A Novel Micro-Batch Mixer That Scales To The Single Screw Extruder

By

Keith Luker, Randcastle Extrusion Systems, Inc., Cedar Grove, NJ

Jennifer K. Lynch, Rutgers University

Thomas J. Nosker, Rutgers University

Co-Authors

- Jennifer Lynch, of Rutgers
- Tom Nosker, of Rutgers

Background

- Batch mixers mix.

Background

- Batch mixers mix.
- Single Screw Extruders (SSE) do not mix.

Background

- Batch mixers mix.
- Single Screw Extruders (SSE) do not mix.
- Therefore, to suggest making a batch mixer to scale to a single screw extruder, is an oxymoron.

Background

- Until Antec 07, few took the SSE as a serious compounder.

Background

- Until Antec 07, few took the SSE as a serious compounder.
- At Antec 07, an SSE was described that:
  - Compounded to the 500 nm scale.

Background

- Until Antec 07, no one took the SSE as a serious compounder.
- At Antec 07, an SSE was described that:
  - Compounded to the 500 nm scale.
  - Vented over a thin film.

Background

- Until Antec 07, no one took the SSE as a serious compounder.
- At Antec 07, an SSE was described that:
  - Compounded to the 500 nm scale.
  - Vented over a thin film.
  - Used 3 vents in a 36/1 L/D

Background

- Until Antec 07, no one took the SSE as a serious compounder.
- At Antec 07, an SSE was described that:
  - Compounded to the 500 nm scale.
  - Vented over a thin film.
  - Used 3 vents in a 36/1 L/D
  - Created multiple elongational flow fields—the same mechanism as the parallel twin compounder.

Background: Yesterday Antec 08

- A variant of this 07 SSE reported the ability to compound thermally sensitive materials:
  - EVOH in multilayer regrind.

Background: Yesterday Antec 08

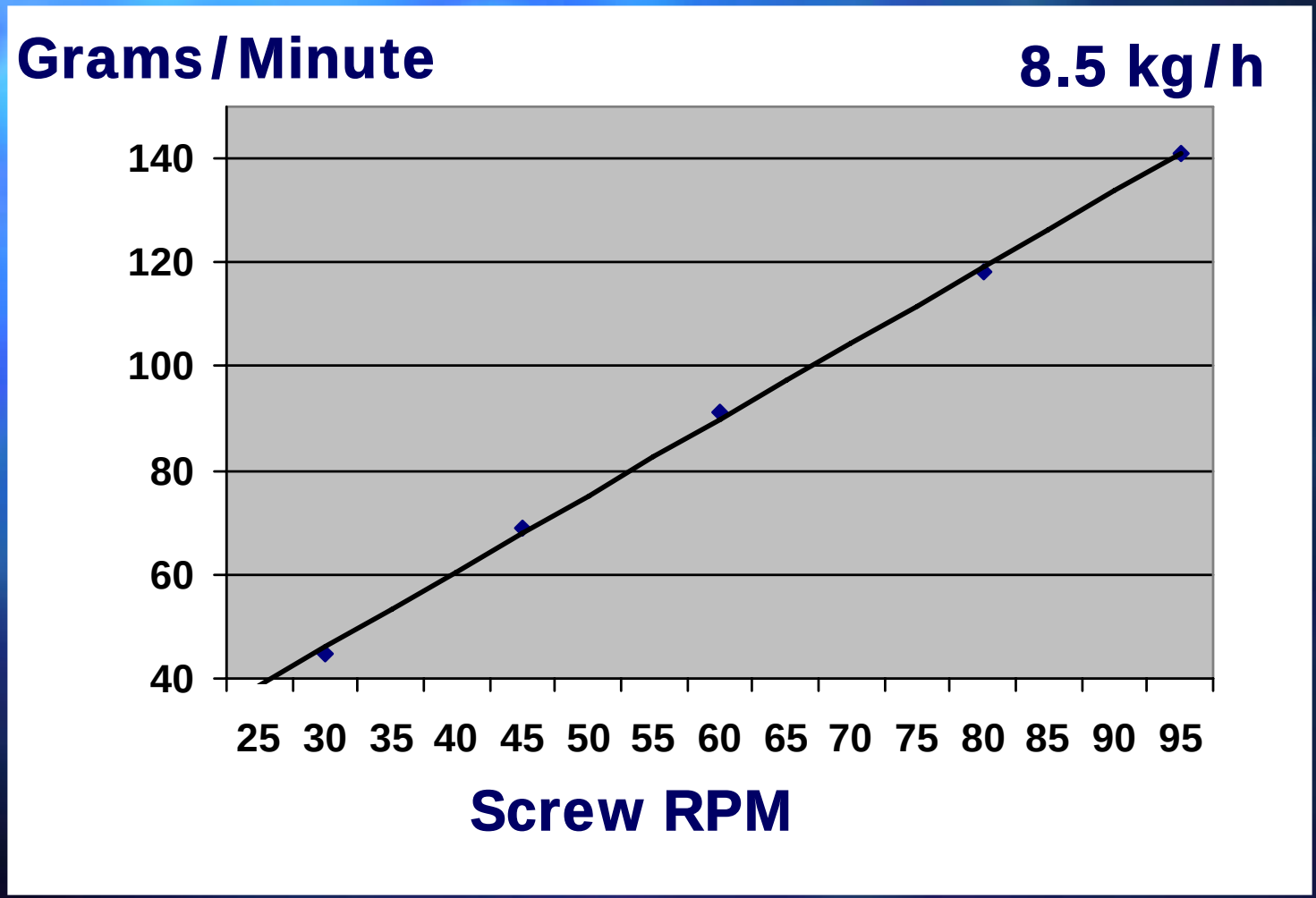
- A variant of this 07 SSE reported the ability to compound thermally sensitive materials:
  - EVOH in multilayer regrind.
  - Cellulose and oil

Background: Yesterday Antec 08

- A variant of this 07 SSE reported the ability to compound thermally sensitive materials:
  - EVOH in multilayer regrind.
  - Cellulose and oil
  - RPVC Pellets—at unheard of high screw speeds.

Output RPVC Pellets

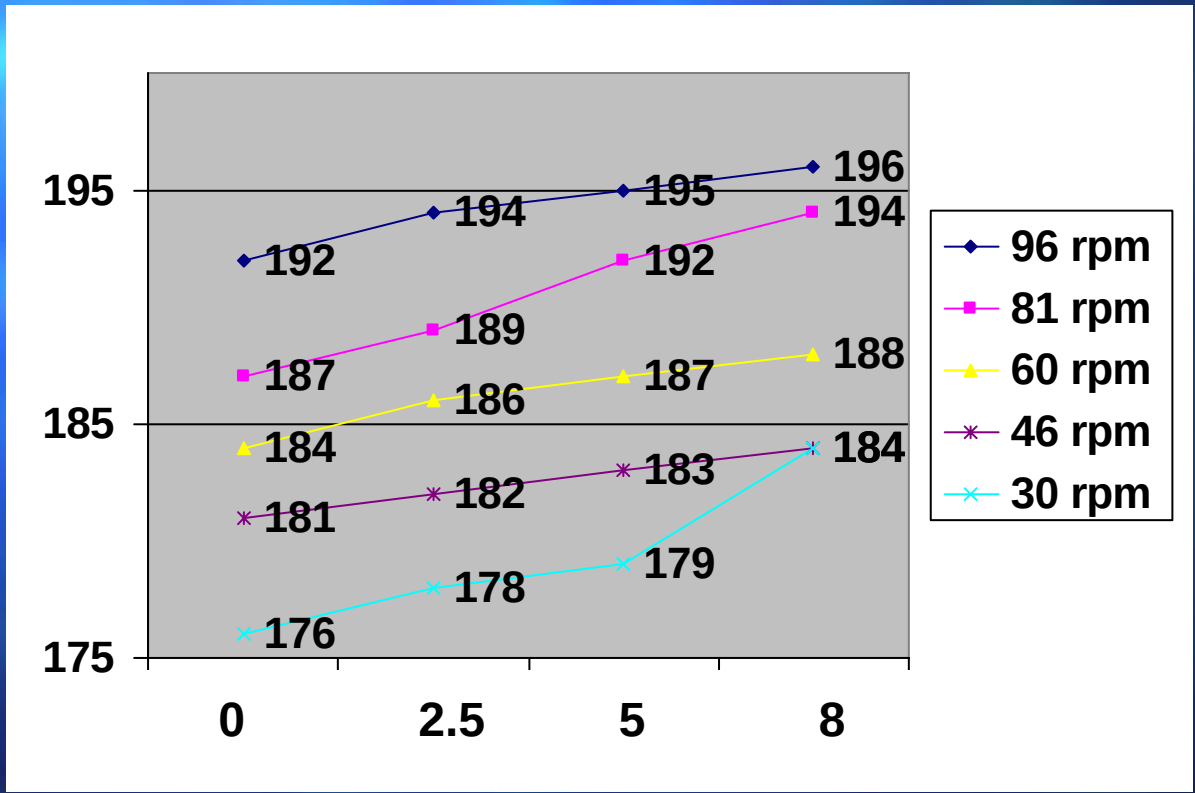
1 Inch 36/1 Extruder



Stock Temperature

RPVC Pellets 25 mm, 36/1 Extruder

Degrees C



Immersion Depth (mm)

(Through a 25 mm bore)

Background: Yesterday Antec 08

- A variant of this 07 SSE reported the ability to compound thermally sensitive materials:
  - EVOH in multilayer regrind.
  - Cellulose and oil
  - RPVC Pellets—at unheard of high screw speeds.
  - RPVC Powder—currently dominated by the conical twin—now processed easily at even higher screw speed and scaled up to production!

Background: Yesterday Antec 08

- RPVC Powder:
- 25 mm:
  - 180 RPM
  - Melt 177C
  - 13.2 kg/hr

Background: Yesterday Antec 08

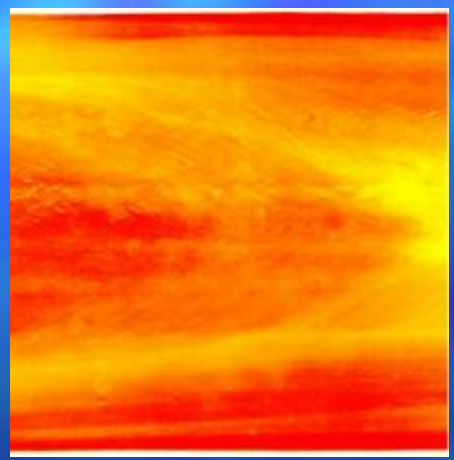
- RPVC Powder:
- 25 mm:
  - 180 RPM
  - Melt 177C
  - 13.2 kg/hr
- 63 mm:
  - 70 RPM
  - Melt 191
  - 70 kg/hr

