A Novel Flexible Extrusion Platform for Energetic Material Processing

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History

- 100+ Years Batch Technology
- Low Specific Energy, Extensive Mixing, Slow Reaction
- Few Successful Continuous Mixing Production Programs
    - Polaris
    - Air Bag
    - LOVA
- Estimated @ 97% Batch
- Early Attempts at Processing Likely Premature
- Several Incidents
    - Early Development Empirical
    - Higher Specific Energy
    - Intensive and Extensive Mixing
    - Fast Reaction
    - Poor Understanding of Specific Interactions

Properties

- Materials Must ignite to serve the intended purpose
  - Controlled ignition Good
  - Unintended ignition Unacceptable

- Materials Are Sensitive to Ignition Stimulated by
  - Impact
  - Friction
  - Electrical Discharge
  - Pressure
  - Thermal Excursions

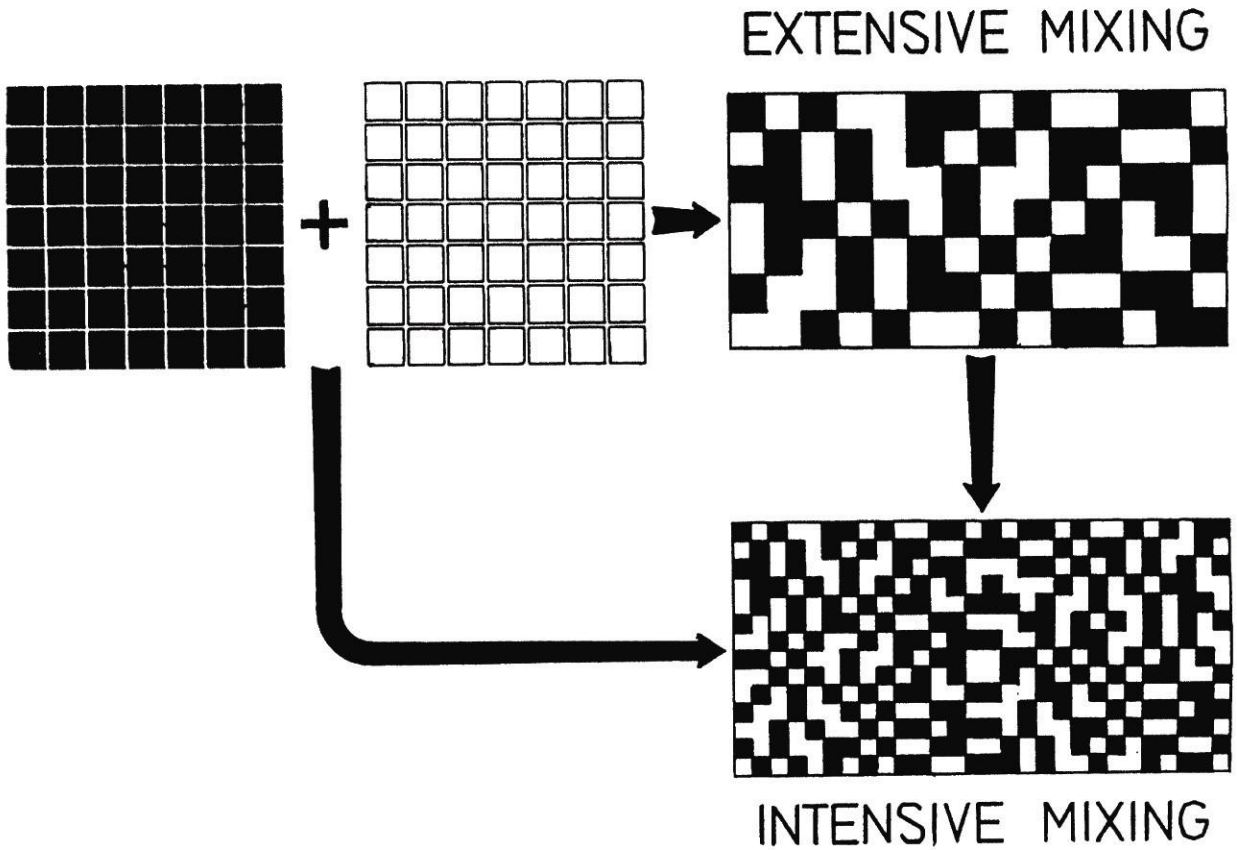
Significant Challenges, why adapt.

Benefits

- Higher Productivity
- Lower in Process Volume
- Superior Goodness of Mix (Extensive Mixing)
- Uniformity and Repeatability
- Mix, Devolatilize / Deairate, Form in Same Machine
- Lower Personnel Exposure
- Better Process Control (Surface to Volume Ratio)
- Capability to do more Unique Formulations (High Specific Energy, Intensive Mixing)

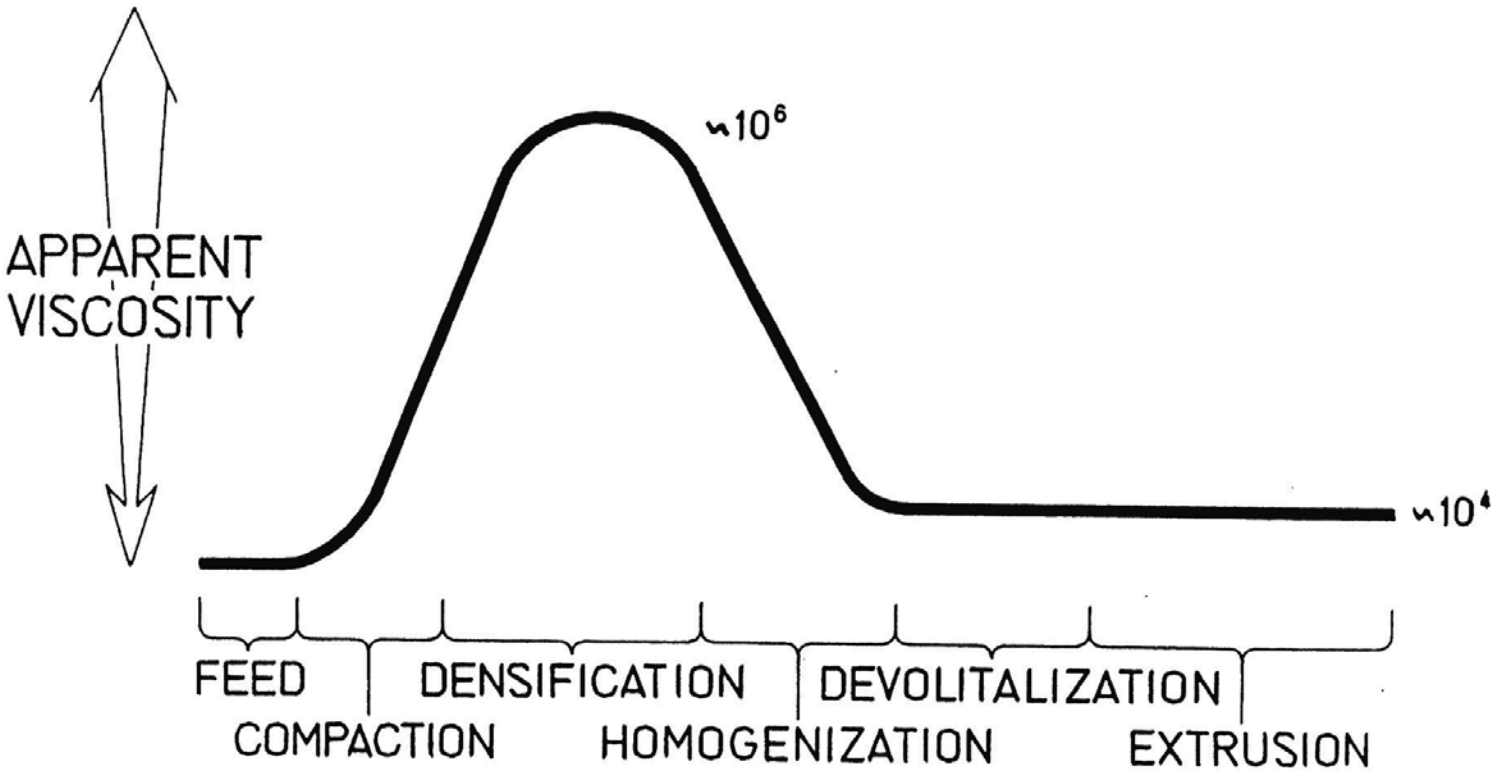
Types of Continuous Mixing / Extrusion Equipment

- Single Screw Extruders
- Co-Rotating Fully Intermeshing Twin Screw Mixer / Extruders
- Counter Rotating Fully Intermeshing Twin Screw Mixer/ Extruders
- Co-Rotating Tangential Twin Screw Mixer / Extruders
- Counter Rotating Tangential Twin Screw Extruders



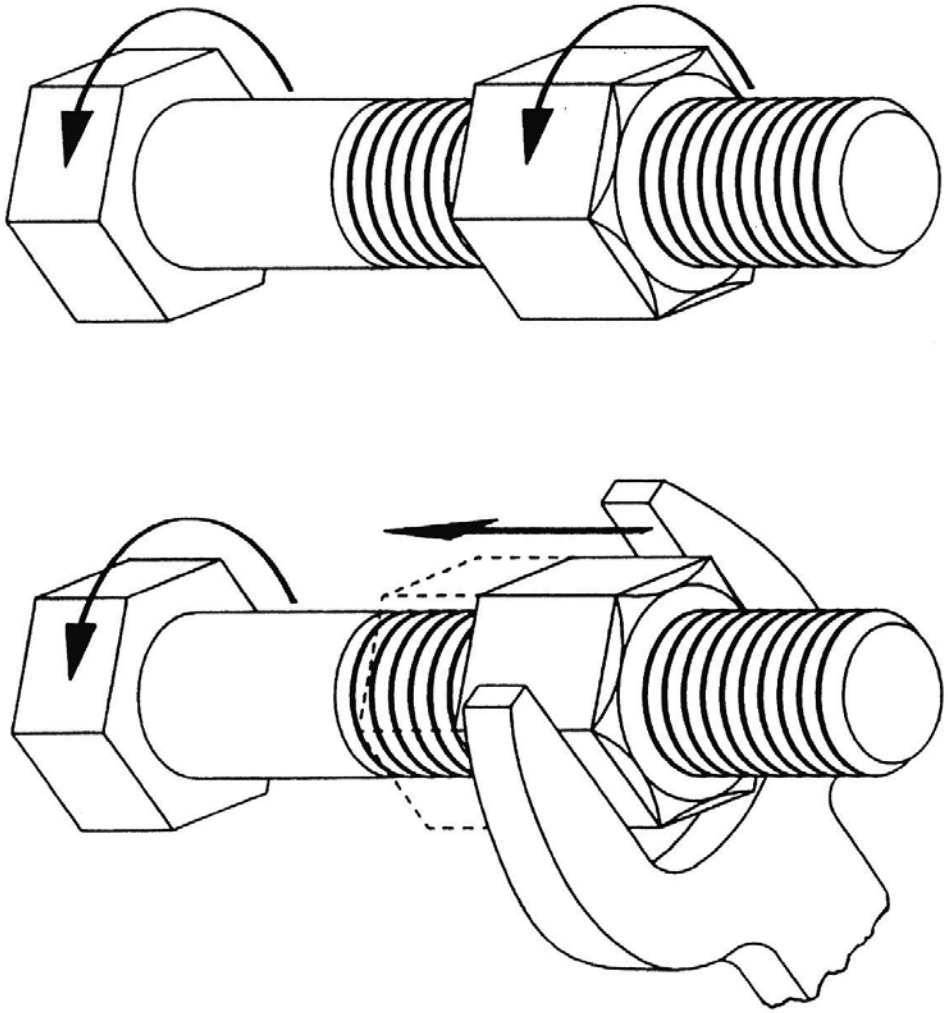
TYPES OF MIXING

Most Energetic Materials Require Only Extensive Mixing. Intensive Mixing Imparts High Specific Energy to the Product.



