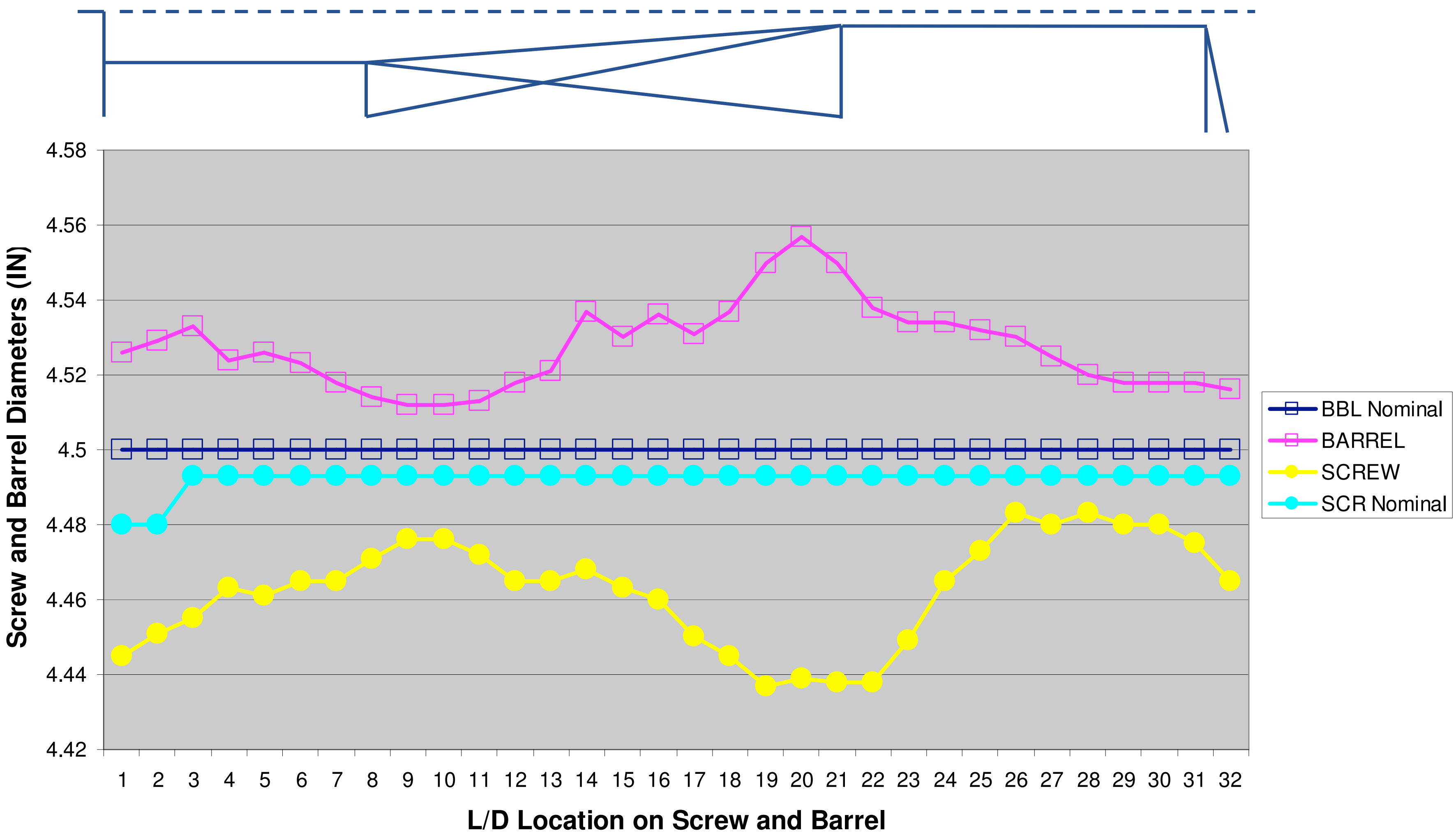
4.5” x 32:1 L/D Screw & Barrel Wear

(Due to improper barrel temperature profile)