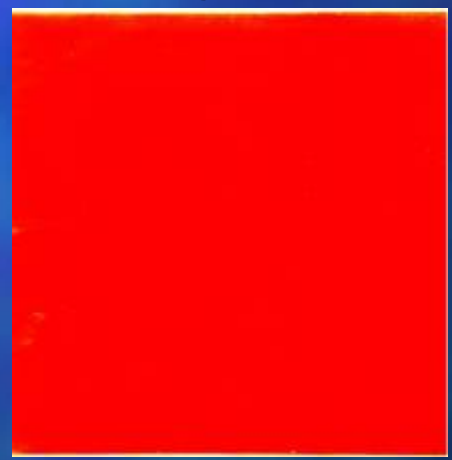
Background:
SSE Compounding SFEM

Coloring Vinyl Film

Flexible PVC pellets/0.5% red/0.5% yellow concentrate

UC Mixer





SFEM

Background:
SSE Compounding SFEM

Single Screw Mixer Comparison
10% Elastomer & LDPE

UC Mixer

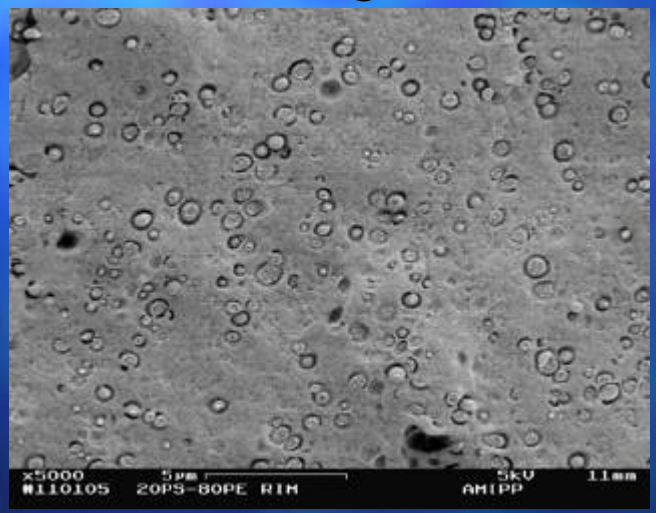
Double Wave

SFEM

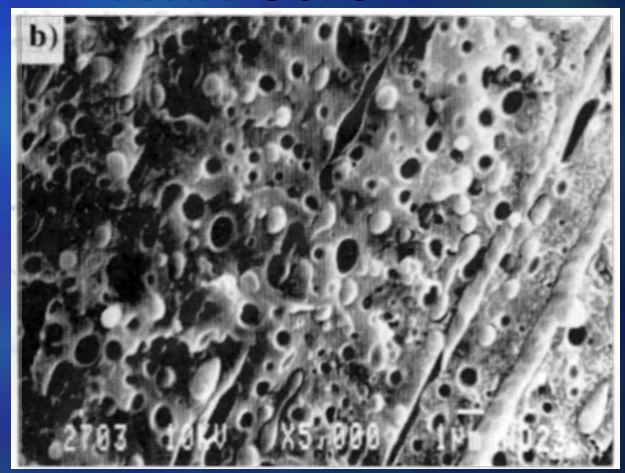
Background: SSE Compounding SFEM

Single Screw vs Twin Screw Continuous: 20PS/80PE

SFEM Single Screw

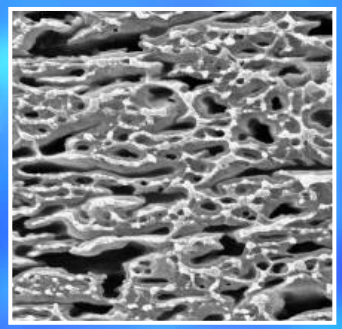


Twin Screw



Background:
SSE Compounding SFEM

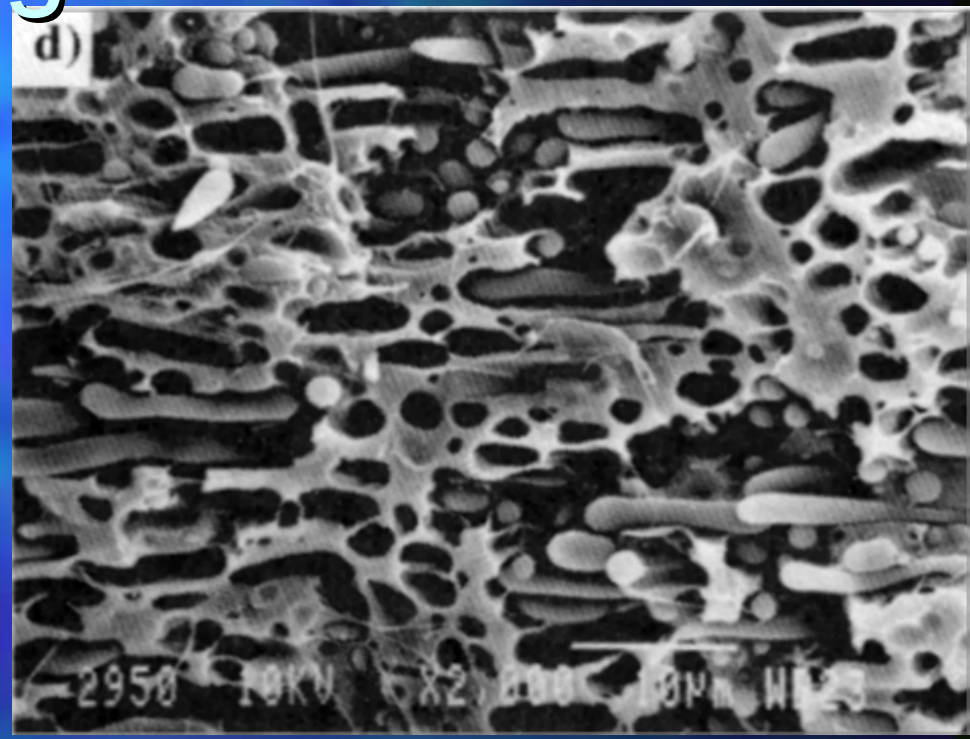
10 microns ⟷



Picture courtesy Rutgers.

Single Screw SFEM

@ 2,000 X



10 microns ⟷

Twin @ 2,000 X

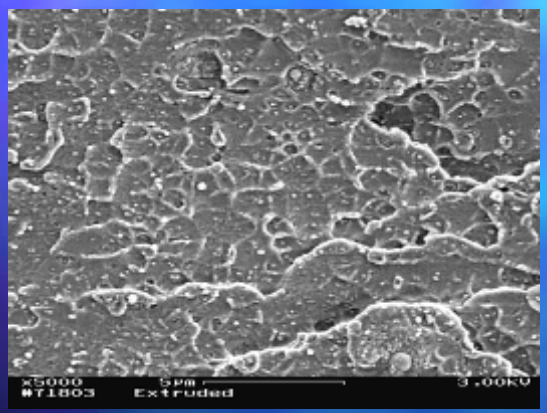
Note: Material viscosity different.

Right picture, Antec 95, "CO-CONTINUITY AND PHASE INVERSION IN HDPE/PS BLENDS: THE ROLE OF INTERFACIAL MODIFICATION" by Daniel Bourry and Basis D. Favis

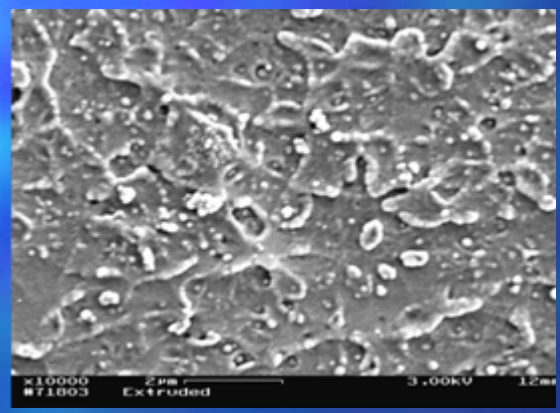
Background:
SSE Compounding SFEM

Ceramic Nano-Composites

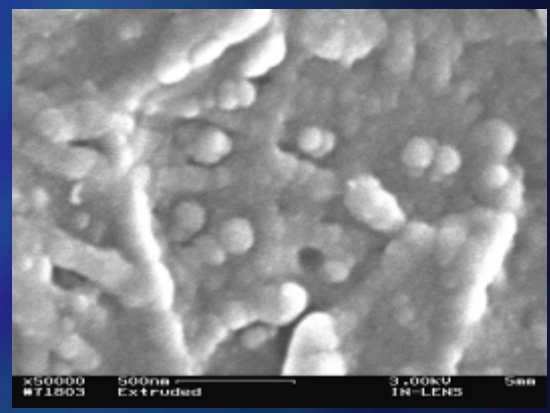
PMMA Pellets & 5% Nano Ceramic 30 to 60 nm



5,000 X



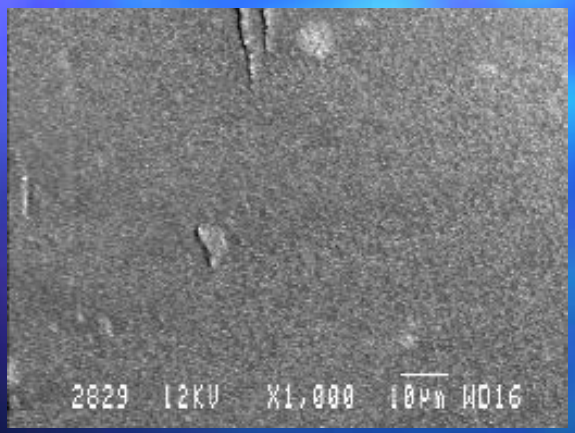
10,000X

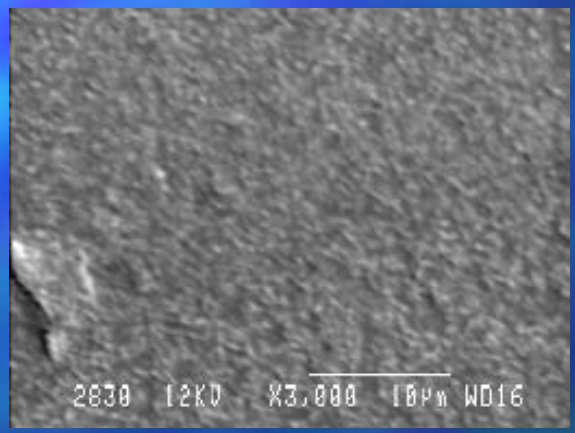


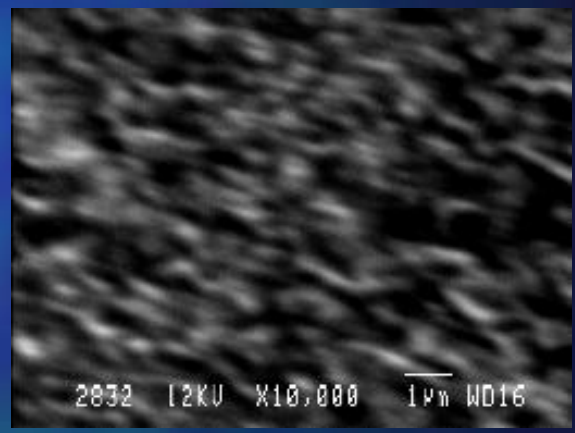
50,000X

Background:
SSE Compounding SFEM

Single Wall Carbon Nano Tubes





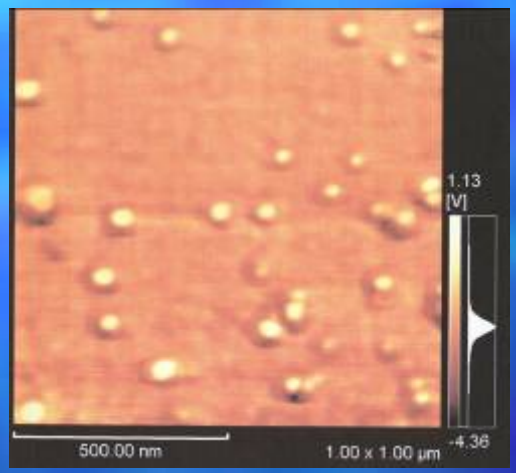


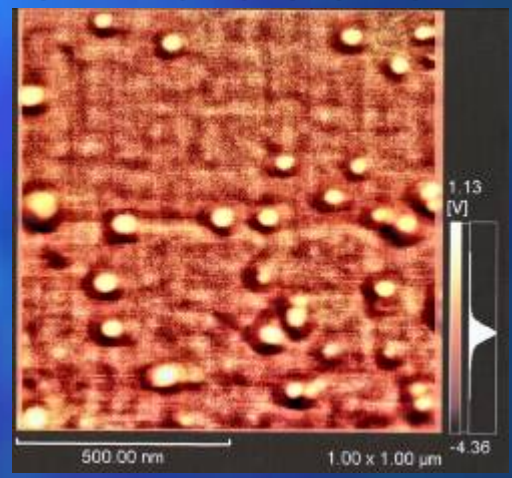
This picture shows untangled CNT's

Background:
SSE Compounding SFEM

2% Carbon Nano-Tubes & PC

100,000 X





100,000 X (Enhanced)

Background:
SSE Compounding SFEM

5% Carbon Nano-Tubes In Acetal

Conductive to Dissapative Range

Multi-wall CNT's tested IEC 60093:

35 to 85 Ohms/sq

Background:
SSE Compounding SFEM

Wood Flour & LDPE Pellets

Background:
SSE Compounding SFEM

Wood Flour & RPVC Powder

100% RPVC Powder

60% RPVC 40% Woodflour
Before Degassing

1” x 0.125 Tensile Bar

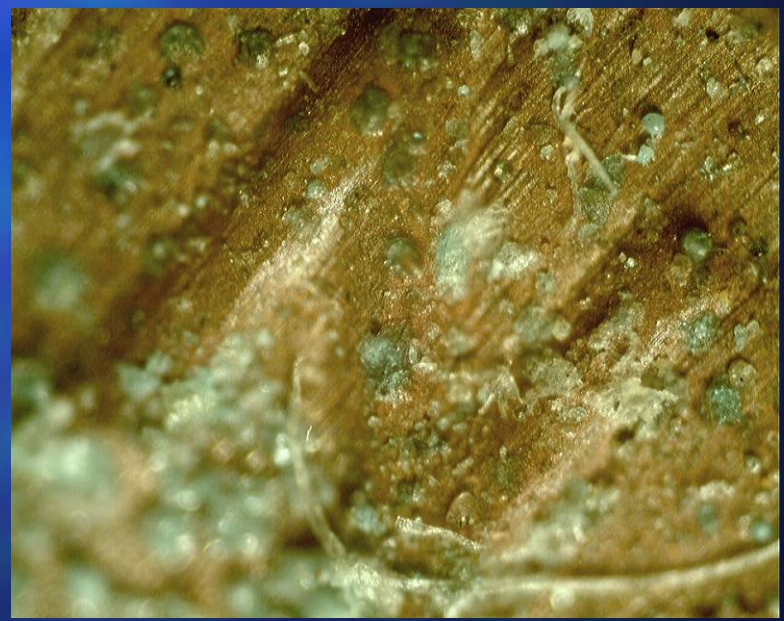
1” x 0.062 Tensile Bar

Background:
SSE Compounding SFEM

RPVC Pellets &
15% Calcium Carbonate

Background:
SSE Compounding SFEM

35% Calcium Carbonate Powder
With PP Pellets: Two Vents



Background: SSE Compounding SFEM

- The “Elongator” is a **S**piral **F**luted **E**longational **M**ixer. Generically: SFEM.

Background

- Micro-batch mixers useful for rare or expensive ingredients.

Background

- Micro-batch mixers useful for rare or expensive ingredients.
- Several types are known:
  - A miniature conical twin screw with a recirculation loop.
  - A cup and rotor mixer.
  - An internal batch mixer with roller blades.
  - Miniature dual pistons driving material back and forth.

Purpose of This Study

- Find out how well the SFEM SSE compares to the new micro batch mixer.

Experimental:

- Macroscopic: Extrude samples with SFEM and compare to the micro-batch mixer.