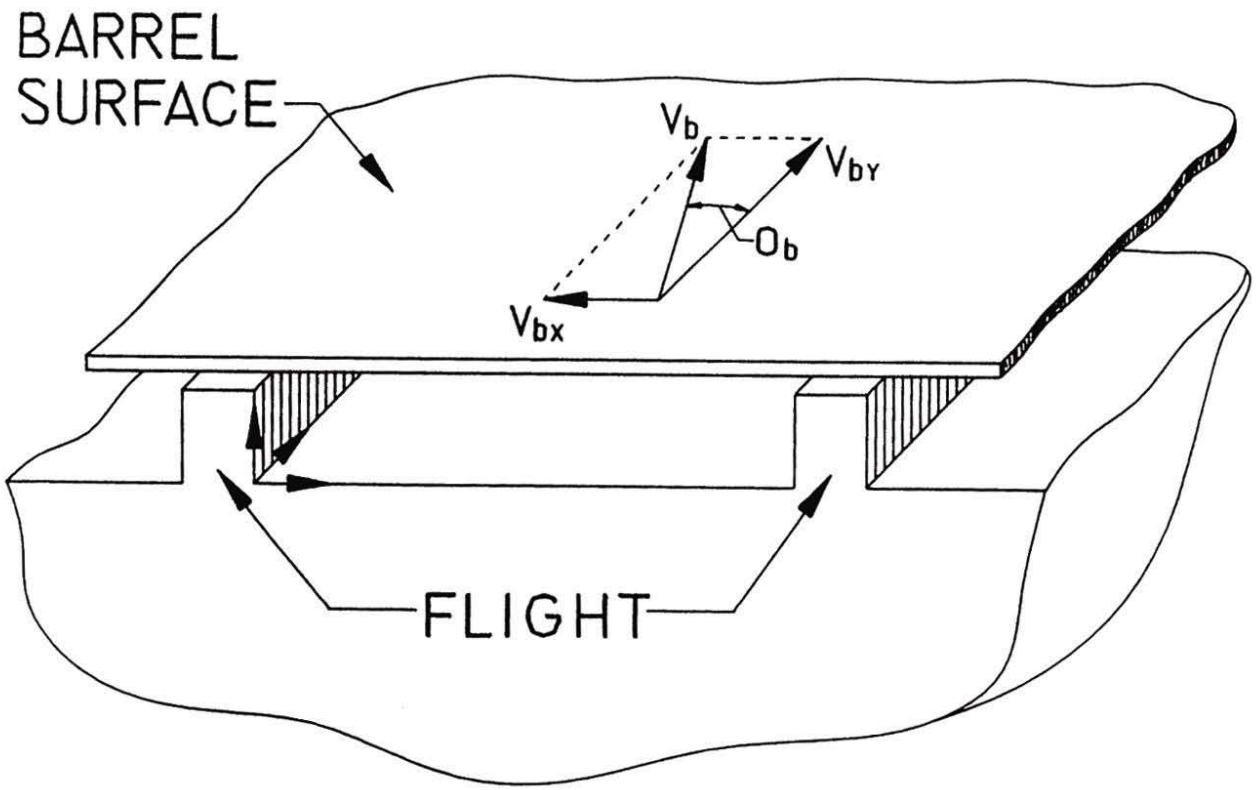
TYPICAL MIX PROFILE

Basic Interactions of a Typical Mixer Extruder System



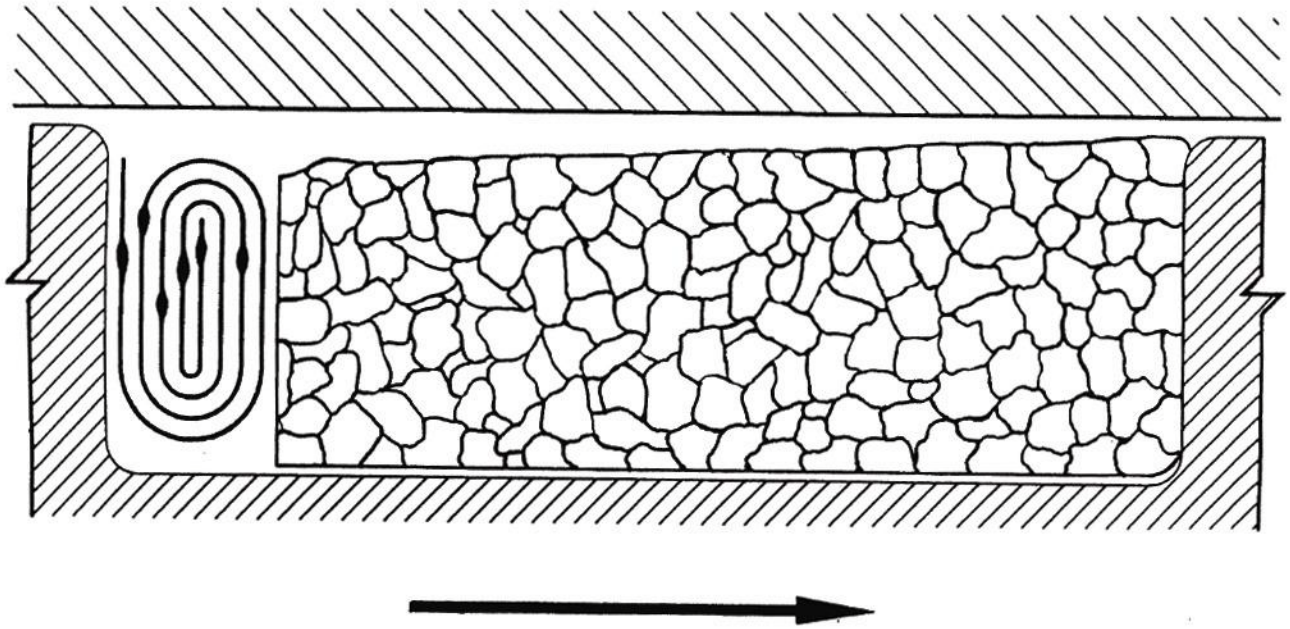
DRAG FLOW

Adhesion to the Wall is Critical for the Transport of Materials in a Drag Flow Device.



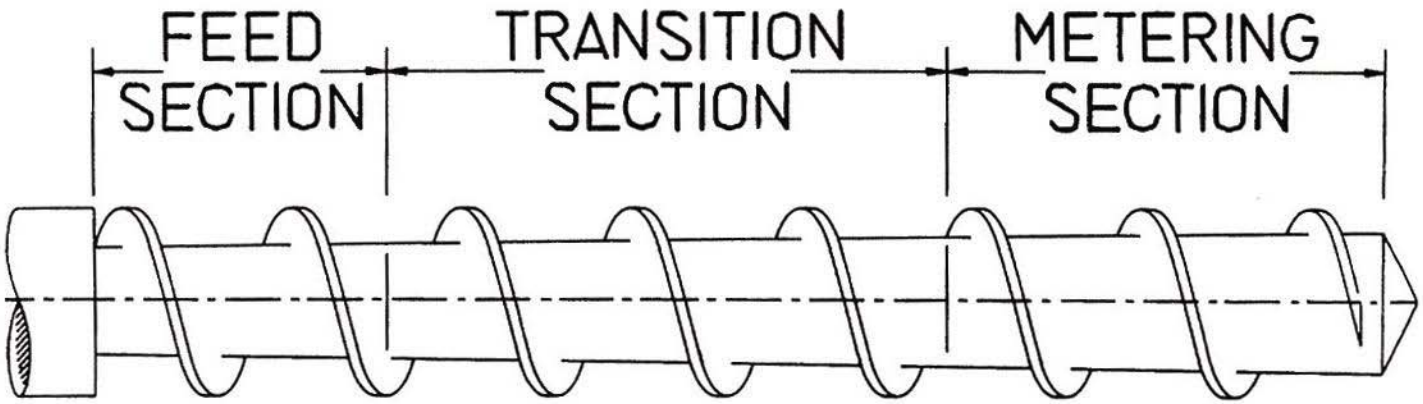
DRAG FLOW PRINCIPLE

Drag Flow Imparts Both Axial and Radial Velocity to the Process Materials.



PRESSURE FLOW, CROSS CHANNEL MIXING PRINCIPLE

In a Simple Drag Flow Device Such as a Single Screw Extruder, Both Extensive and Intensive Mixing are Achieved by Re-Circulation in the Channel



TYPICAL SINGLE SCREW EXTRUDER

Simple Single Screw Extruder Screw Design will have a Feed Section, Mixing or Transition Section and Extrusion Section

Single Screw Extruder

Pros:

Simple

Good Pressure Generation Capability for Extrusion

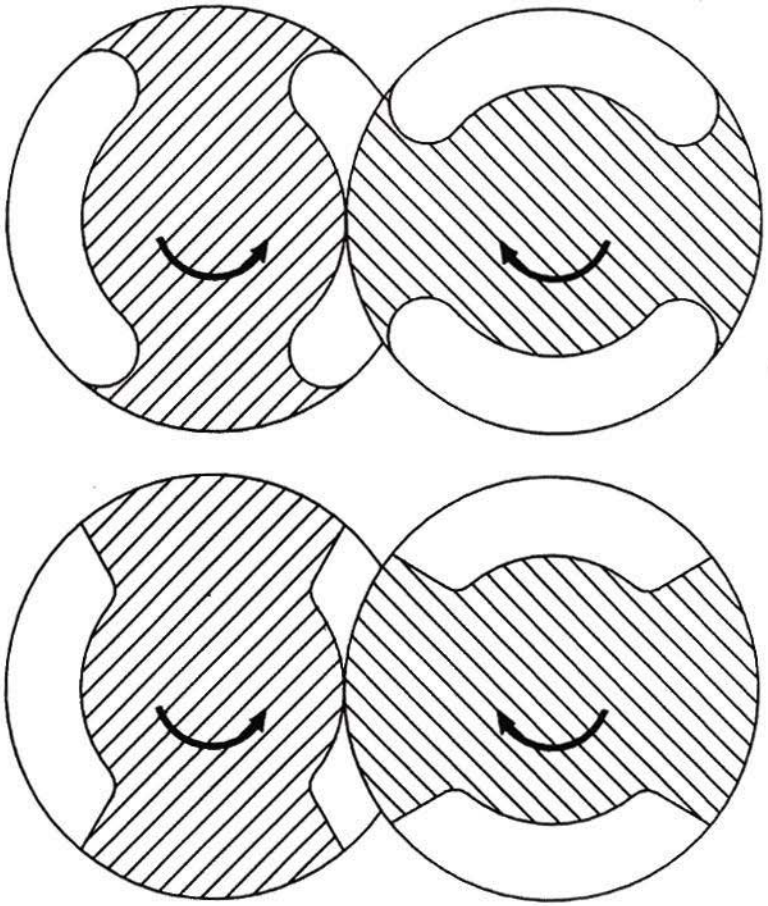
Capacity for unlimited Screw Geometries

Cons:

Strictly Drag Flow

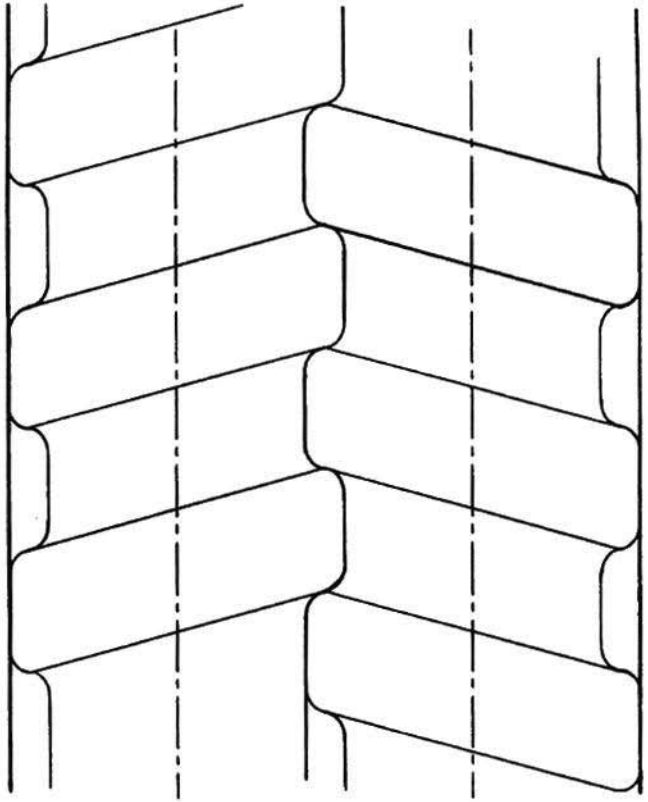
Poor Extensive Mixer (Needs Long L/D to be Effective)

Difficult to De-airate



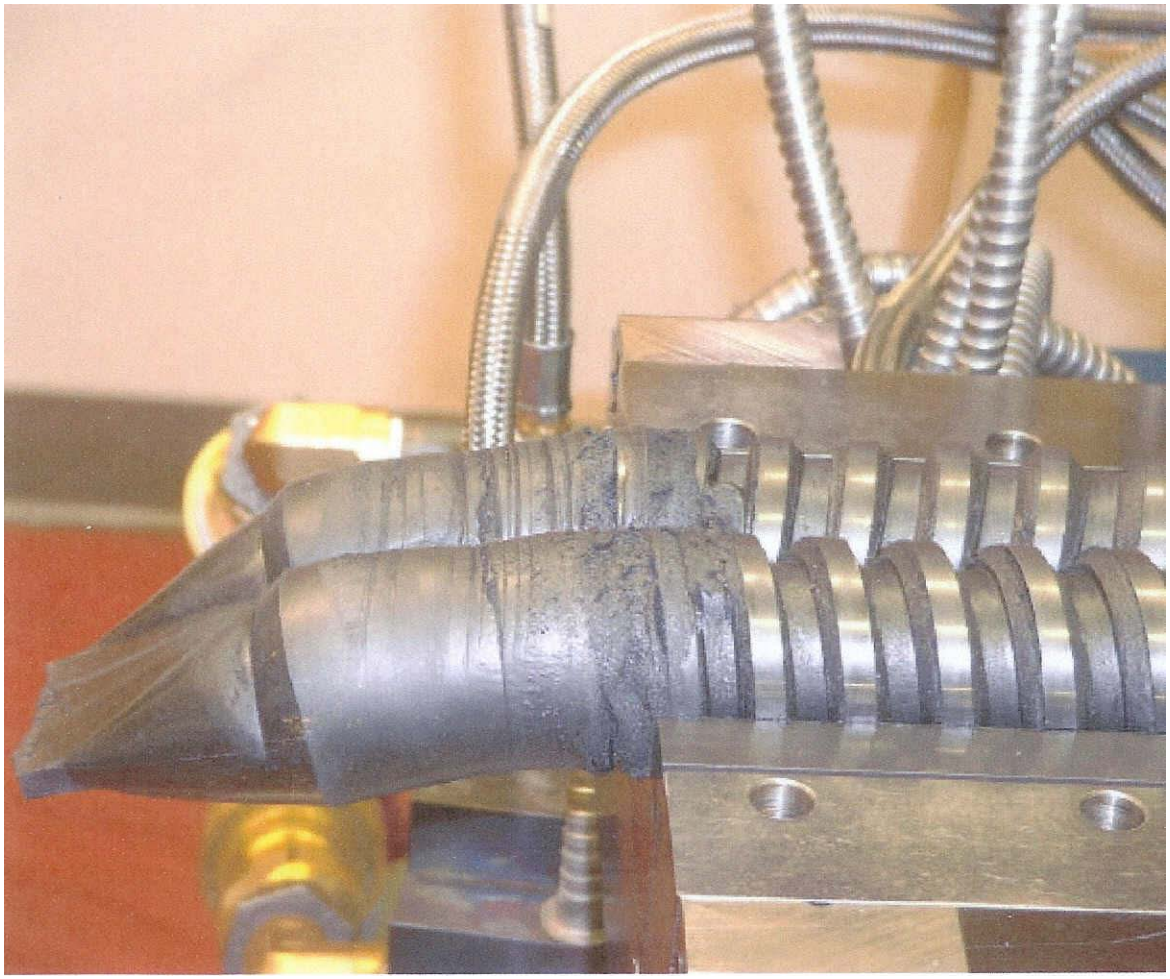
COUNTER ROTATING SCREWS

Closed Channels promote Positive Displacement, but no Cross Channel Mixing to Smooth Feed Irregularities