Two Stage Screw Technology

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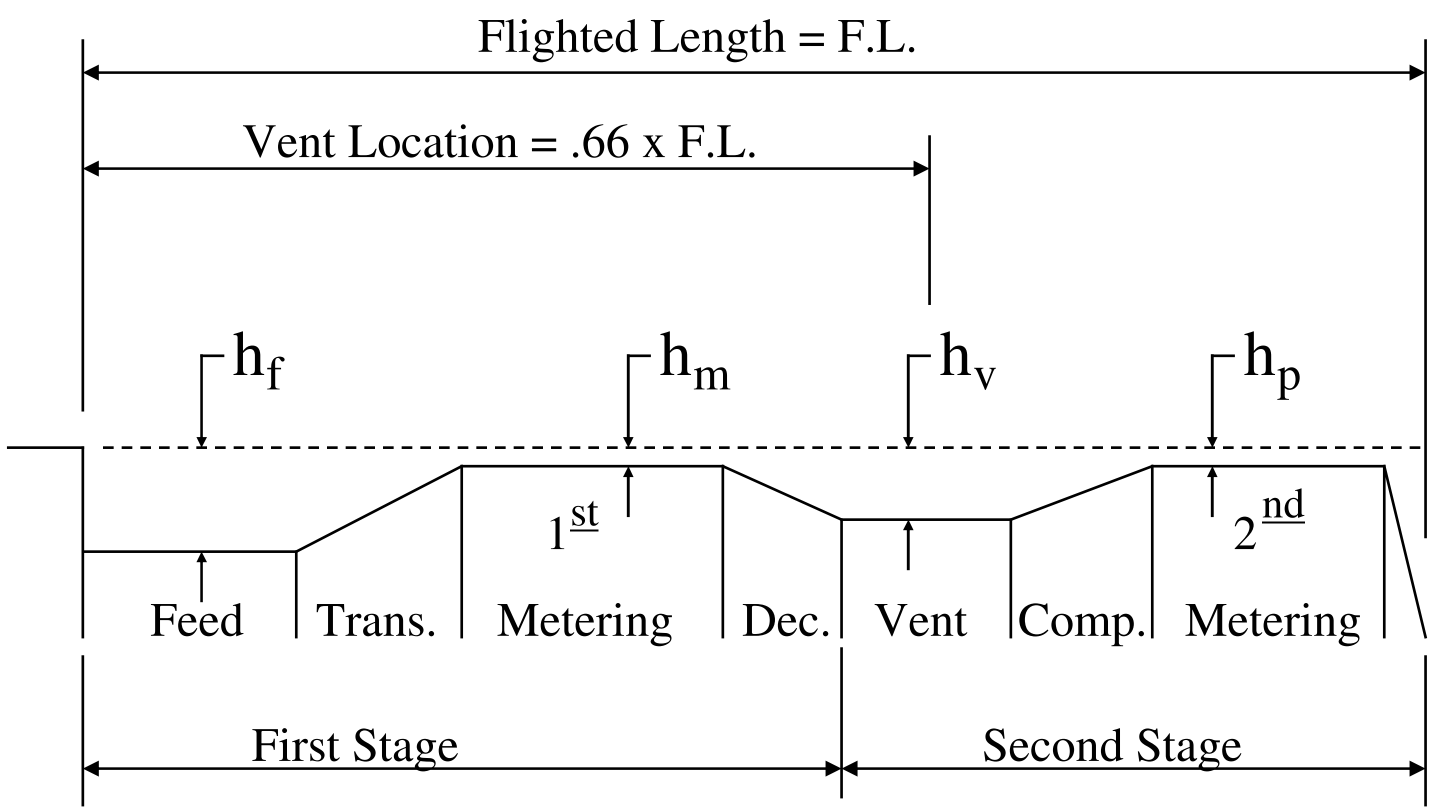
Two Stage Nomenclature



Features of Two Stage Screws

- Primary Purpose is for Devolitization or Venting for the removal of Moisture and /or gases.