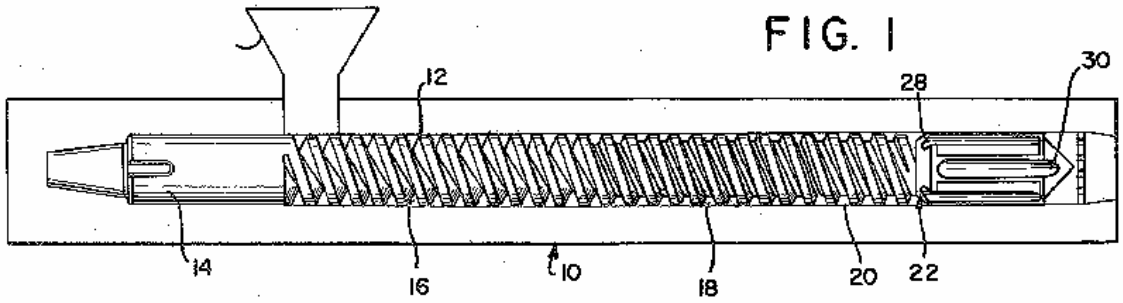
Experimental:

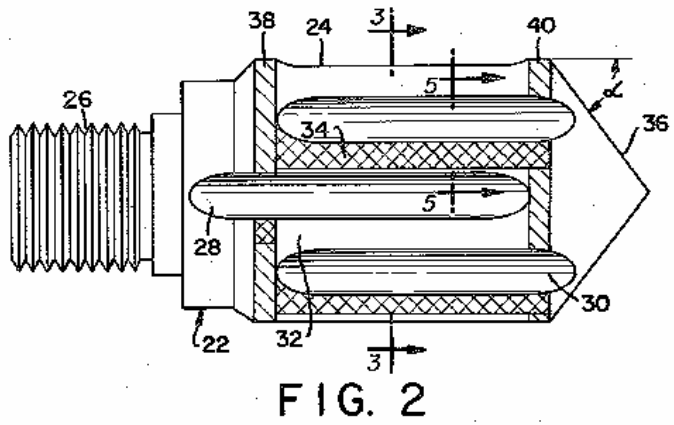
- Macroscopic: Extrude samples with SFEM and compare to the micro-batch mixer.
- Microscopic: Look at the immiscible blends of polystyrene and polyethelene and see if the domains compare.

Historically Single Screw Mixers Push!

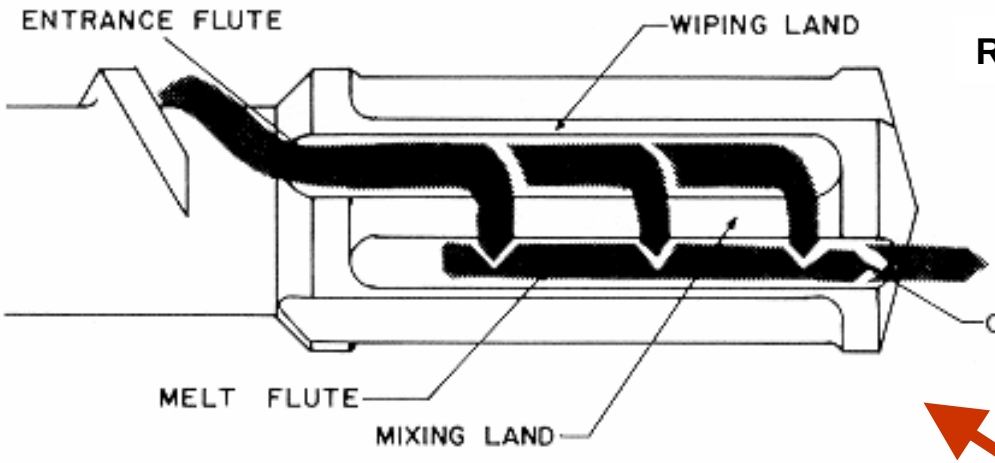
Push to create melting.

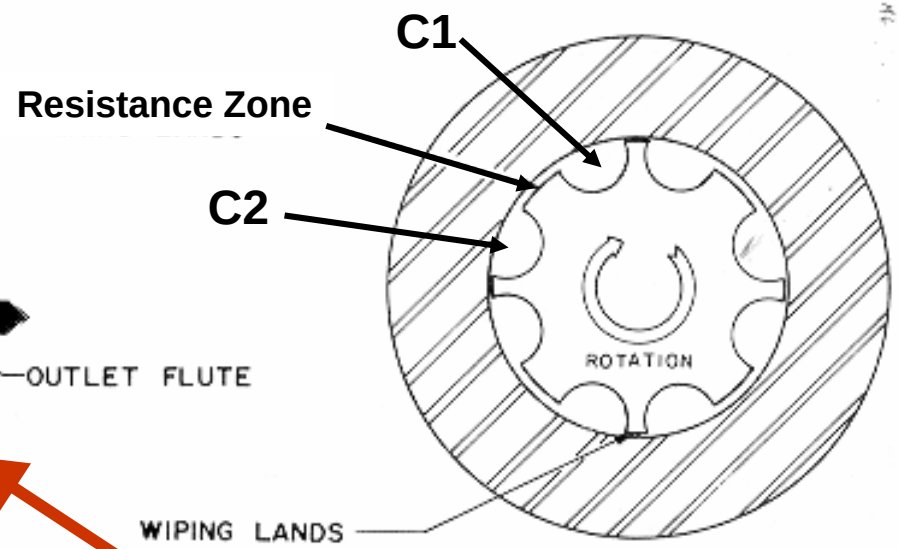
Then push *after* melting for mixing as shear.

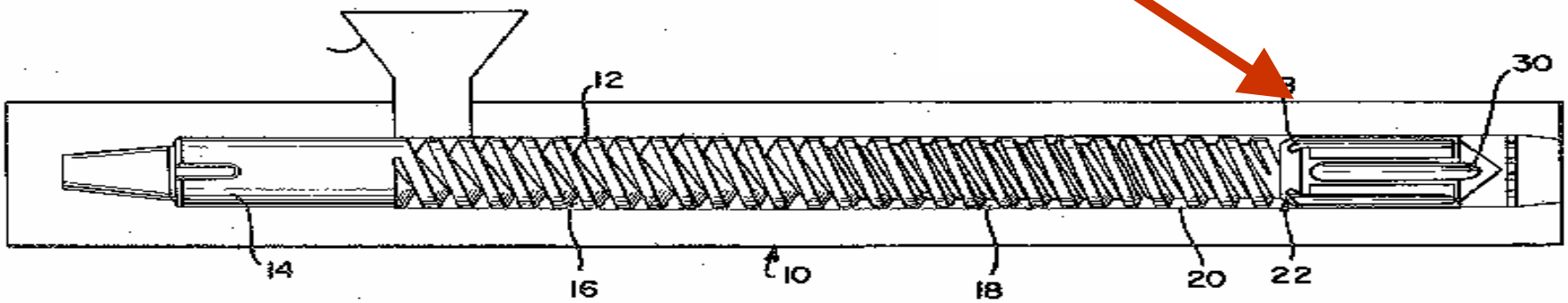




Union Carbide Mixer (aka Maddocks Mixer)

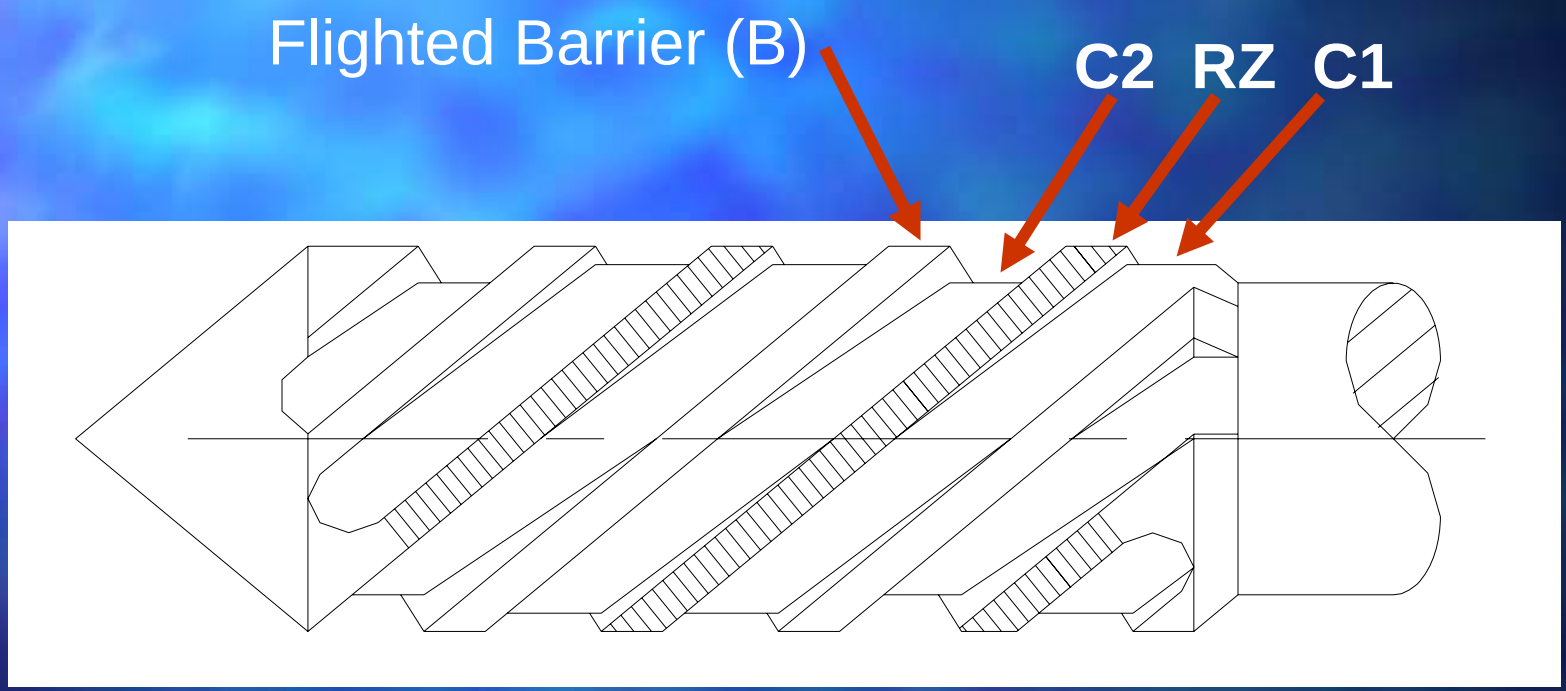






Twisted UC Mixer Is An Egan Mixer

With Shaded Resistance Zone And Channels



C1 dead ends into B causing resistance. Pressure, generated upstream and by the spiral geometry forces material over the shaded resistance zone (RZ) where the material is sheared.

Pushing Is Bad For Mixing

→ *A-B-B-B-B-A* ←

Pushing Is Bad For Mixing

→ *A-B-B-B-B-A* ←

A- ***B*** *-A*

Since Pushing Equals Bad...

A-B-B-B-B-A

A- B -A

Suppose We Pull ?

Then…

Then…

Then...

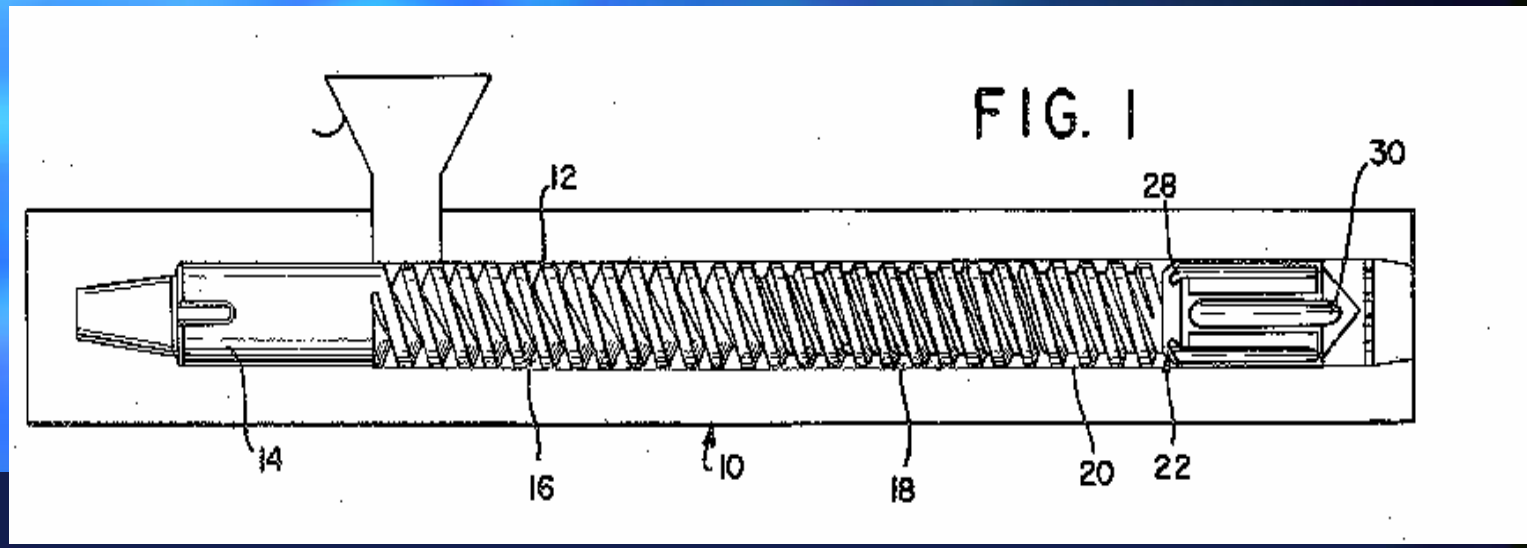
Pulling Is Good For Mixing!

The smaller the domains, the better the mixing.

Suppose We Only Want To Melt?

Pulling Is Good For Melting Too!