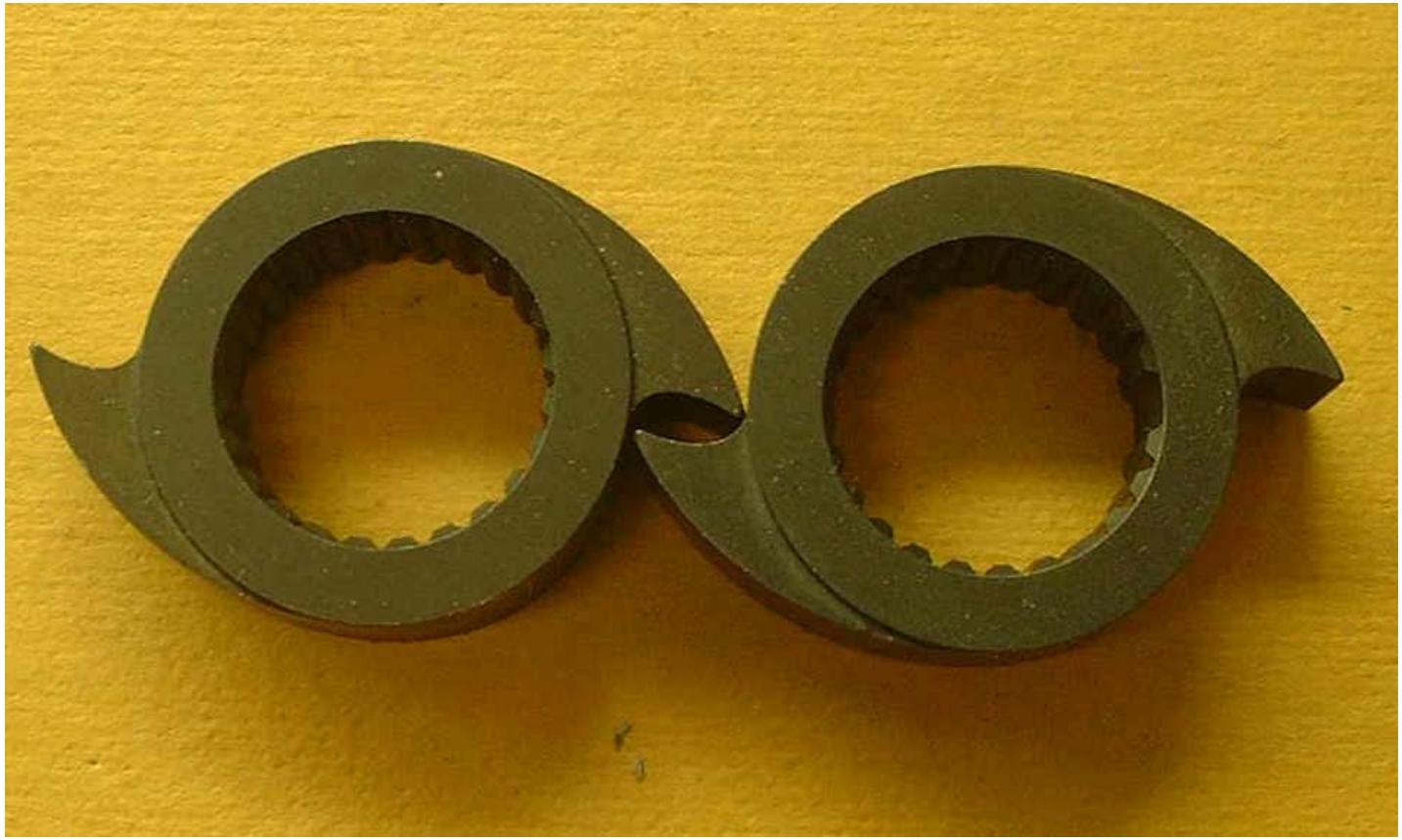


COUNTER ROTATING TWIN SCREW
CLOSED CHANNELS

Positive Displacement Gives Rise to High Pressure Capability for Extrusion

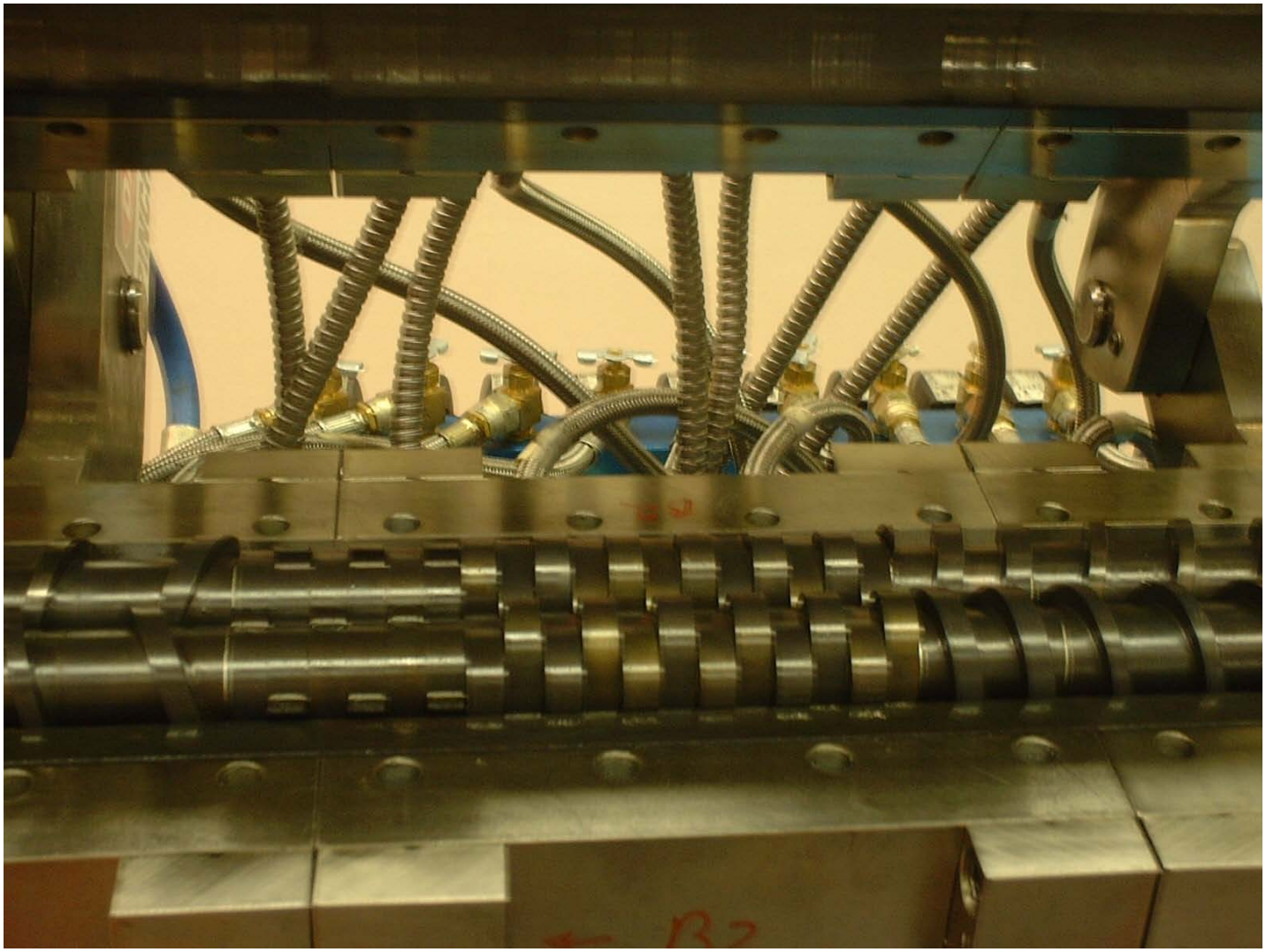


Counter rotating fully conjugal extrusion

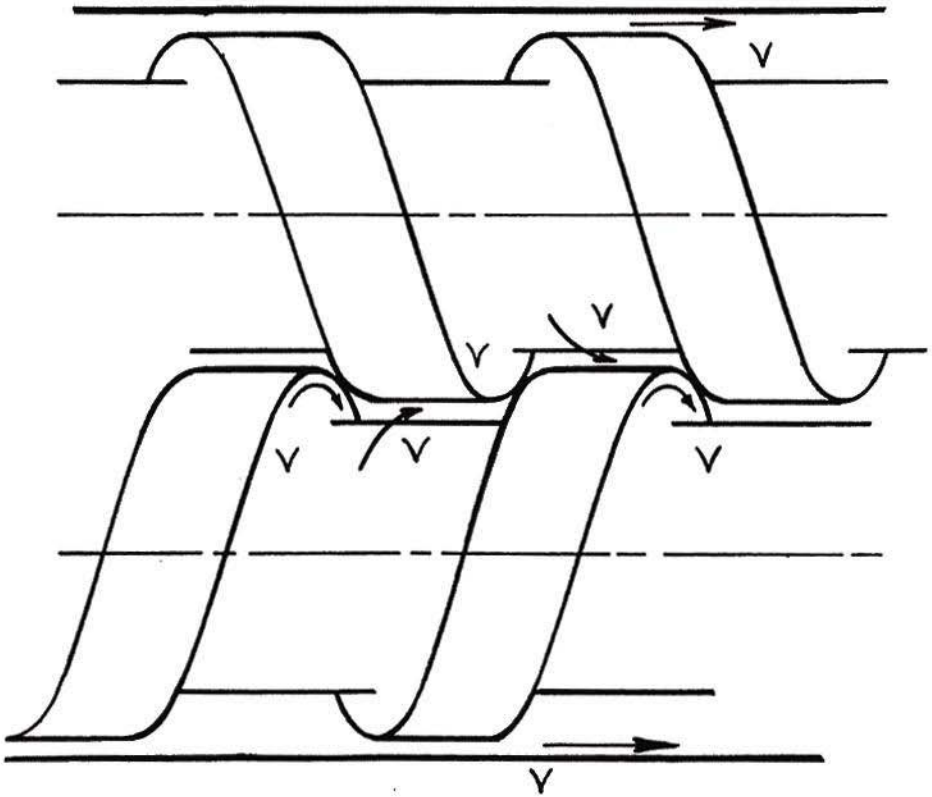


New Novel Individual Element Designs give Rise to Adding Extensive Mixing Capacity to Counter Rotating Machines

New Novel Individual Element Designs also add the Capacity for High Intensive Mixing Capability to Counter Rotating Machines



Extensive and Intensive Mixing Elements Counter Rotating



COUNTER ROTATING TWIN SCREW
CALLENDERING ACTION

Calender Action of the Screws in Counter Rotating Devices Introduce High Shear Areas and Shaft Deflections

Counter Rotating Twin Screw Extruder

Pros:

Positive Displacement (Good Extrusion Capabilities)

Capacity for Unlimited Screw Geometries

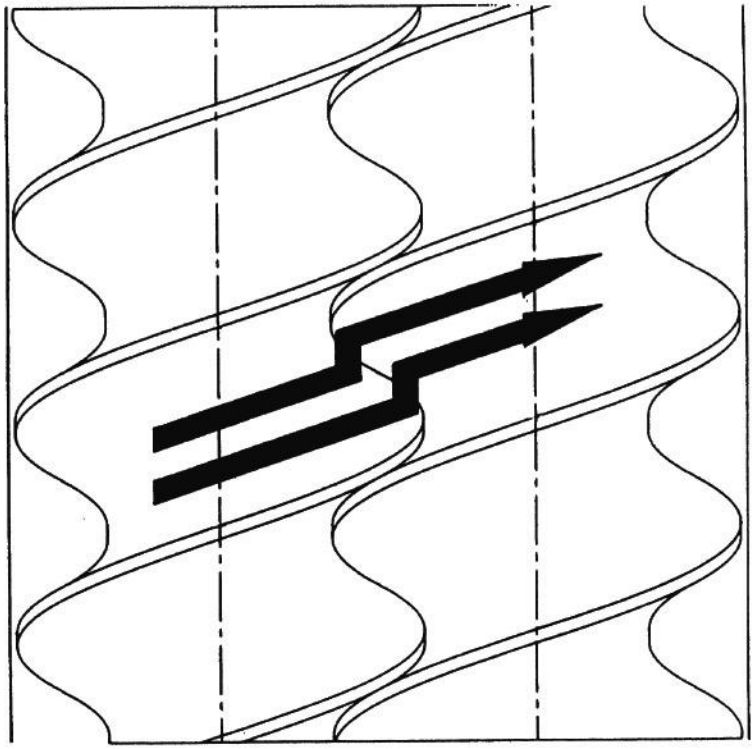
Excellent Self Feeding Capability

Cons:

Calender Action Can Create Local High Shear Areas

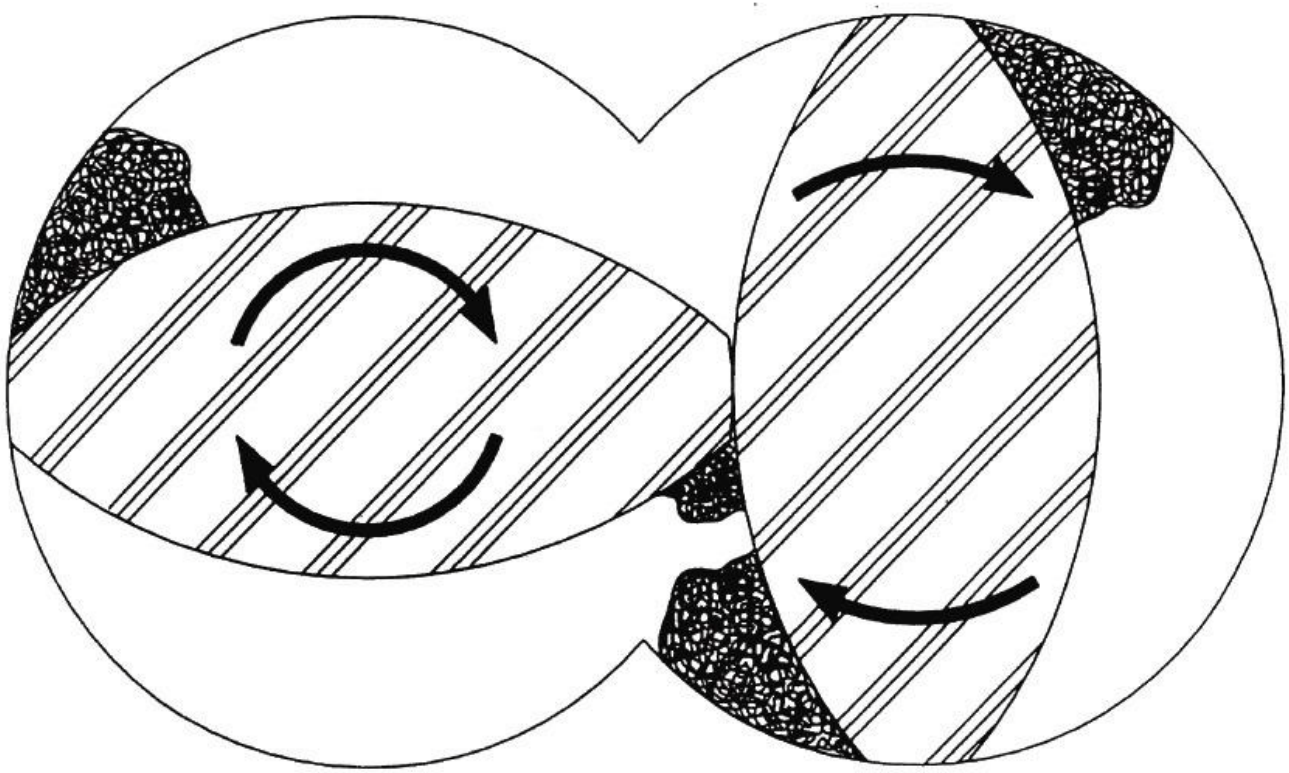
Separating Forces can Cause Significant Shaft Deflections