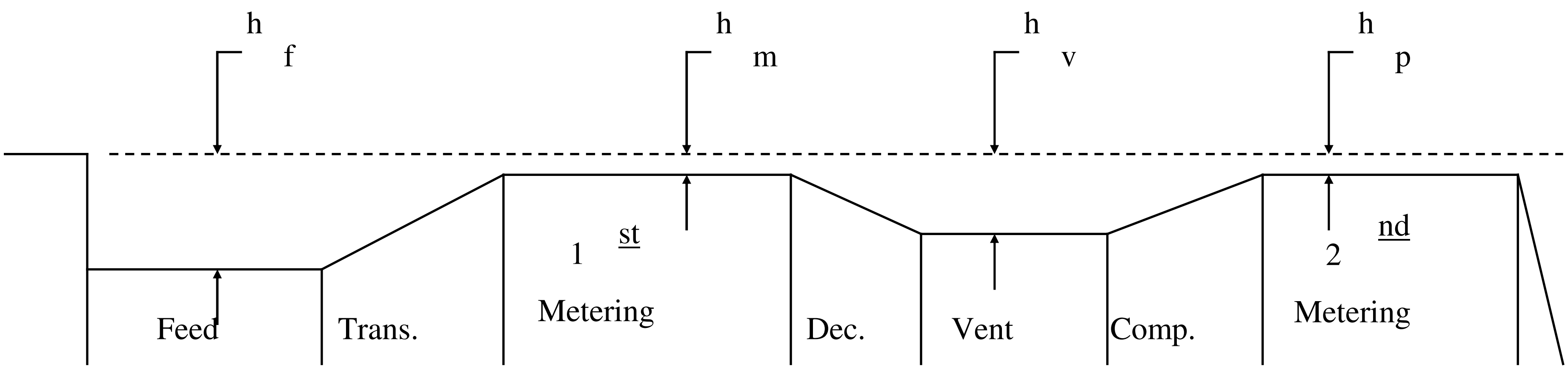
- Typical L/D of Two Stage screws are 32:1 to 36:1 L/D with extremes of 24:1 L/D to 40:1 L/D and longer.

- Throughput Rates of Two Stage Screws is typically 2/3 of an equivalent length Single Stage Screw.

Design Requirements for Two Stage Screws

- Rheological data - for any design is essential.
- What is the typical headpressure?
- Is a melt pump being used in the system?
- Is the vent being operated with a vacuum or is it being vented to atmosphere?

Two Stage - Pump Ratio



Old Method

$$\text{Pump Ratio} = \frac{h_p}{h_m} = 1.6$$

Correct Method

$$\text{Pump Ratio} = \frac{Qnet_{ss}}{Qnet_{fs}}$$

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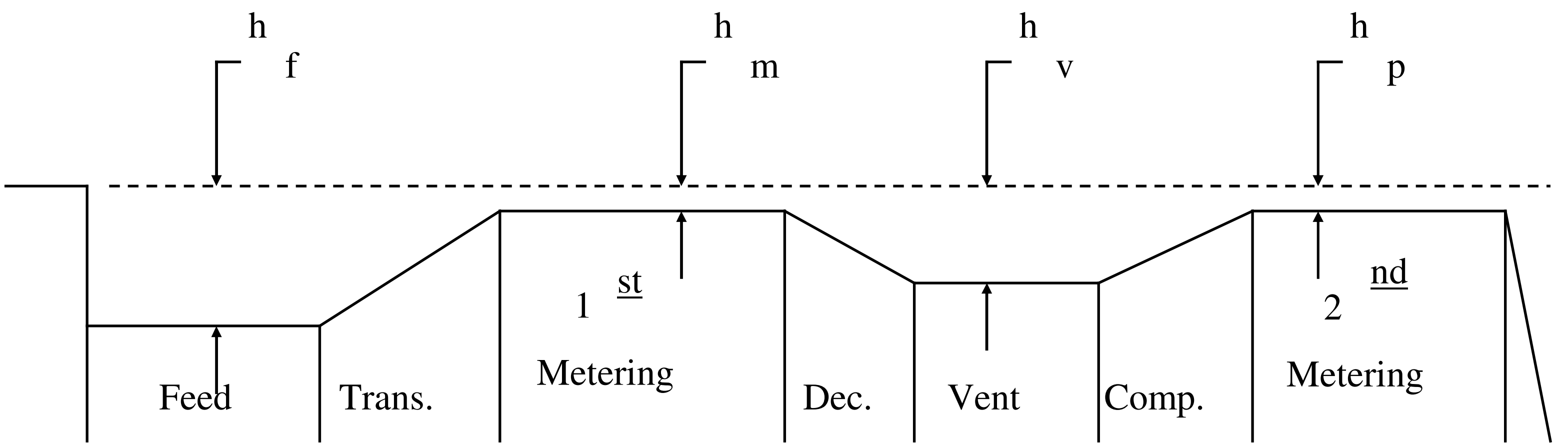
Two Stage - Compression Ratio



$$\text{First Stage C/R} = \frac{h_f}{h_m} \qquad \text{Second Stage C/R} = \frac{h_v}{h_p}$$

NOTE:

Typically the Second Stage Compression Ratio is between 2:1 and 2.5:1

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Conclusion

- Make sure you provide your screw manufacturer with good resin information.
- Understand how the mechanics of a screw's design functions.
- Hopefully this presentation has help make everyone here a little more knowledgeable in the functions of a feedscrew.

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Thank You !