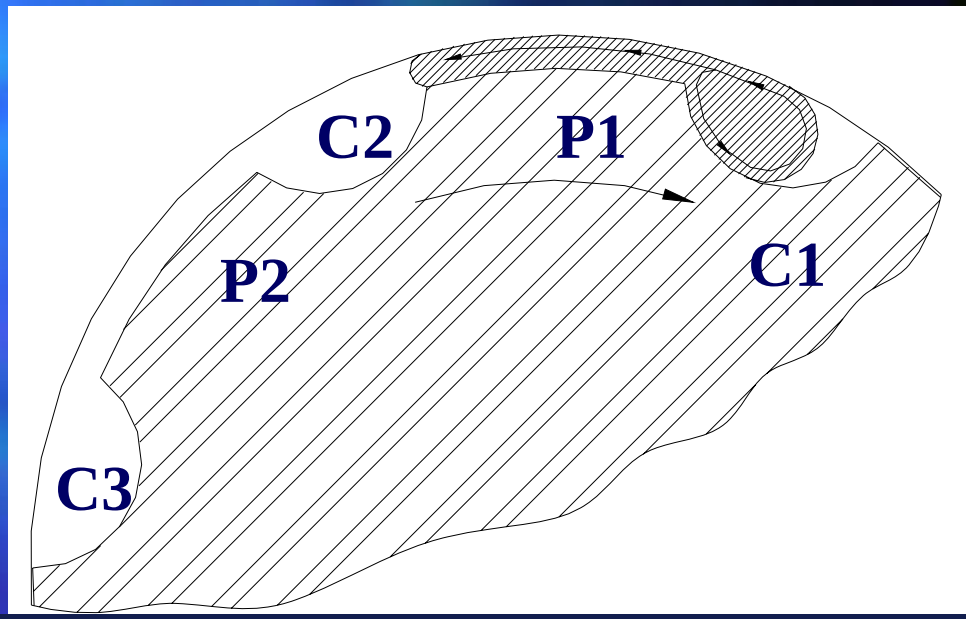
New Generation of Mixers *Pull* And *Pull* Right Away

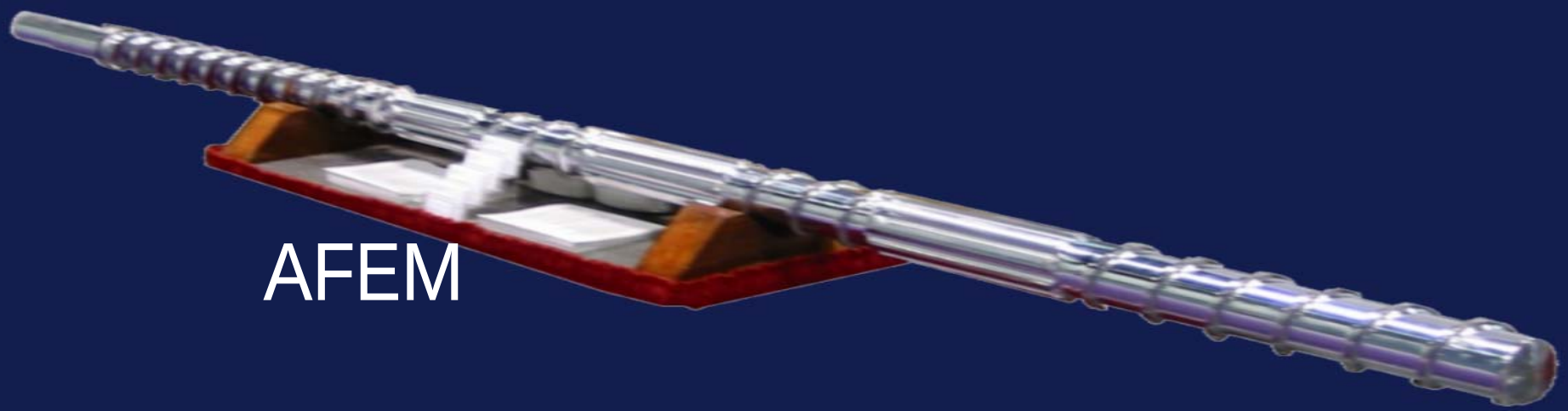


AFEM

How Does the SFEM Work?

P = Pump
C = Channel



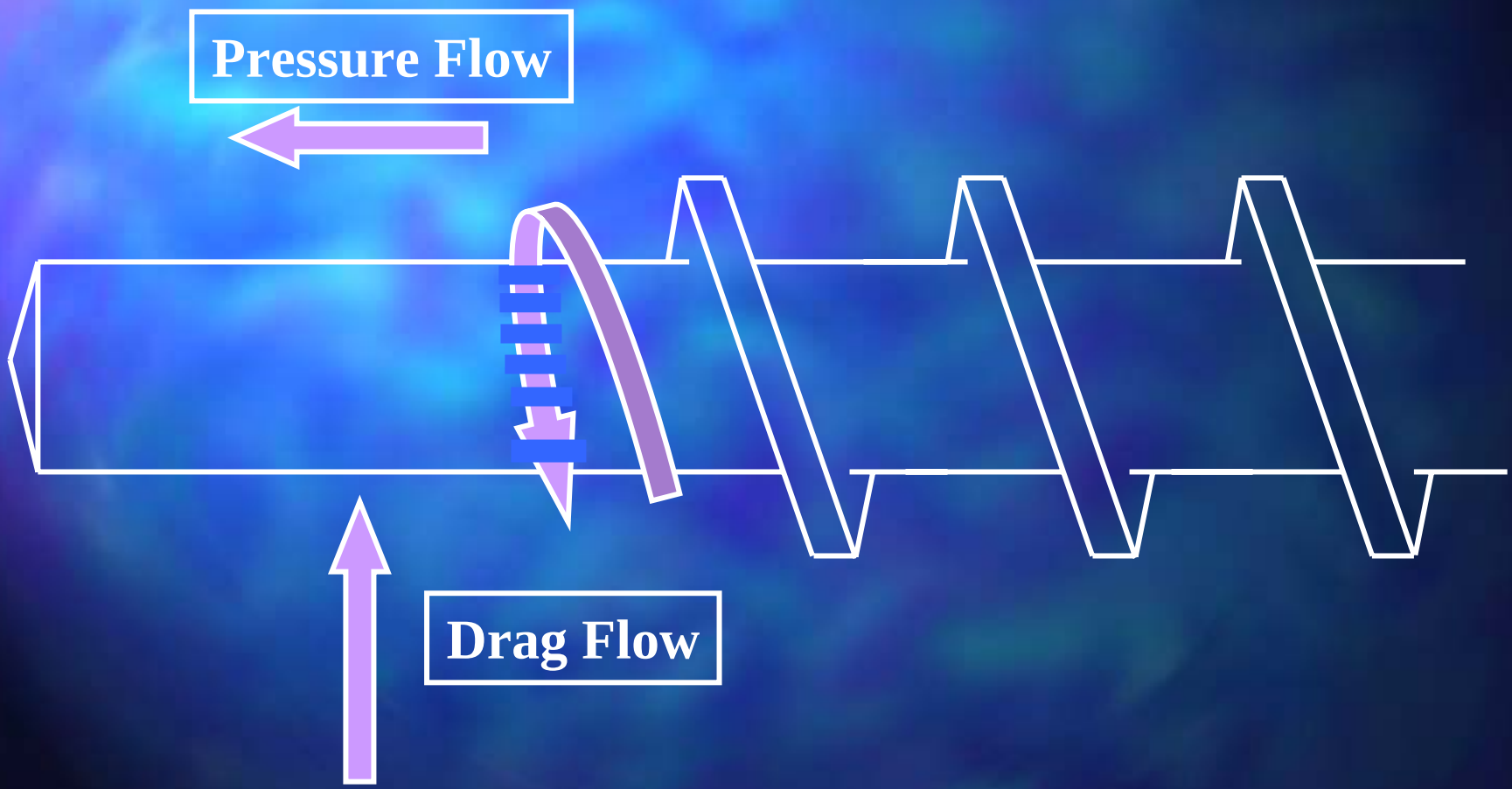


AFEM

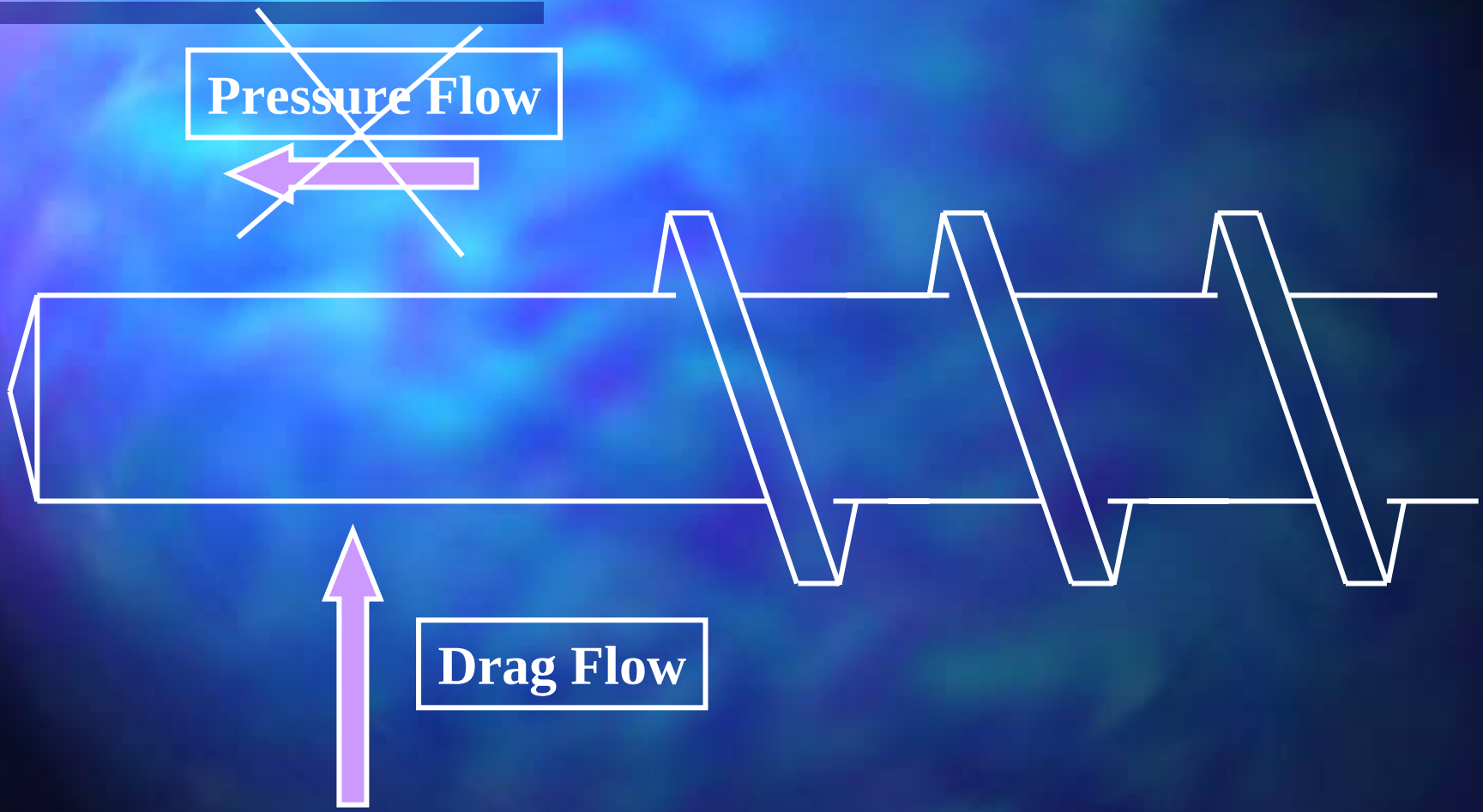
Imagine A Screw Without A Flight At The End

In The Smooth Section, What Path Will A Particle Take?