Little Back Mixing if it’s Kept Fully Conjugal



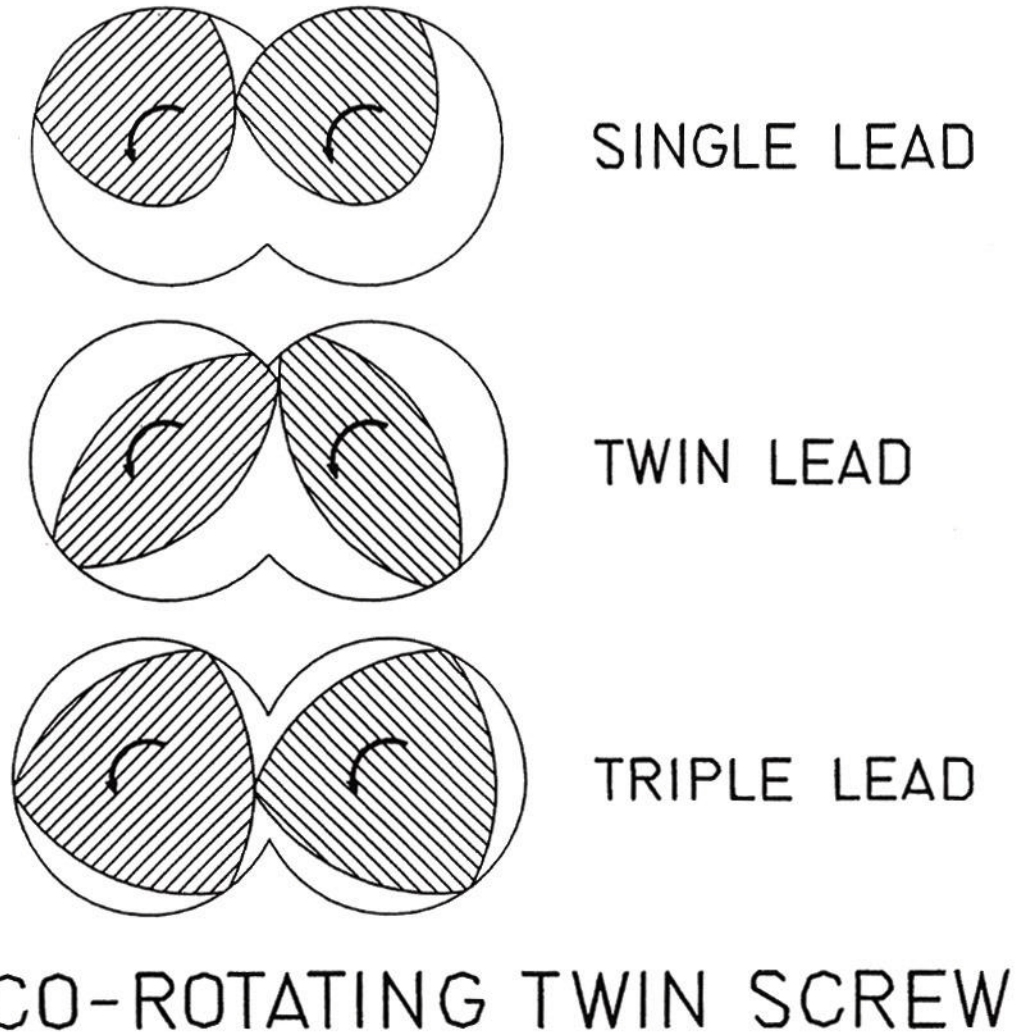
CO-ROTATING TWIN SCREW
OPEN CHANNELS

Co-Rotating Twin Screws are Drag Flow Devices with Large Open Channels for Mixing

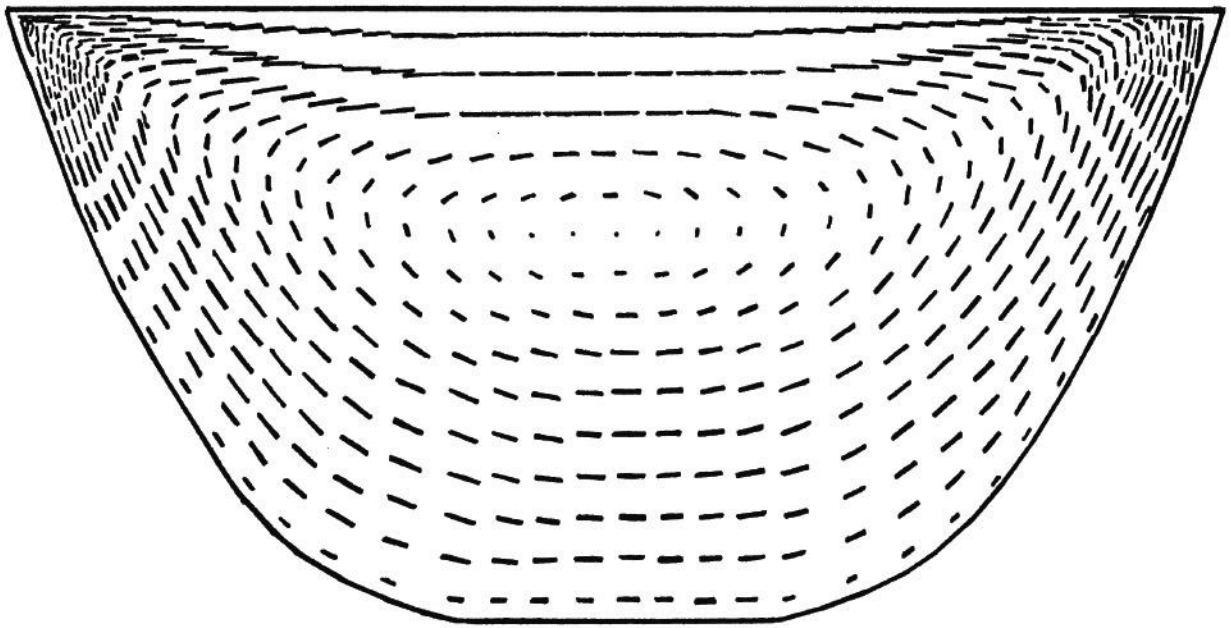


CO-ROTATING TWIN SCREW

The Interaction of the Screws Reduce the Possibility of Cylindering due to High Velocity Wall Slip



Varying Intermeshing Geometries Offer Different Degrees of Open Volume for Mixing and Extrusion



CO-ROTATING TWIN SCREW
CROSS CHANNEL FLOW

As with all Screw Extruders There is an Interchannel Flow Pattern the Co-Rotating Machine also has a significant Cross Channel Flow Which aids in Back Mixing

Typical Screw Geometries for Co-Rotating Twin Screw

Co-Rotating Twin Screw Extruder

Pros:

Large Open Channels for Extensive Mixing

Good Back Mixing as Drag Flow Device

Interrupted Radial Flow Prevents Cylindering

Good Capacity to Deairate or Devolatilize

Cons:

Poor Extrusion Capability due to Large Open Channels

Limited Screw Geometries if Kept Fully Conjugal

Tangential

Counter and Co-Rotating

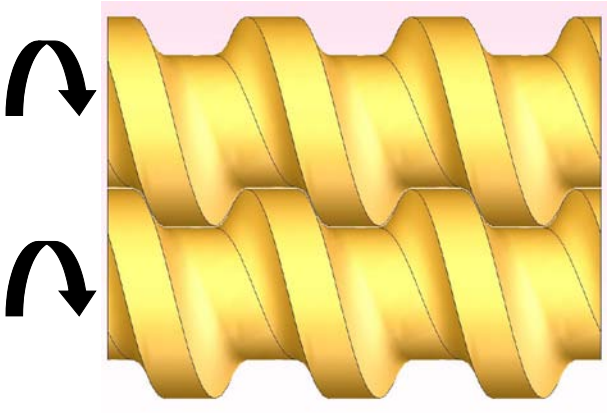
Machines

These are Simply Single Screw Extruders Side by Side Which Offer the opportunity to Interchange the Process Material From One Screw to the Other, Giving the System More Back Mixing Capacity.

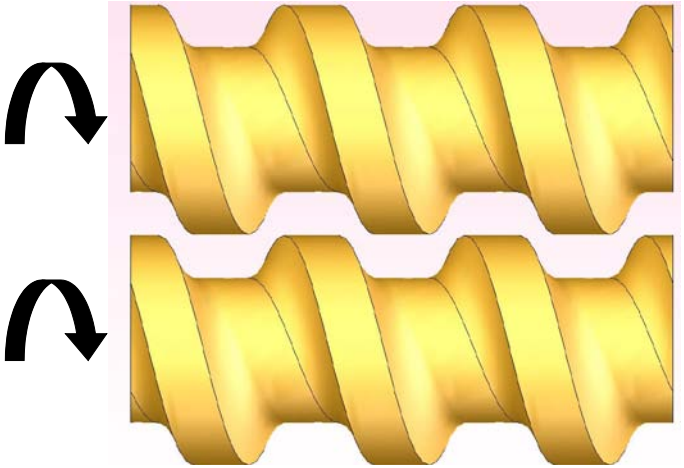
Which System to Use ?

Answer!

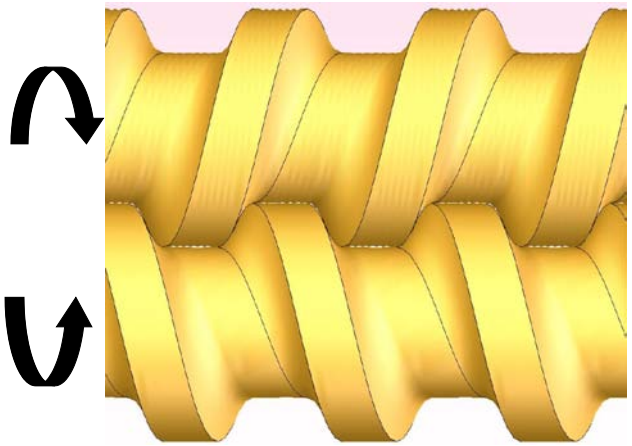
A New Novel Platform
That Incorporates all of
These Technologies



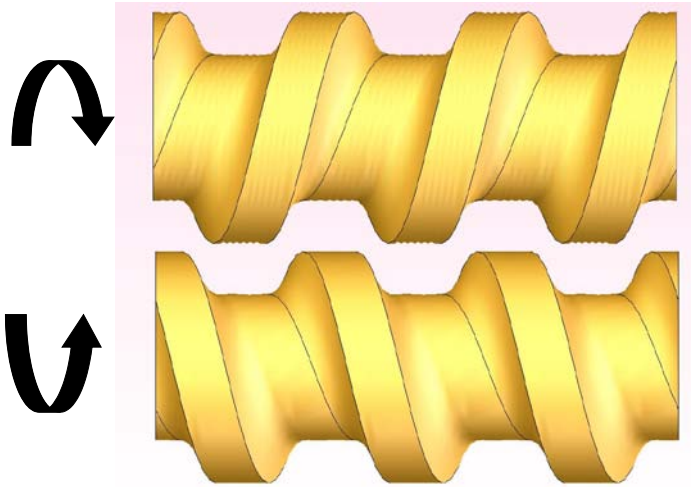
(a) Co-rotating fully intermeshing twin screws.