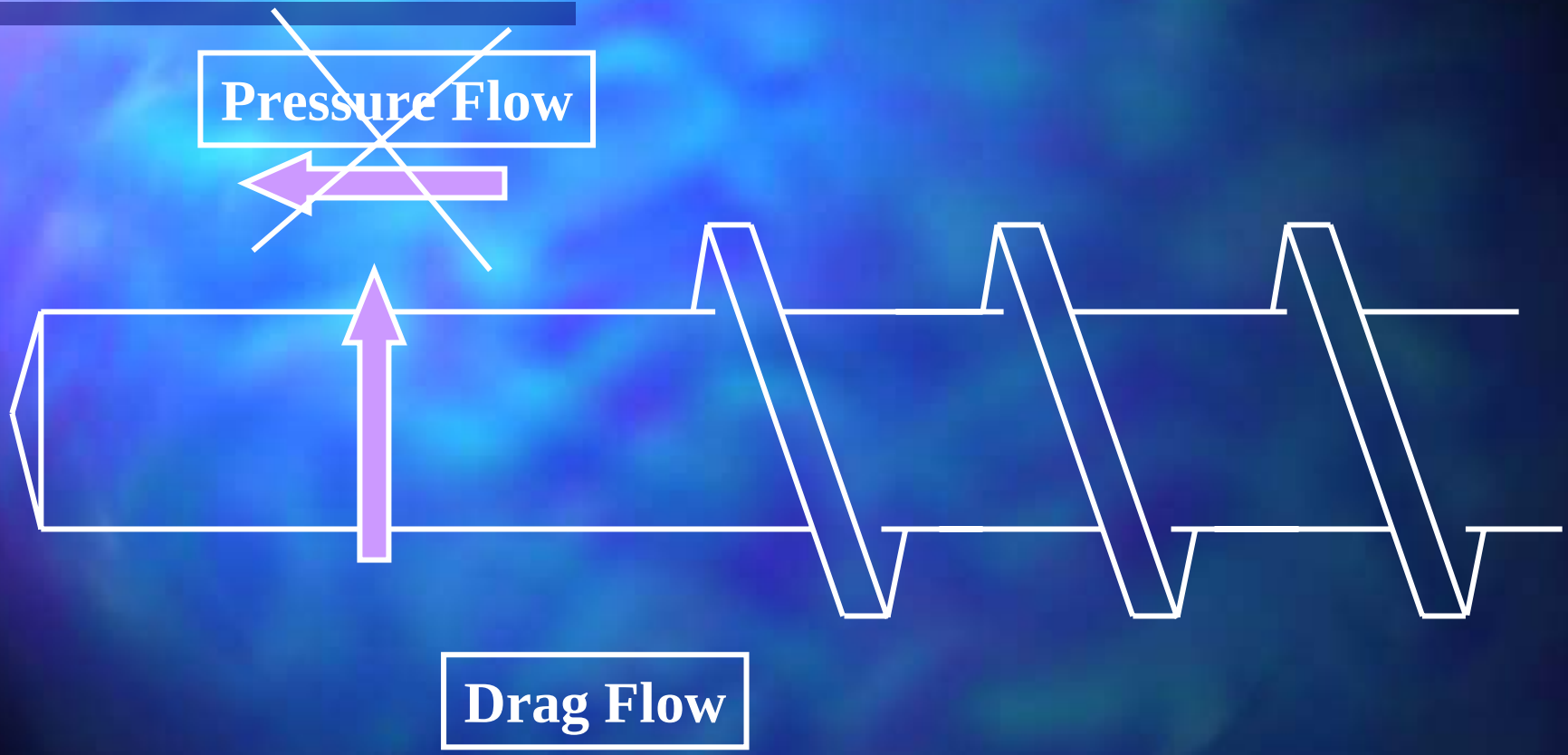
A Spiral



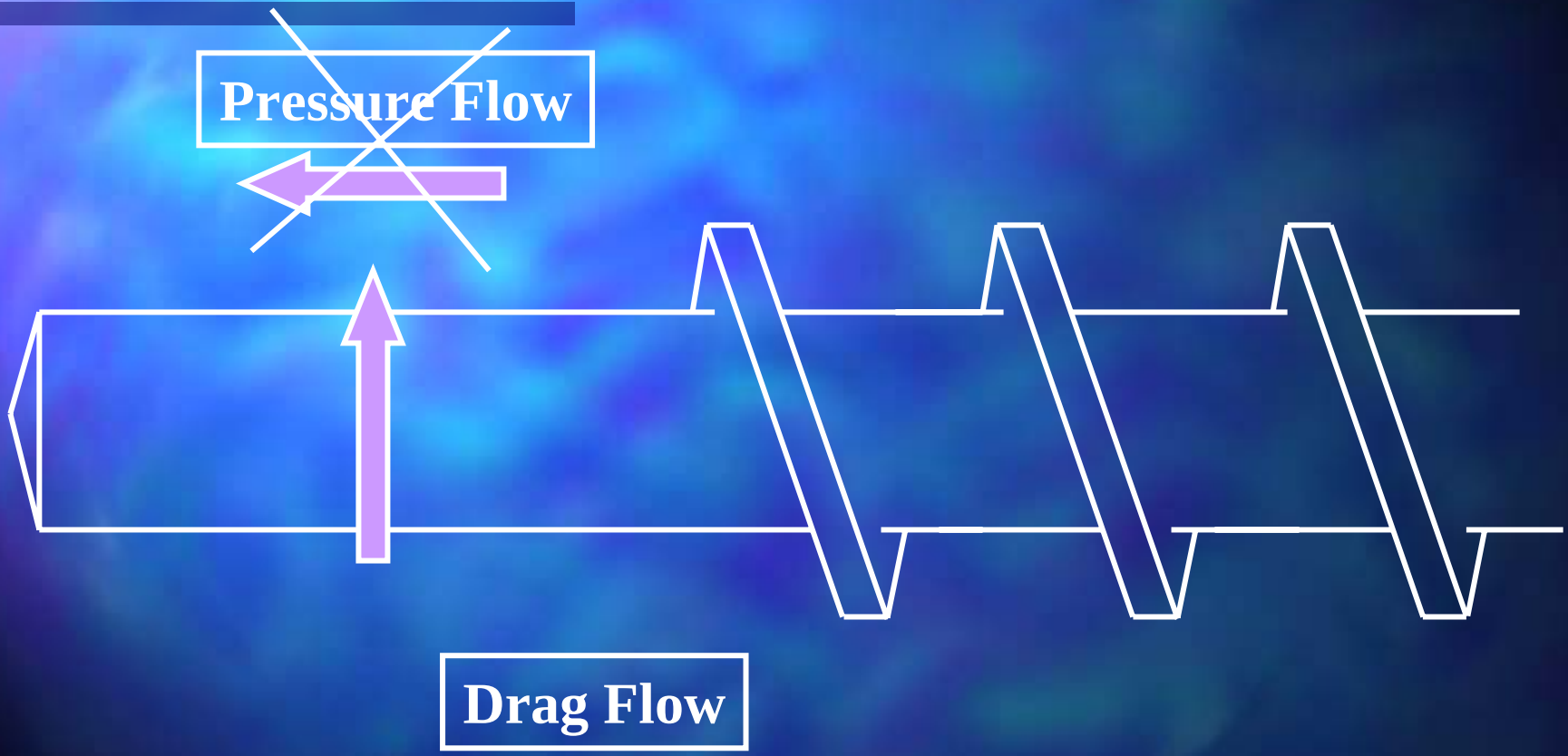
If You Stop The Feed...



Material Is Pumped In A Circle



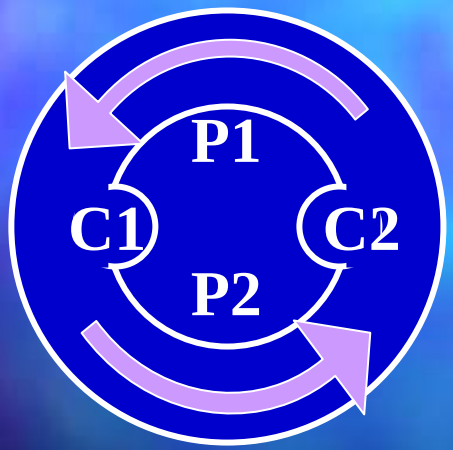
So, A Smooth Section Is A Radial Pump

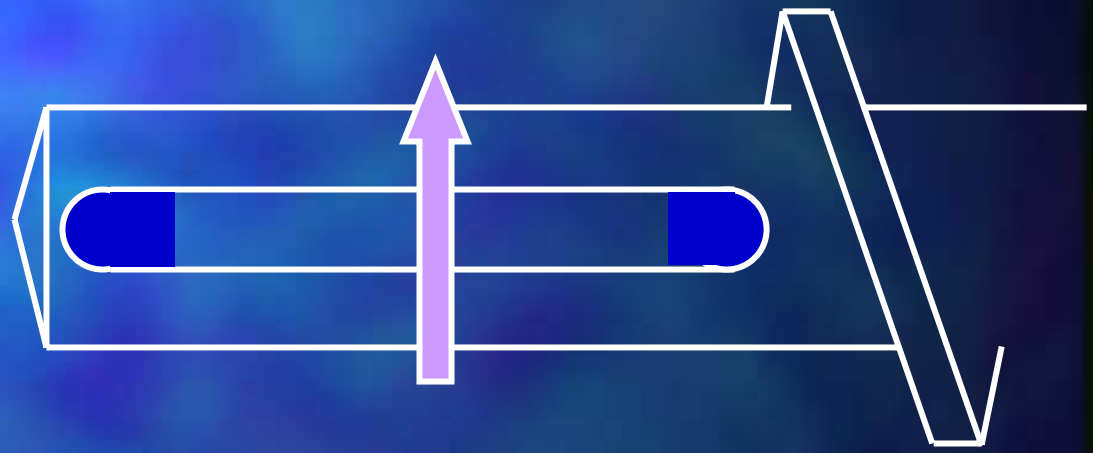


End View Of Radial Pump's Particle Path

Drag Flow

Suppose You Put Two Channels Into The Smooth Section

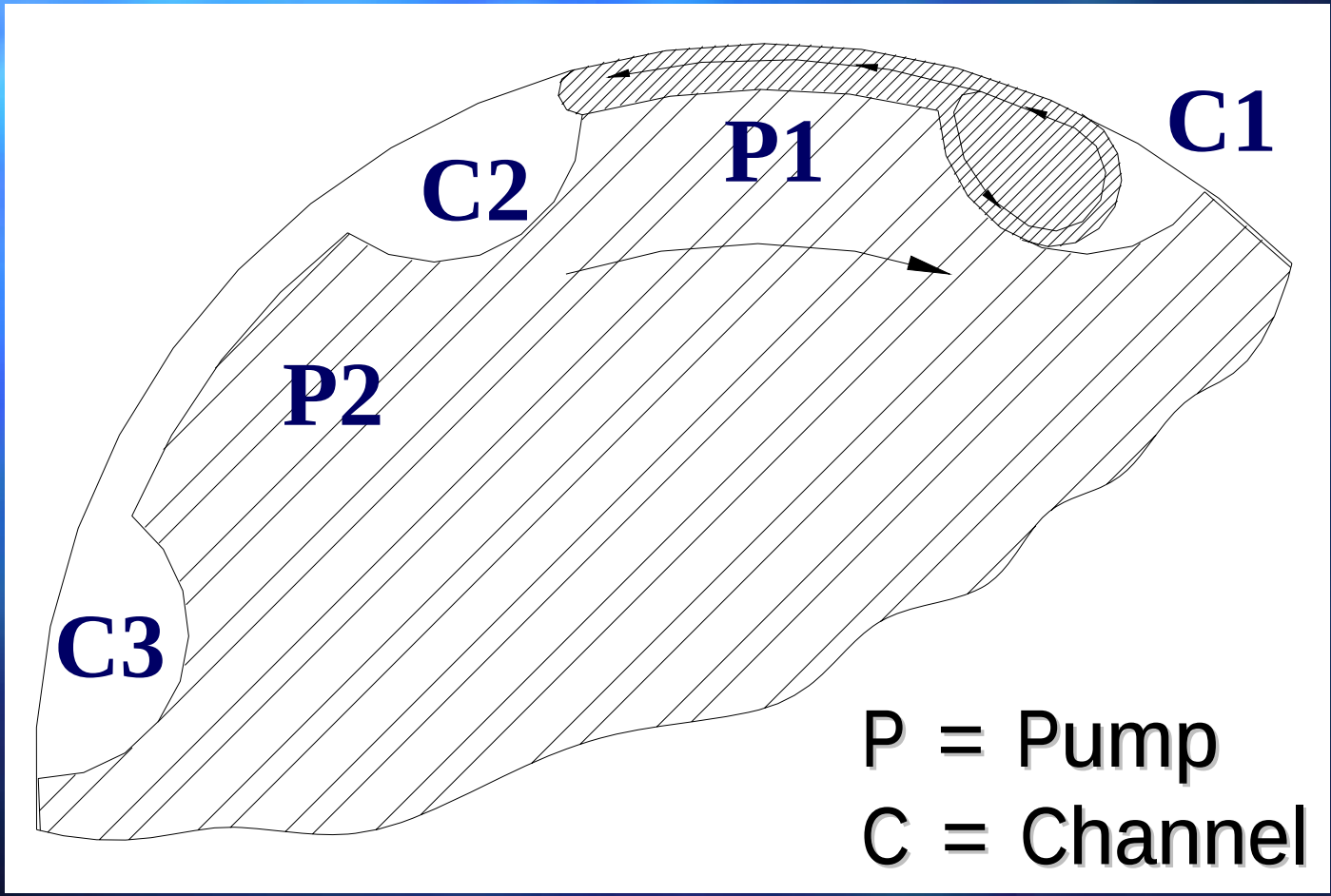




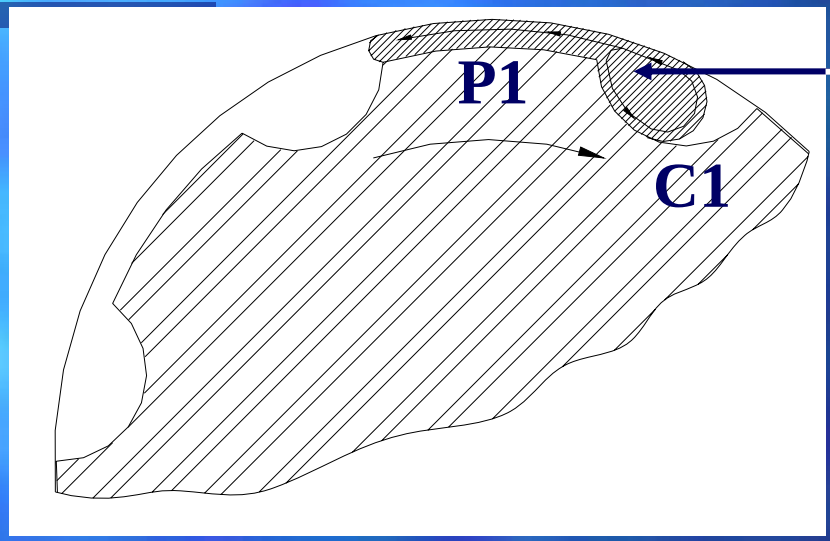
Drag Flow

P = Pump
C = Channel

Cross Section of AFEM or SFEM

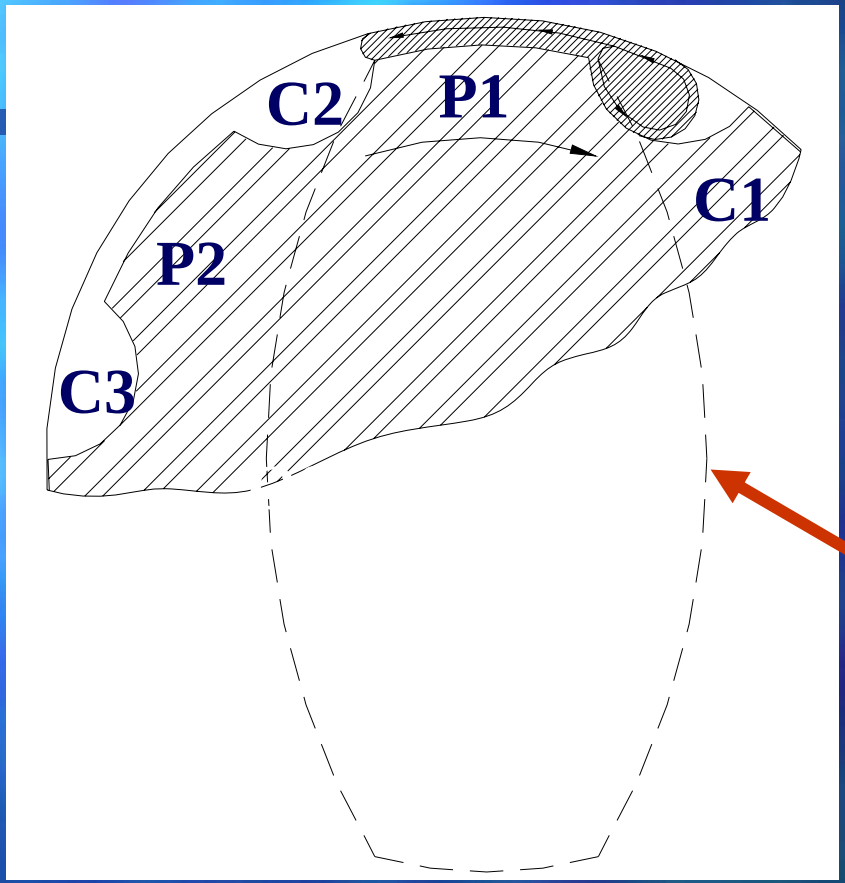


Fine Elongation



- In the approach to the first pump, material experiences fine elongation at low pressure
- Lowest pressure means the lowest possible heat rise! Zero is the lowest.

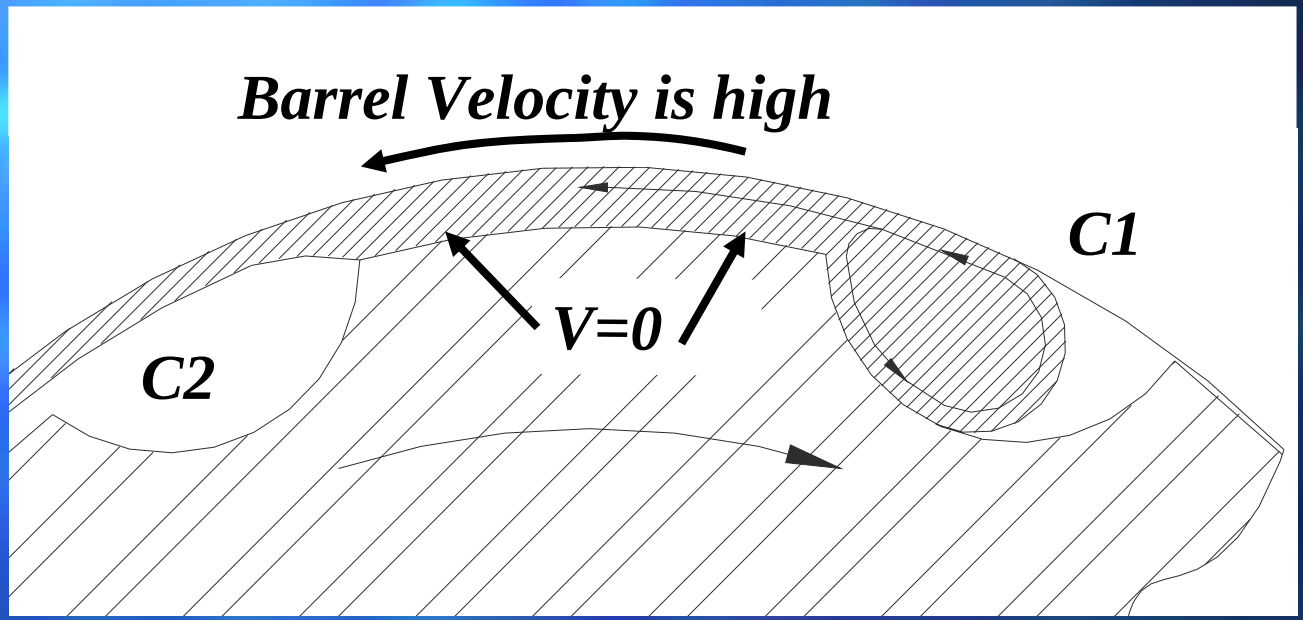
Bi-Lobal Kneading Disc



Outline of twin's Bi-lobal kneading disc

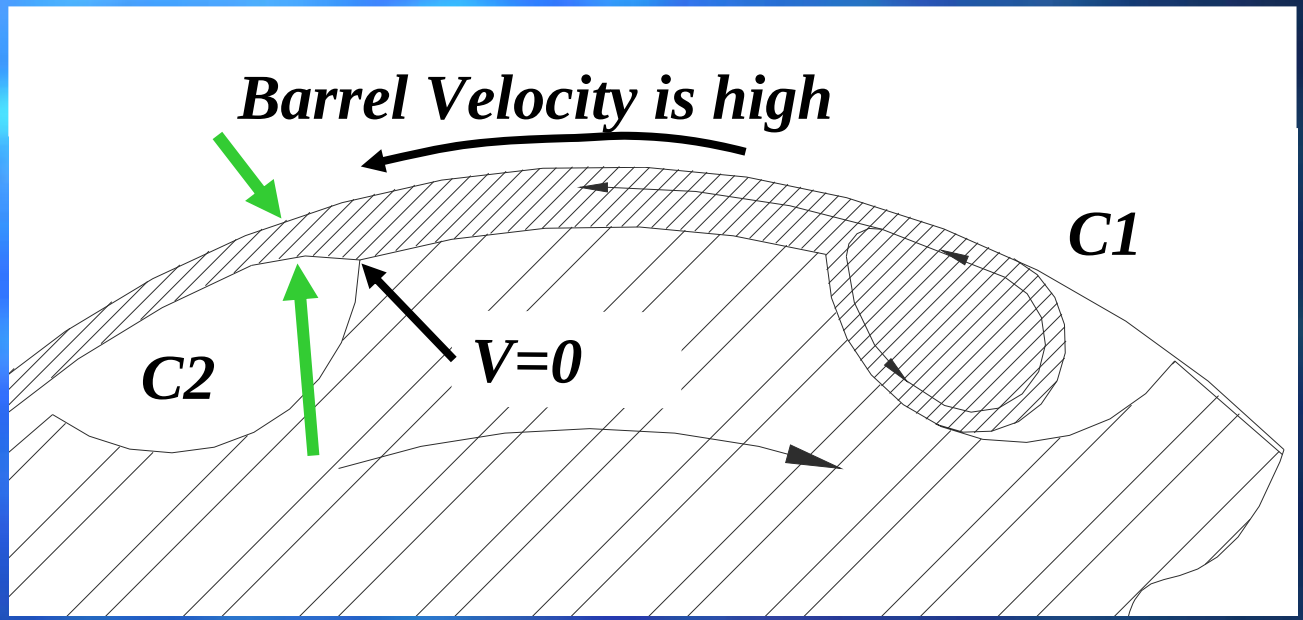
In the approach to the pump, the polymer cannot "know" whether it is in a single or a twin screw.

Shear In P1 Is "Pure"



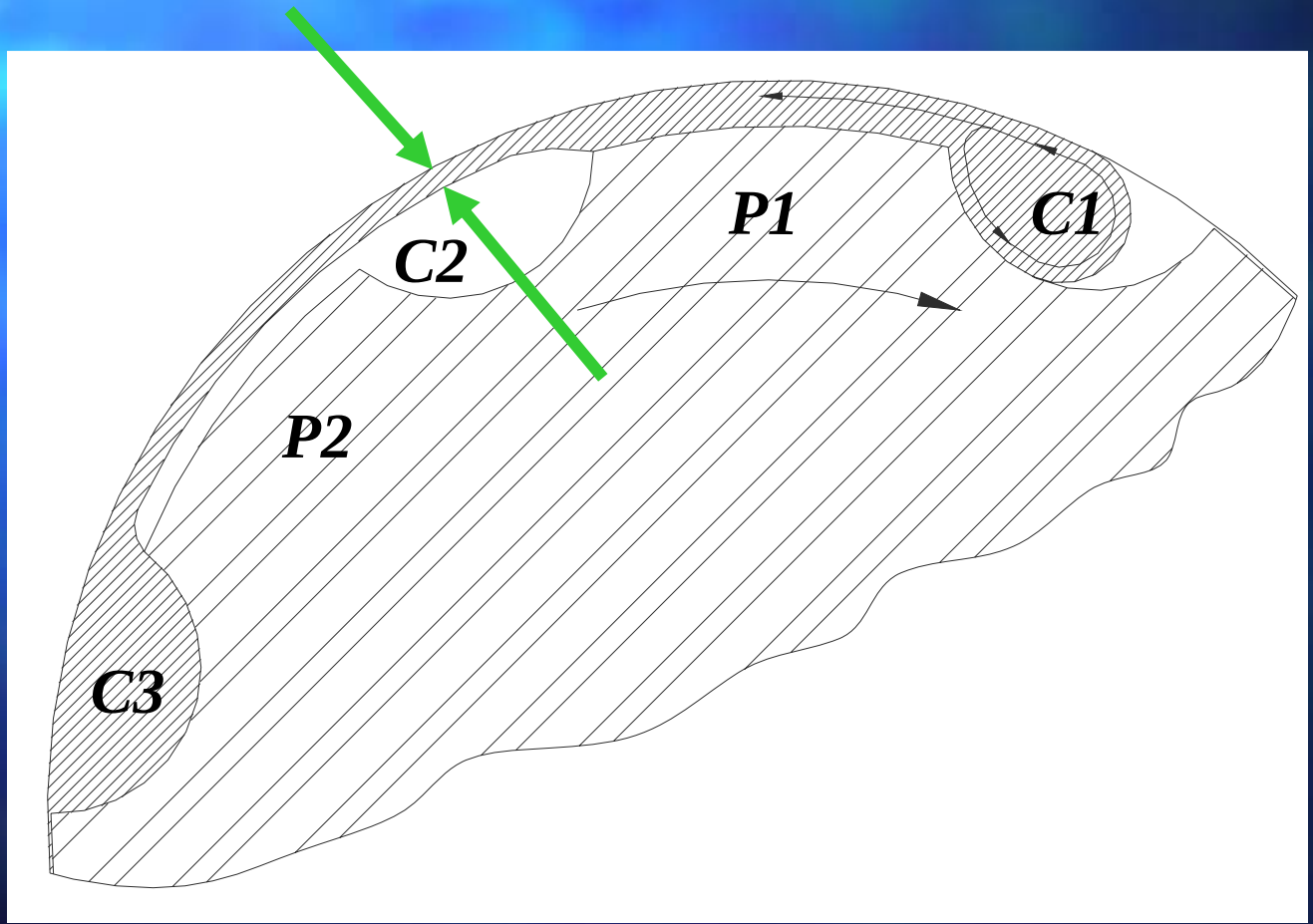
There is no pressure flow pushing material into P1—only drag flow . Shear mixing is maximized. Heat rise is minimized.

Two Dimensional Elongation

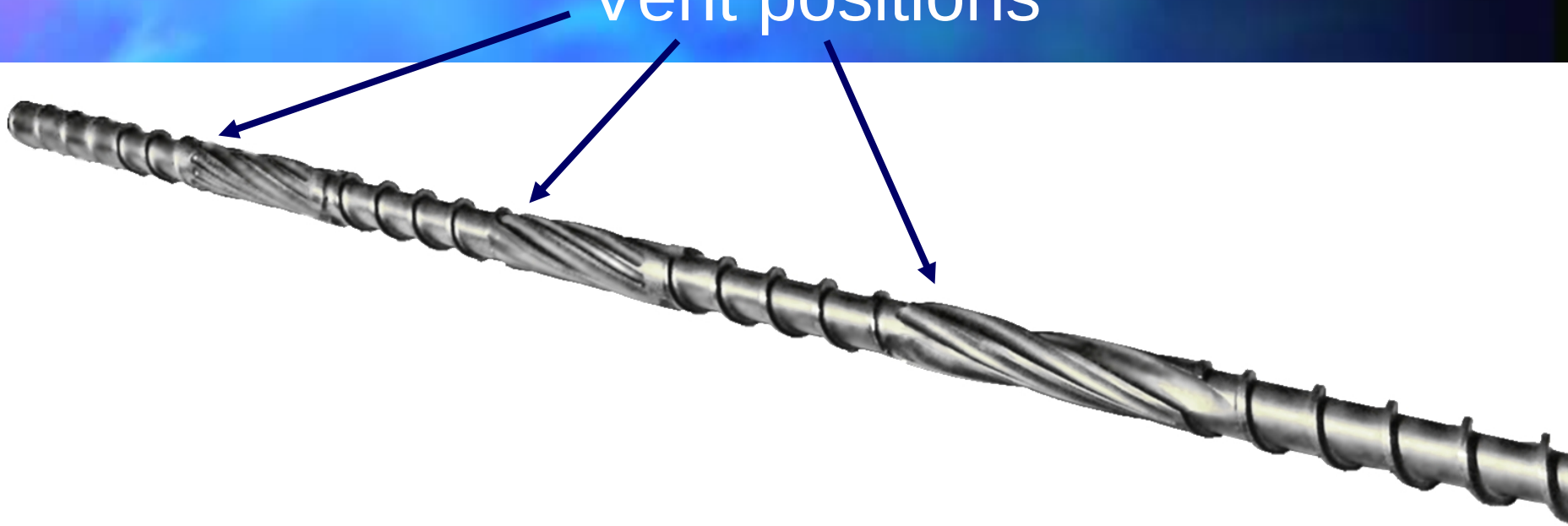


Exiting P1, material is released from P1 but still stuck to the barrel surface. Material extends two dimensionally.