(b) Co-rotating tangential twin screws.

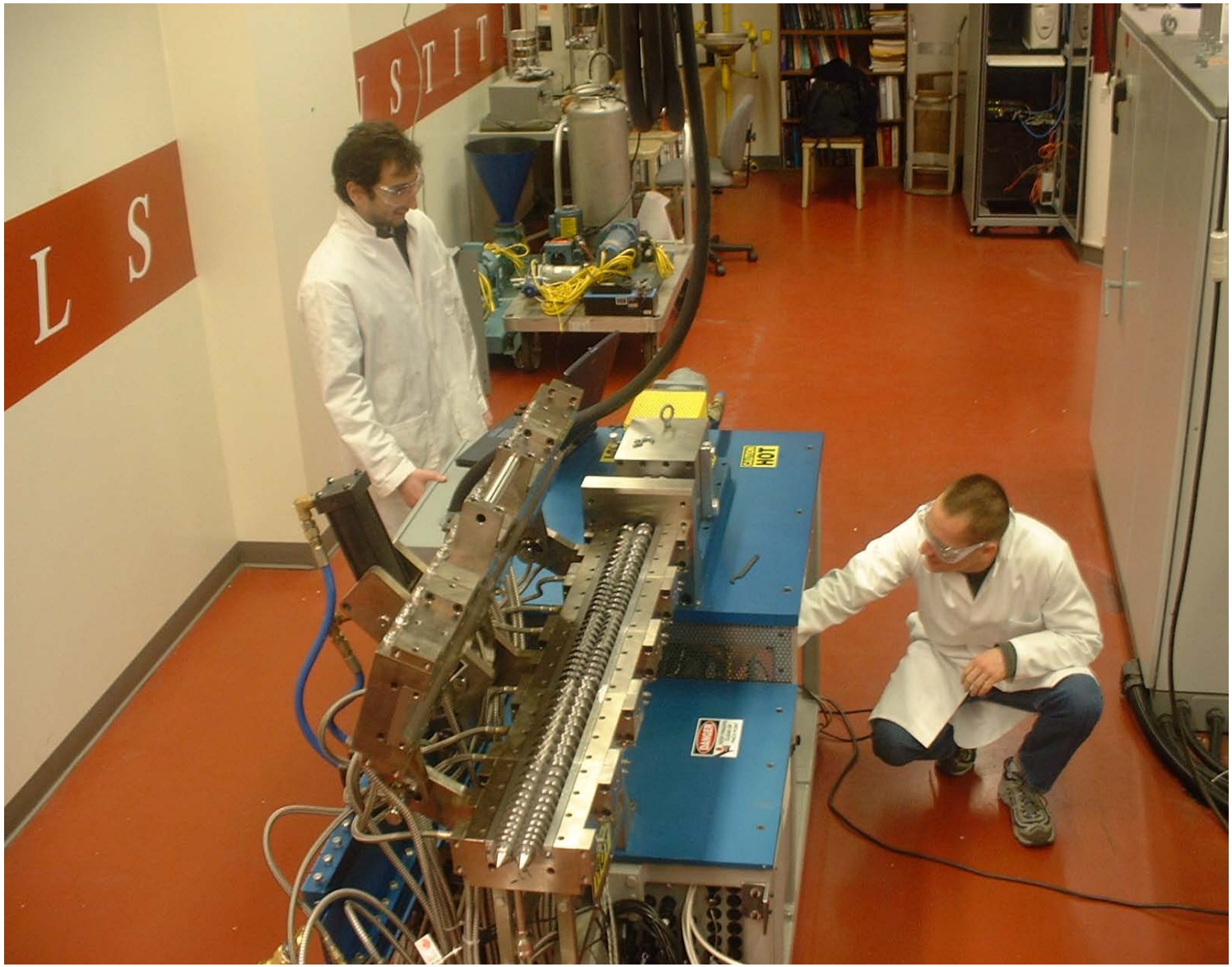


(c)Counter-rotating fully intermeshing twin screws.

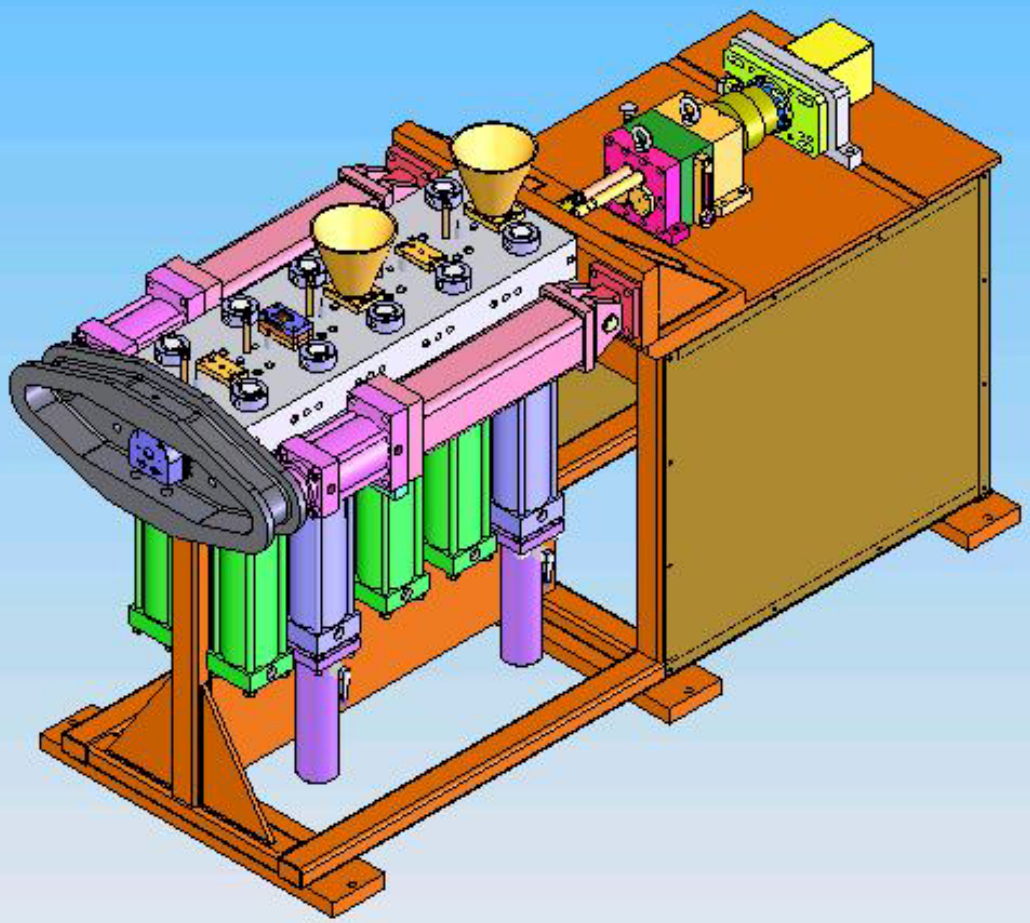


(d) Counter-rotating tangential twin screws.

MPR Universal extrusion platform on the counter rotating mode



MPR Universal extrusion platform on the counter rotating mode



Energetic Version of Universal

Energetic version of Universal beginning assembly

Solution

Define Critical parameters in specific sections of the process, Control these through design of equipment, process design and process controls.

Start with

Rheological Characterization

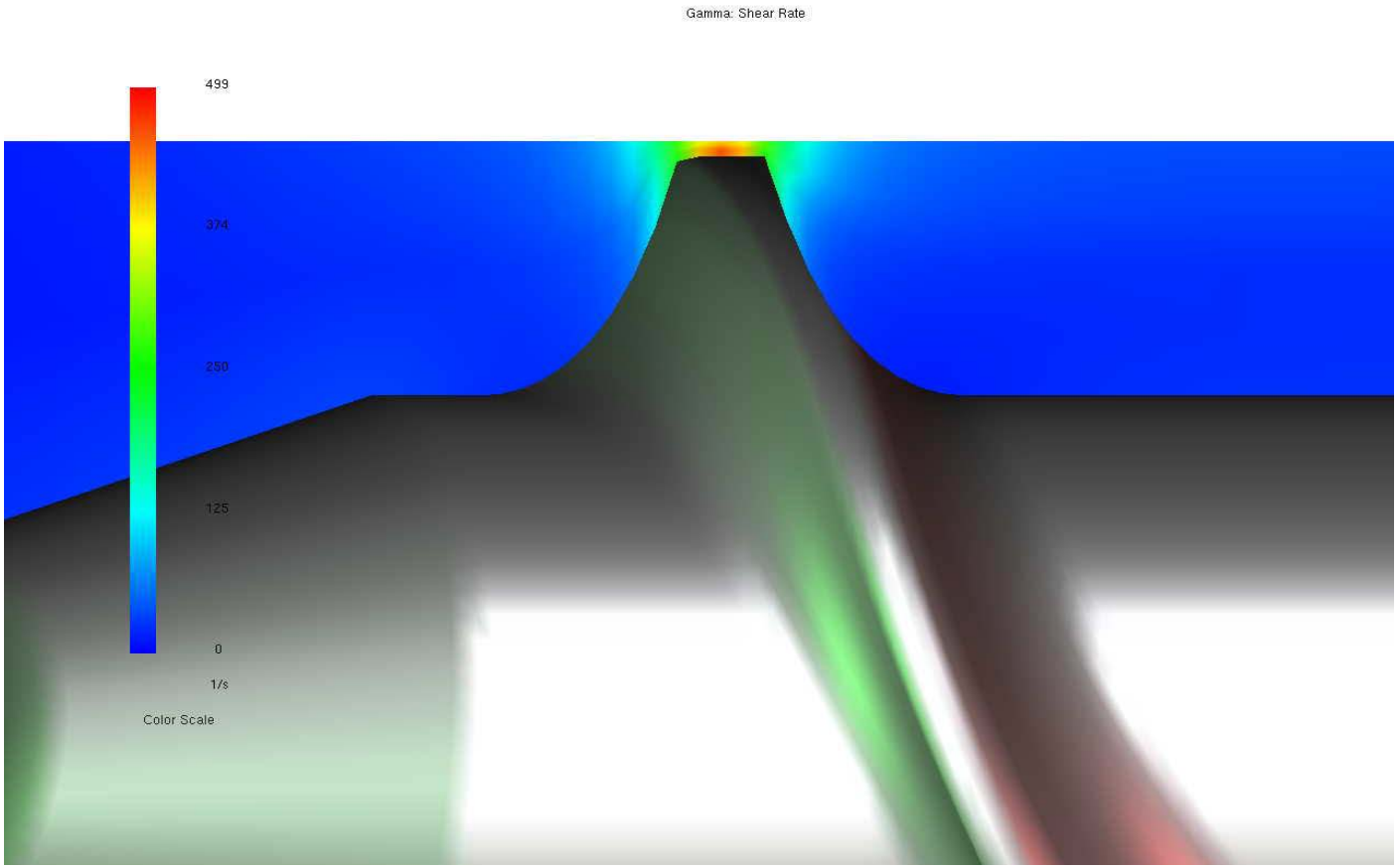
(Physical Properties as a function of Shear Rate, Shear Stress,Thermal Excursions, Wall Slip Etc.)