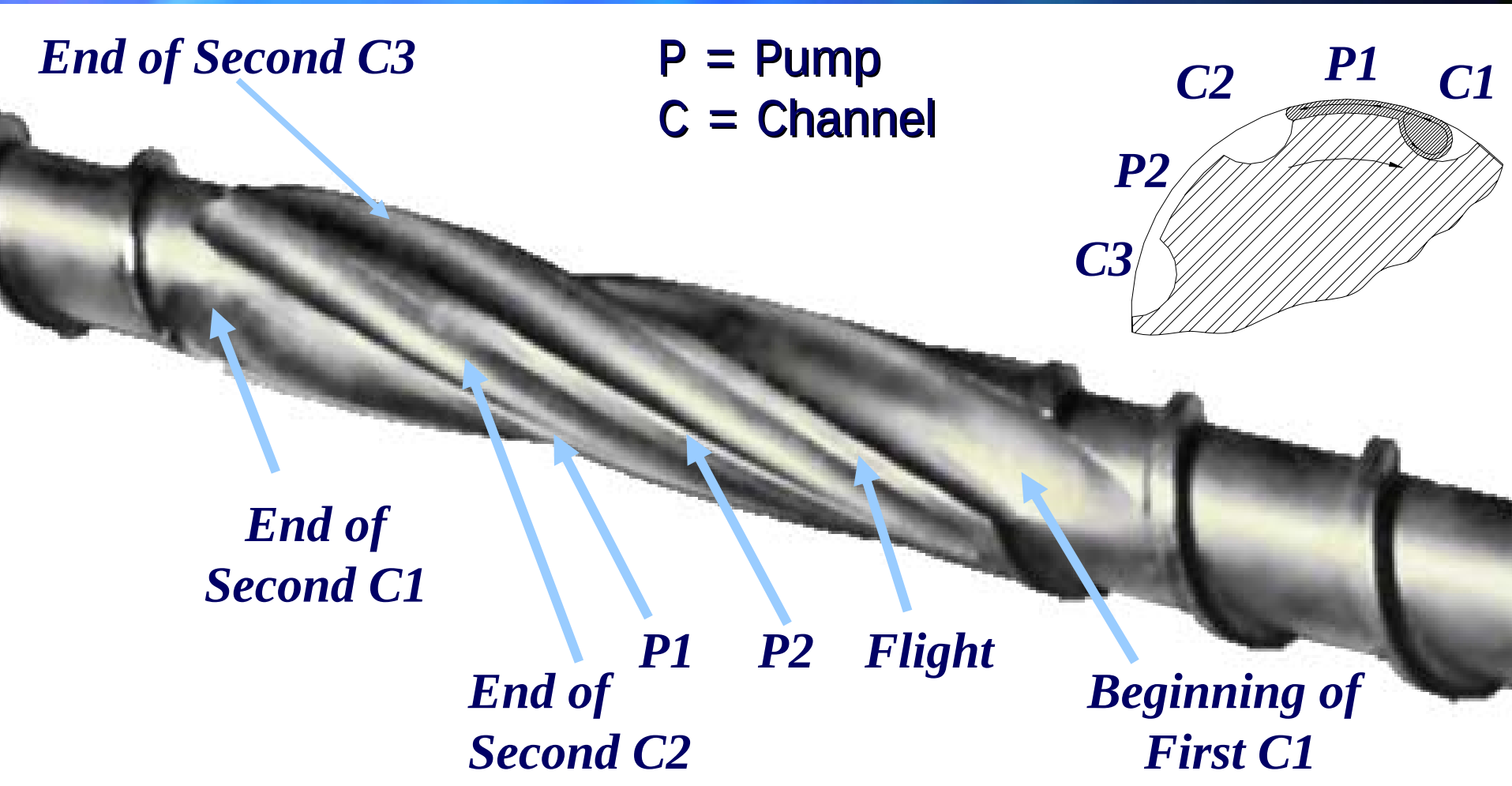
Thin Film Created For Venting



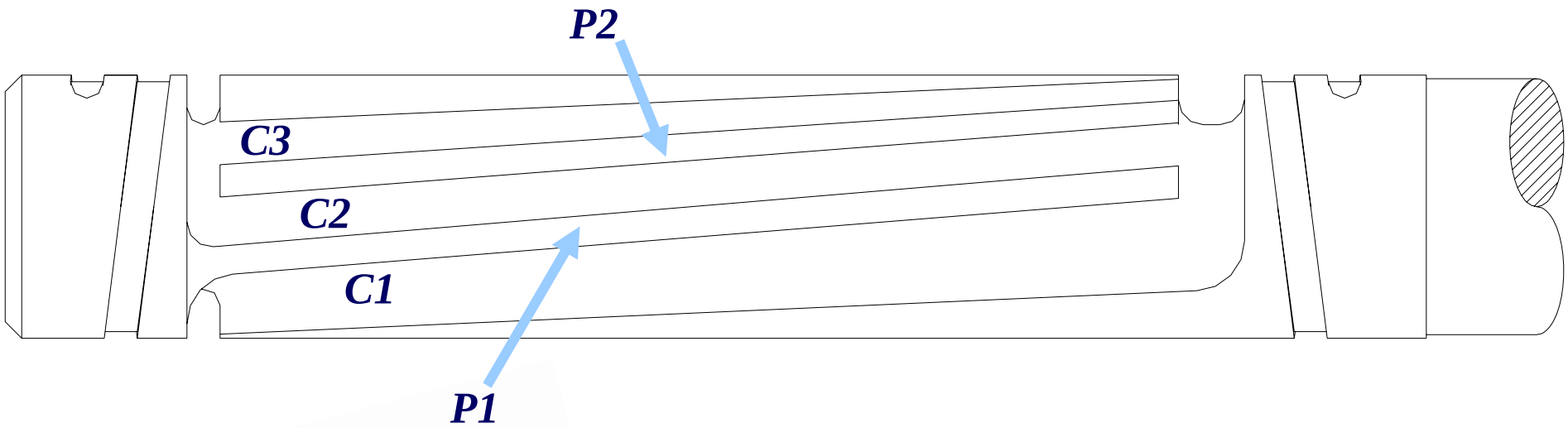
SFEM



SFEM

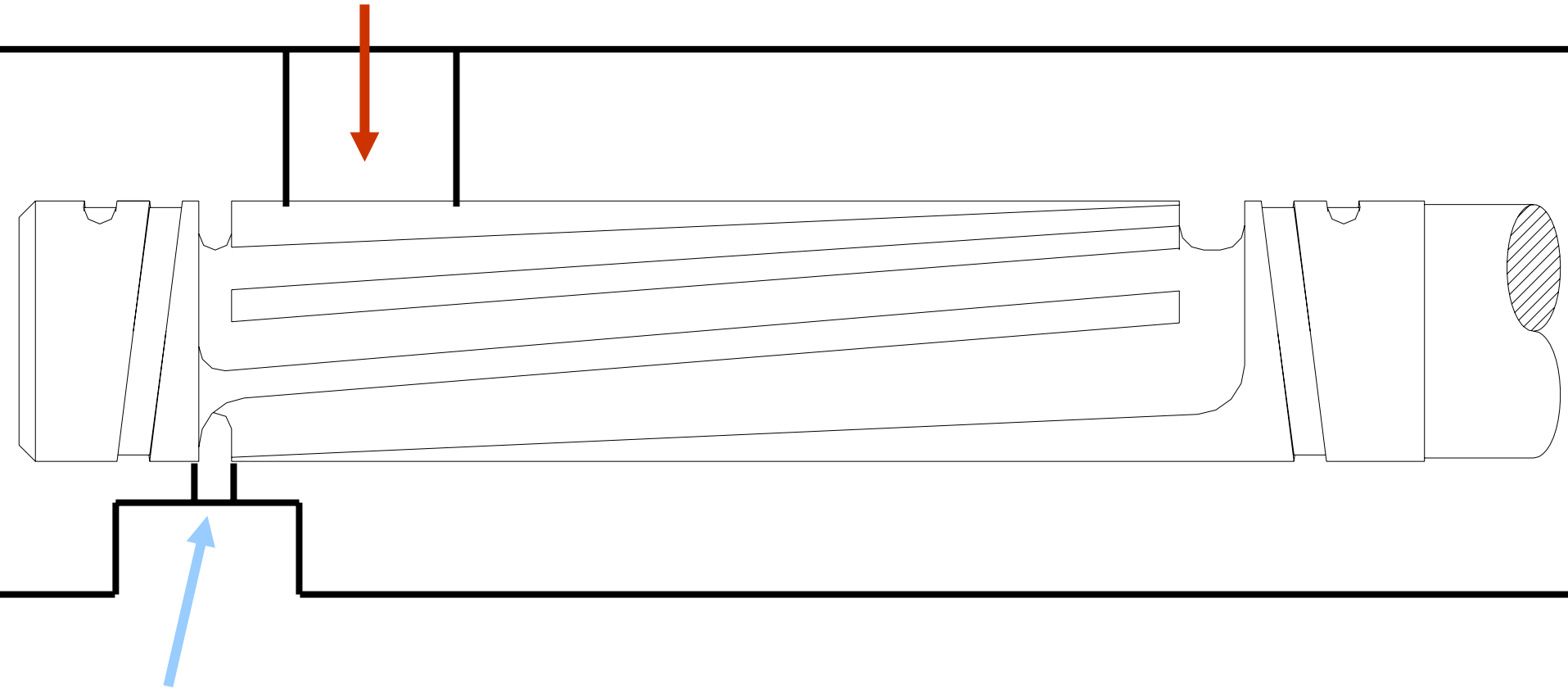

End of Second C3
P = Pump
C = Channel
C2
P1
C1
P2
C3
End of
Second C1
End of
Second C2
P1
P2
Flight
Beginning of
First C1