Define Sensitivity Characteristics

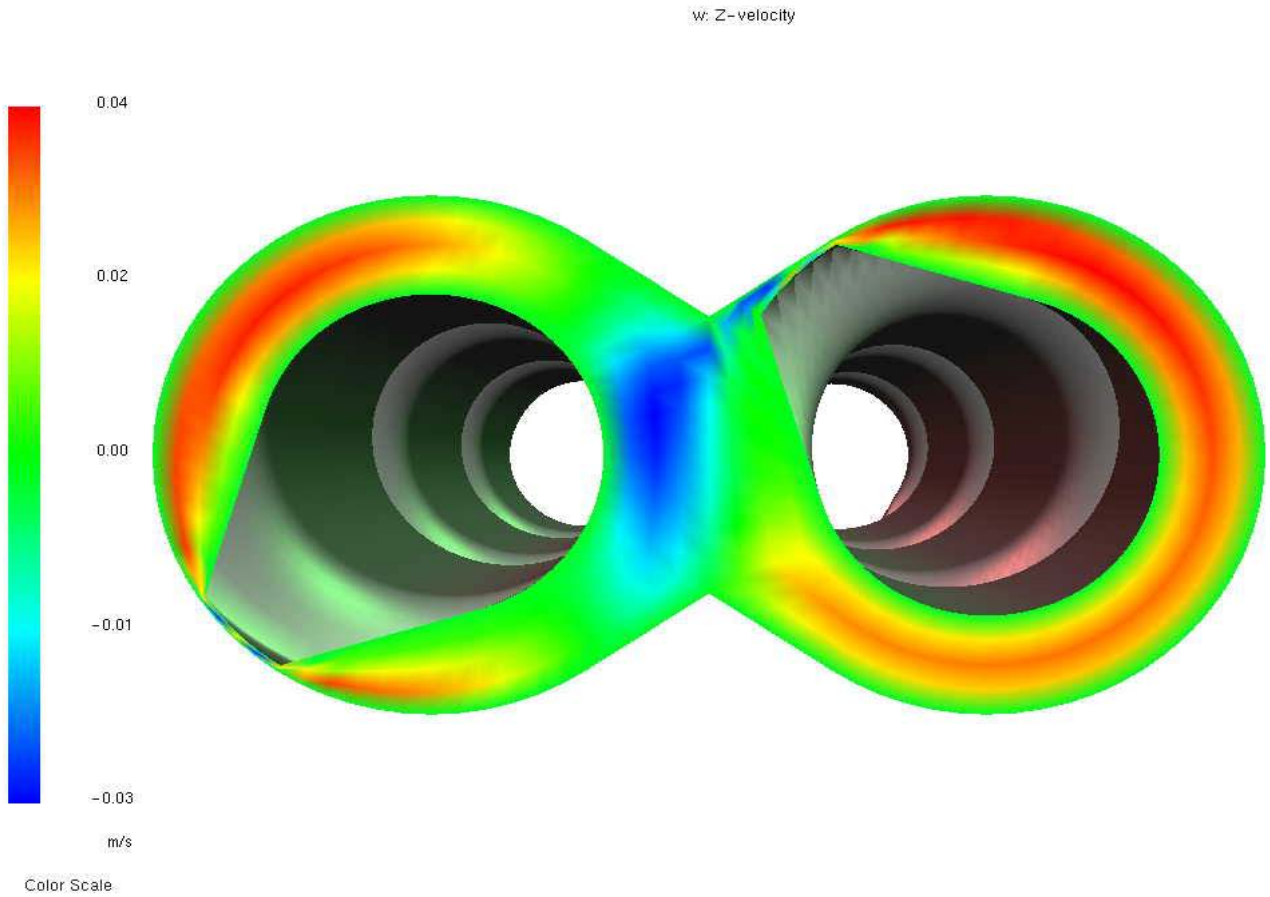
(as a function of Impact, Friction, Electrical Charge, temperature and Pressure)

Model

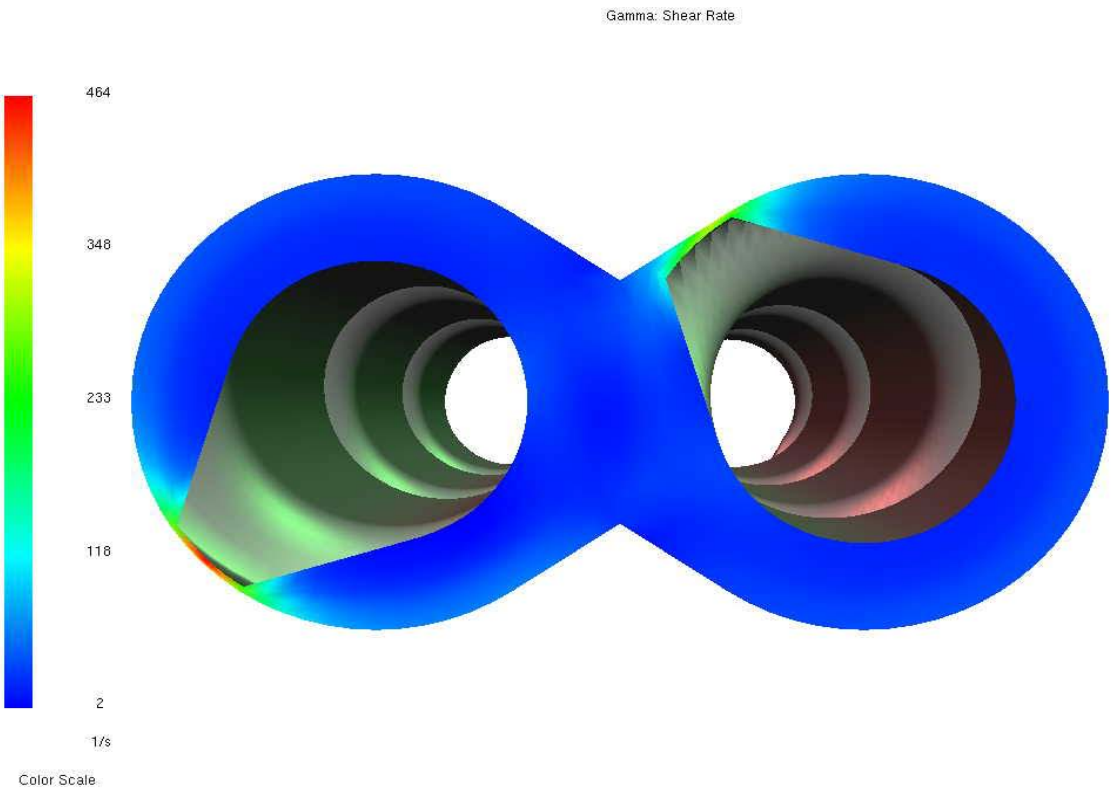
- With Basic Data in Hand, It’s possible to model the process and design the equipment to suit the application.
- Accurate models in development for over a dozen years.
- Newer Models more sophisticated and precise



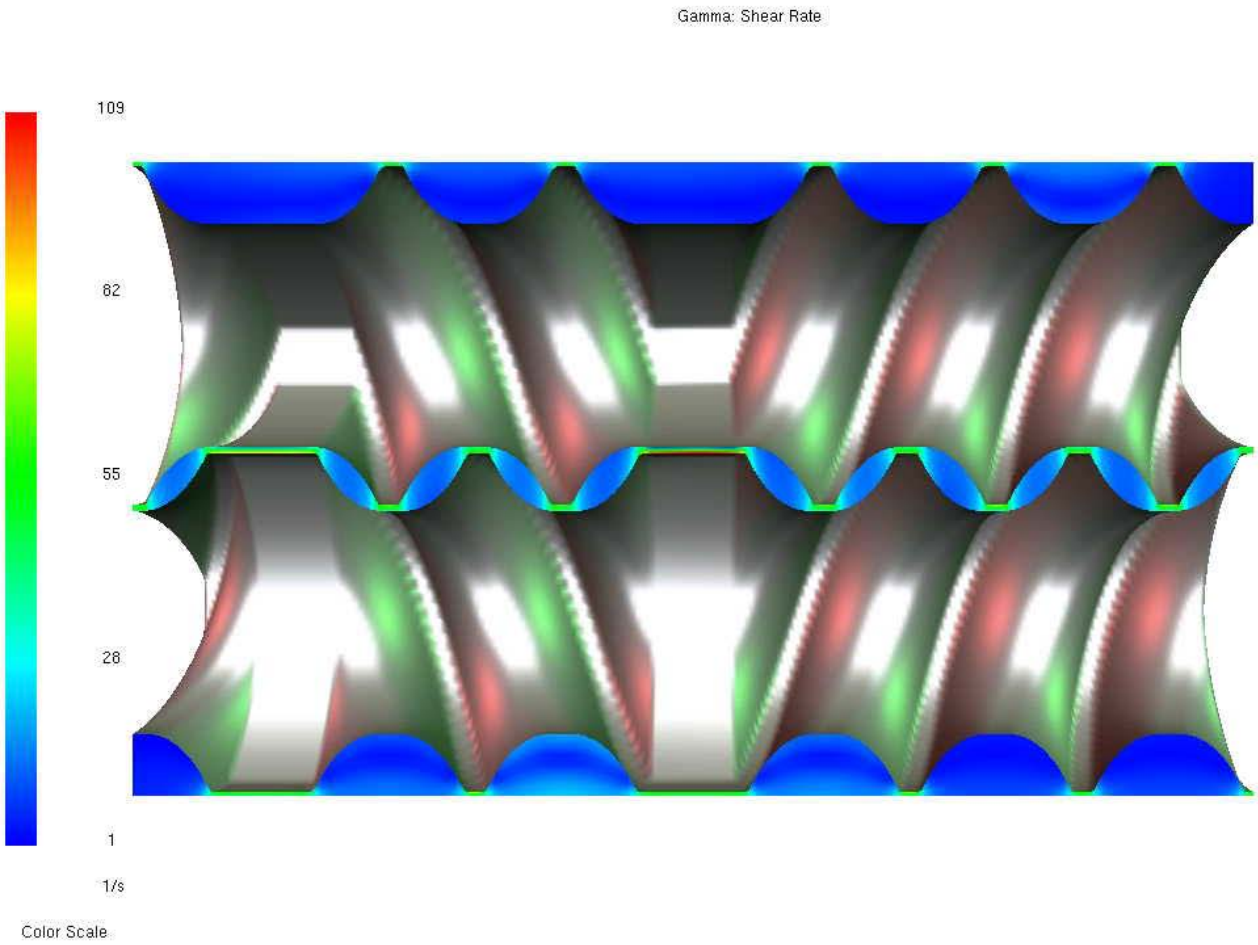
Shear rate distribution at the flight barrel interface:
100 RPM at 180°C in, 72.3 lb/hr, peak pressure = 271 psi