Batch Mixer Element



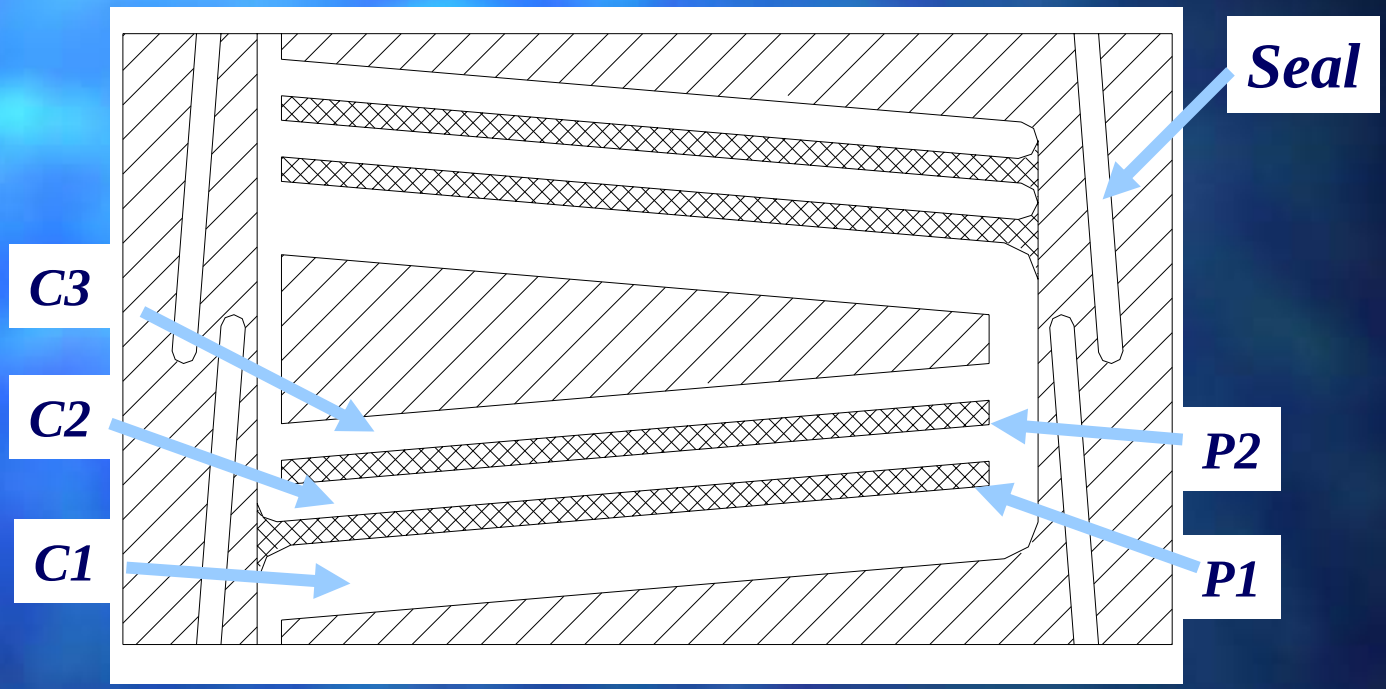
Batch Mixer Element

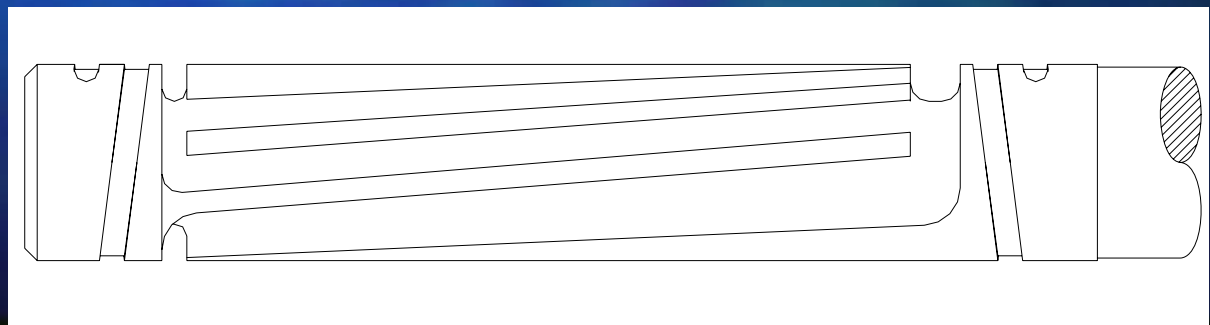
Pellets/Powder Plus



Die hole is covered during compounding then exposed during extrusion

Batch Mixer Element: Flat View





Micro Batch Mixer

Batch Mixer Cooling Experiments

Polypropylene
+
1% Red

Mixed for 2.5 minutes at 4.3 rpm

Batch Mixer Cooling Experiments

Polypropylene
+
1% Red

Mixed for 2.5 minutes at 4.3 rpm

Batch Mixer Cooling Experiments

Polypropylene
+
1% Red

Mixed for 2.5 minutes at 4.3 rpm

Batch Mixer Cooling Experiments

Polypropylene
+
1% Red

Mixed for 2.5 minutes at 4.3 rpm

Batch Mixer Cooling Experiments

Polypropylene
+
1% Red

Mixed for 3.0 minutes at 4.3 rpm

Batch Mixer Cooling Experiments

Polypropylene
+
1% Red

Mixed for 3.0 minutes at 4.3 rpm

Batch Mixer Cooling Experiments

Polypropylene
+
1% Red

Mixed for 3.0 minutes at 4.3 rpm

Batch Mixer Cooling Experiments

2.5 Minutes

3.0 Minutes

At 4.3 rpm

Batch Mixer Cooling Experiments

Polypropylene
+
1% Red

Mixed for 4.0 minutes at 4.3 rpm

Batch Mixer Cooling Experiments

Polypropylene
+
1% Red

Mixed for 4.0 minutes at 4.3 rpm

Batch Mixer Cooling Experiments

Polypropylene
+
1% Red

Mixed for 4.0 minutes at 4.3 rpm

Batch Mixer Cooling Experiments

2.5 Minutes

3.0 Minutes
At 4.3 rpm
~14 Revolutions Total

4.0 Minutes

1% Red Film and 1% Red Rod From Micro-Batch Mixer

10% Elastomer & LDPE

SFEM
Batch Mixer

SFEM
Extruder

Double Wave
Extruder

Batch Mixer: Multiple Batch Test: RPVC

1. Process 15 Grams
2. Extrude 5 grams
3. Close die door.
4. Repeat #2 and #3 five more times for a 30 grams total.
5. RPVC still not yellowed.

35% Calcium Carbonate & PP

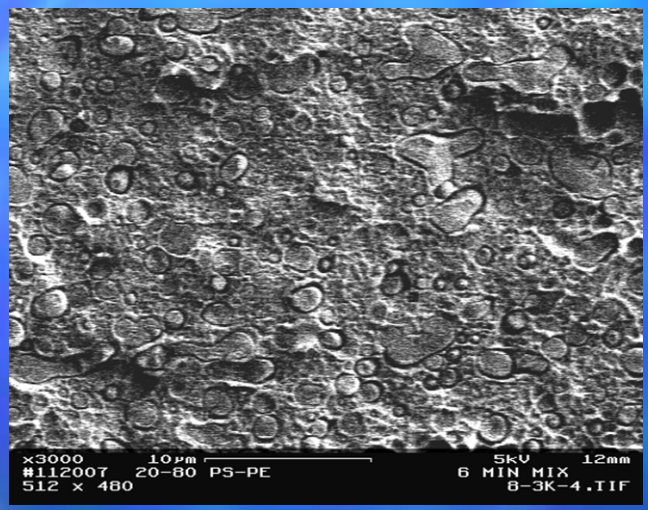
SFEM Extruder

SFEM Batch Mixer

Continuous: 20PS/80HDPE Globules
Domains: 0.2 to 2 Micron

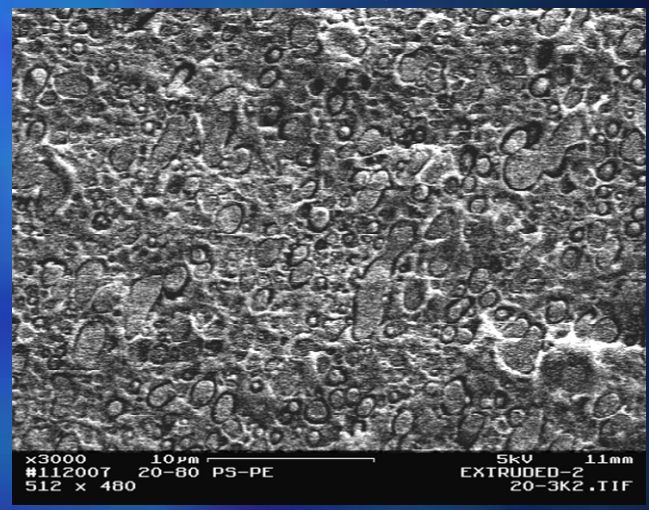
Batch Mixer

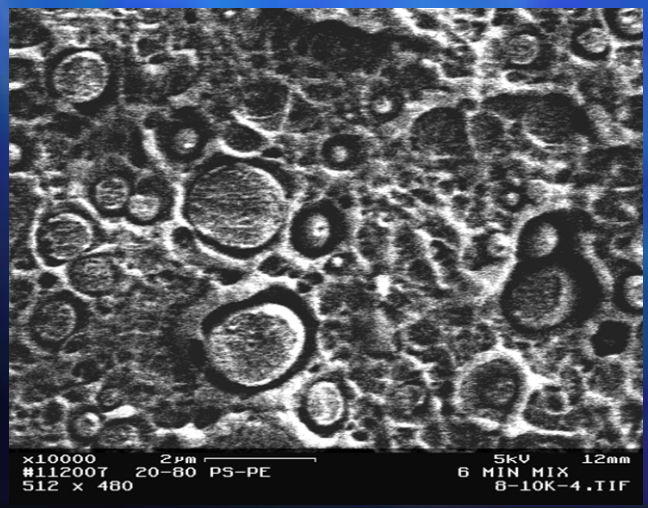
24/1 Extruder, 2 SFEM



(A)

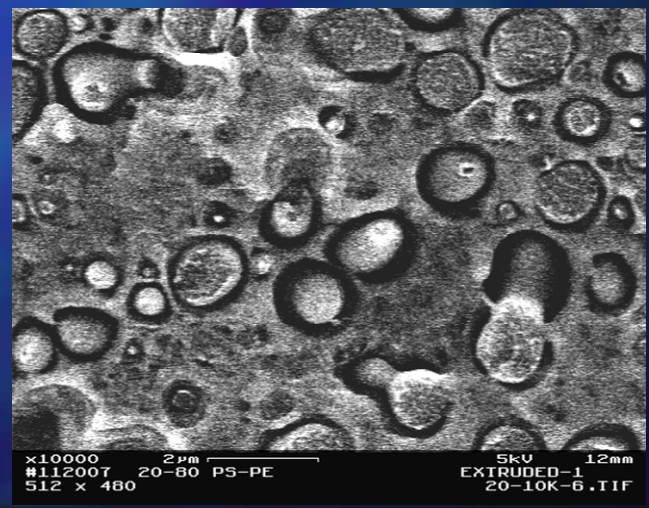
(B)





(C)

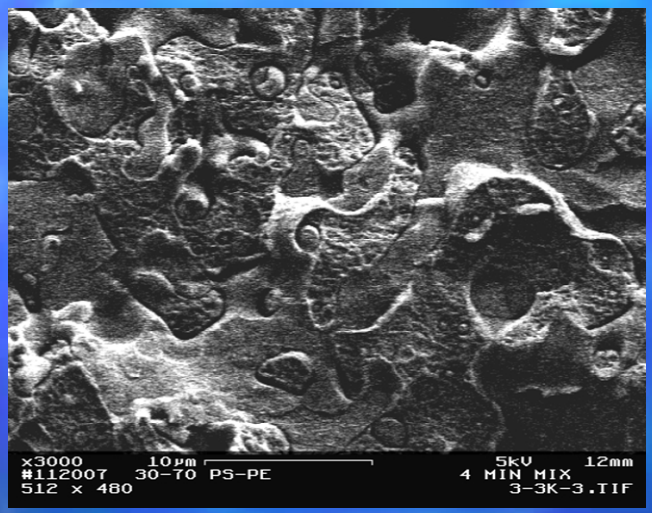
(D)



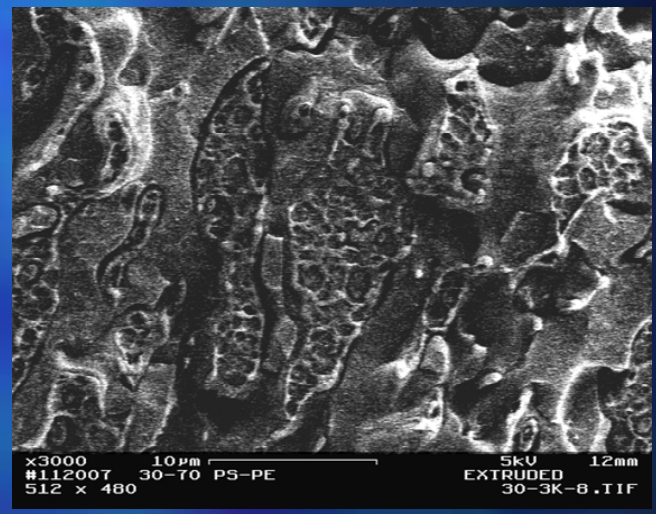
Co-continuous:30PS/70HDPE 3D Puzzle Domains: 02 to 20+ Micron

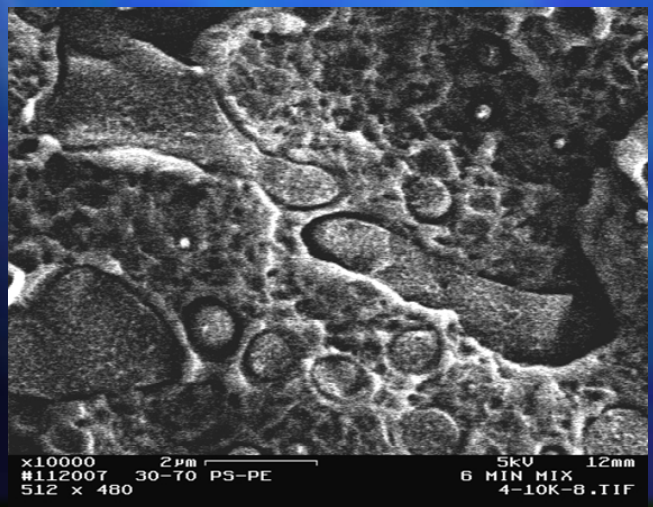
Batch Mixer

24/1 Extruder, 2 SFEM

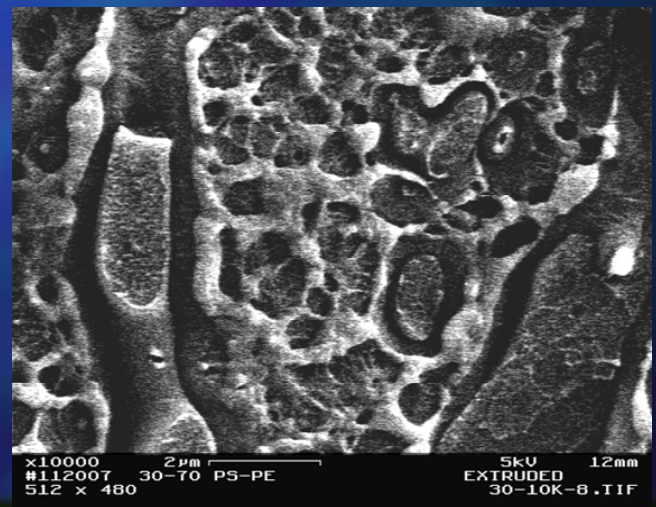


(E) (F)





(G) (H)



Discussion/Conclusions:

- The SFEM Mixer and Extruder:
  - Have very similar physical geometry yielding very similar levels of mixedness.
  - The micro-batch mixer works on a time scale similar to extrusion.

Discussion/Conclusions:

- The SFEM comparisons represent major scenarios in single screw extrusion.
  - Color
  - Thermally sensitive materials
  - High filler levels
  - Melt Blending

Discussion/Conclusions:

- The SFEM mixer:
  - Extrudes a strand!
    - Strands are easy to pelletize.
    - Pellets are the proper feed stock for processing equipment.
  - Avoids degradation.
  - Is really fast so R & D mixtures prepared in the Micro batch mixer will speed results and scale to extrusion.

Thanks To:

- Jennifer Lynch and Tom Nosker of Rutgers for the pictures of the PS/PE blends and the ceramic nano particles.
- Very special thanks to Jennifer Lynch for her effort, patience, advise and gracious style.

Thank You

PRESENTED BY
Keith Luker
President

Randcastle Extrusion Systems, Inc.
keithluker@randcastle.com

Questions?