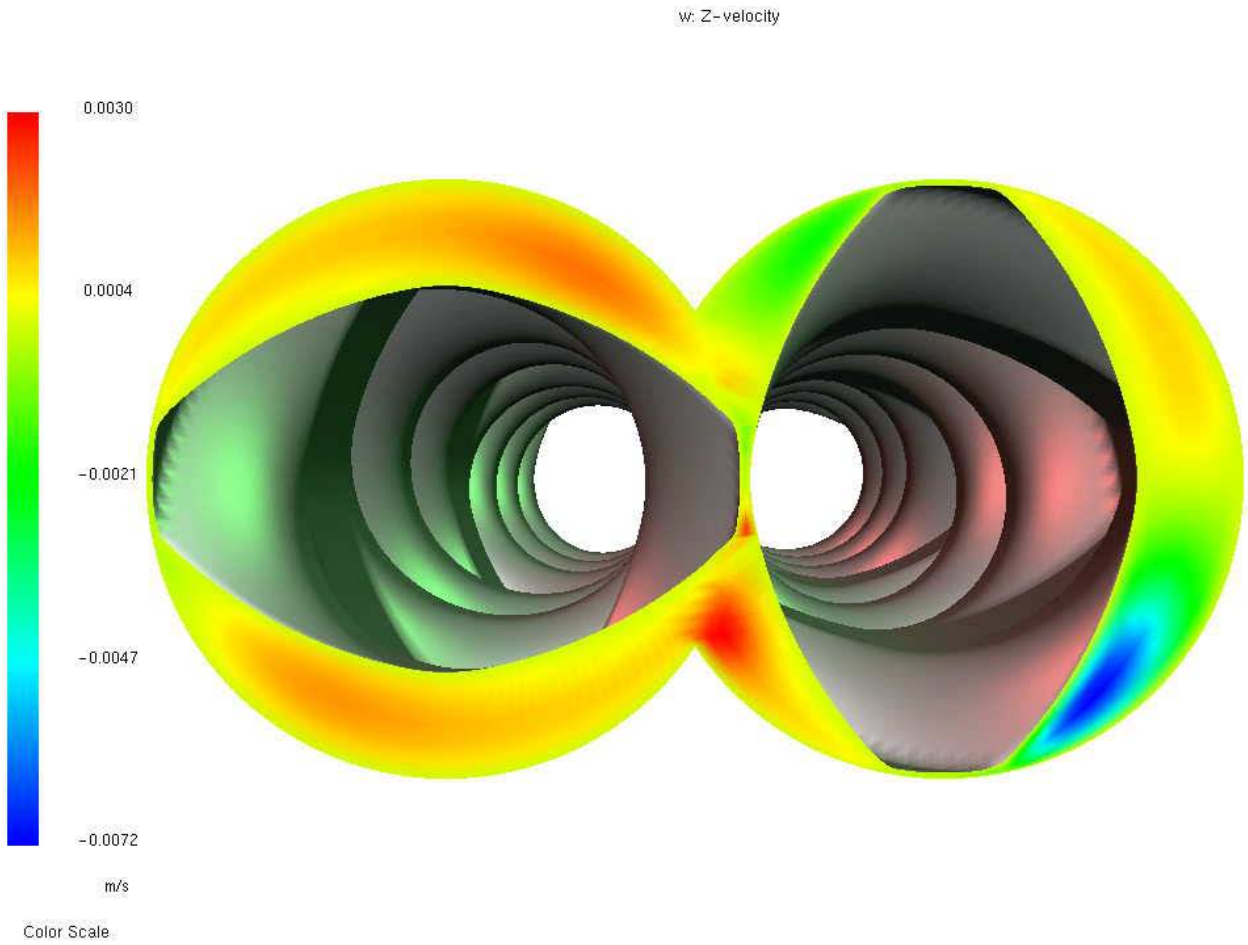
Z-velocity distribution in the screw channel:
100 RPM at 180°C in, 72.3 lb/hr



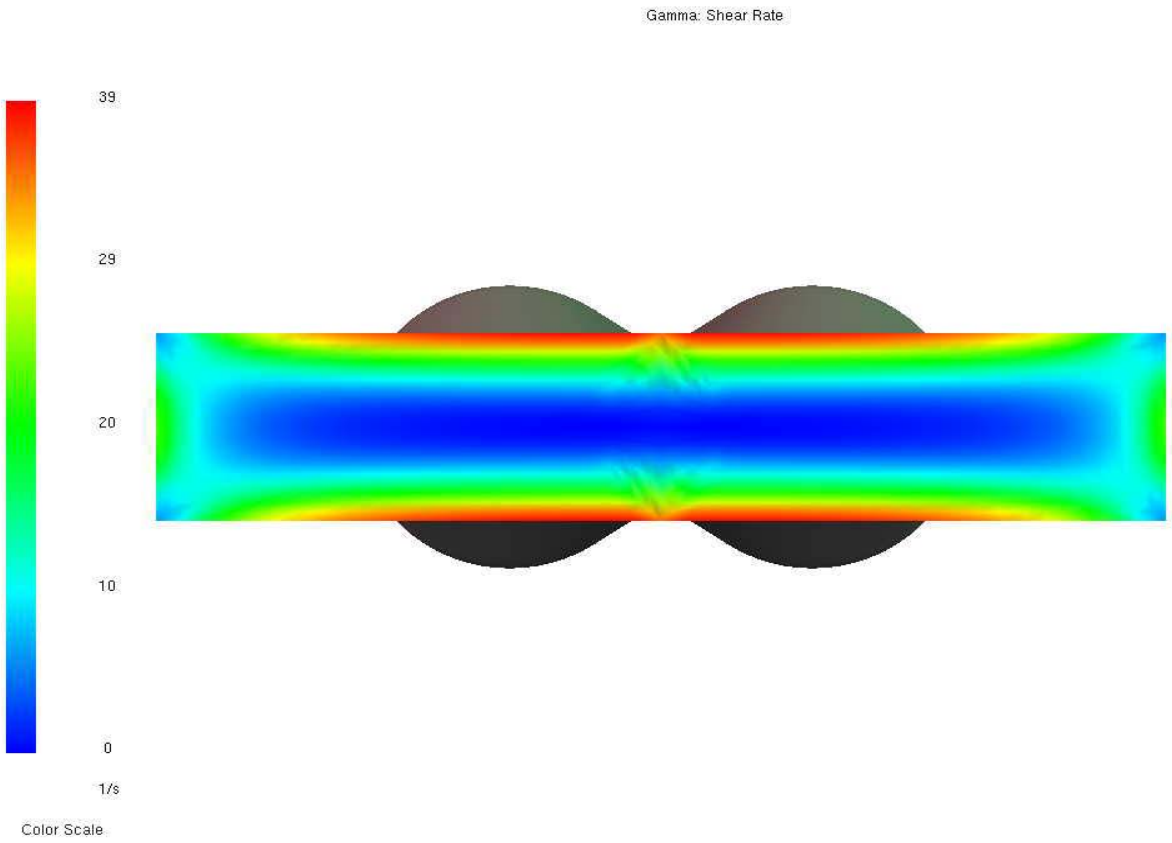
Shear rate distribution in the screw channel: 100 RPM at 180°C in, 72.3 lb/hr



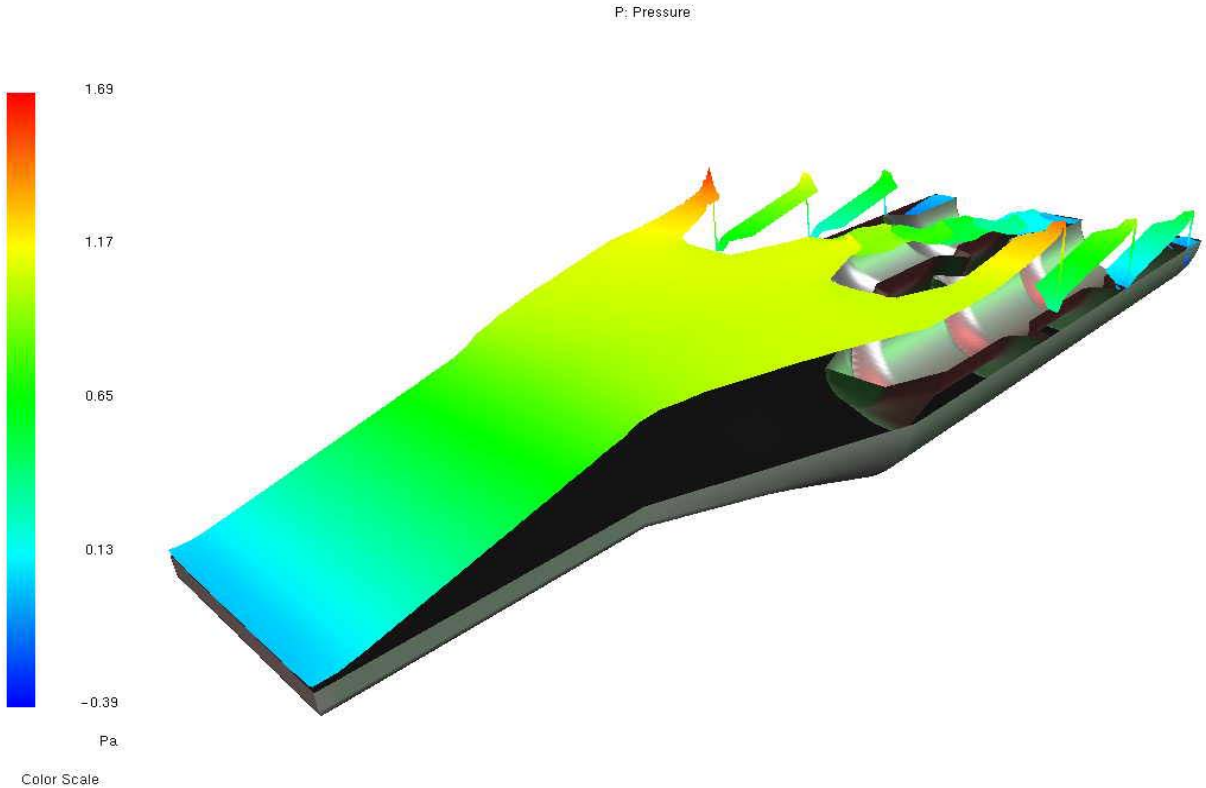
Mini Extruder First Section, 0.05 lb/hr, 105°C, shear rate distribution



Mini Extruder First Section, 0.05 lb/hr, 105°C, z-velocity



Shear rate distribution at the die:
100 RPM at 180°C in, 72.3 lb/hr



Pressure distribution in the Universal extruder (tangential mode) and its slit die configuration:
100 RPM at 180°C in, 72.3 lb/hr, peak pressure = 271 psi

Conclusions

- Essential to Model the Process for Energetic Materials
- The Equipment needs to be Purpose Designed for the Application
- It’s Possible to Test Any System With the Universal Extruder
- The Technology is Available to do it now (Software and Hardware)
- The Technology is Continuously Improving