Great Mixing And Sustainability

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1974 – 1987: Killion Extruders, Sales Manager, Production Manager, Lab Manager and VP of Development.

1988 to Present: Founder/President of Randcastle Extrusion Systems—a manufacturer of small extrusion equipment.   He taught extrusion for SPE for 20 years. He's given many papers on extrusion. He has seven patents on extrusion including compounding, pressure stability, pressure control, coextrusion and has another patent pending for compounding—the subject of these presentations.

Introduction

- The Baker's Transformation—Conceptual multiplicative mixing.

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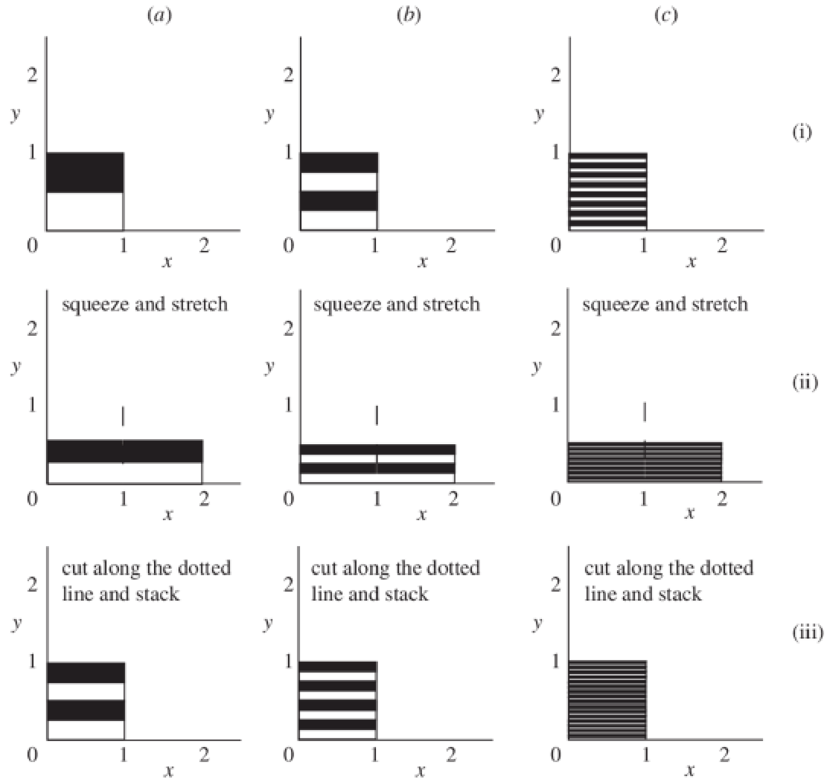
- Conclusions.

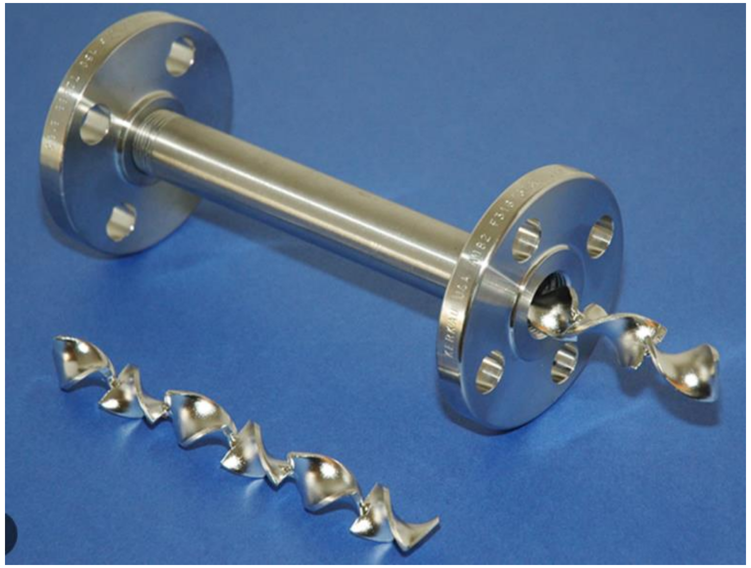
The Baker's Transformation: Multiplicative Mixing



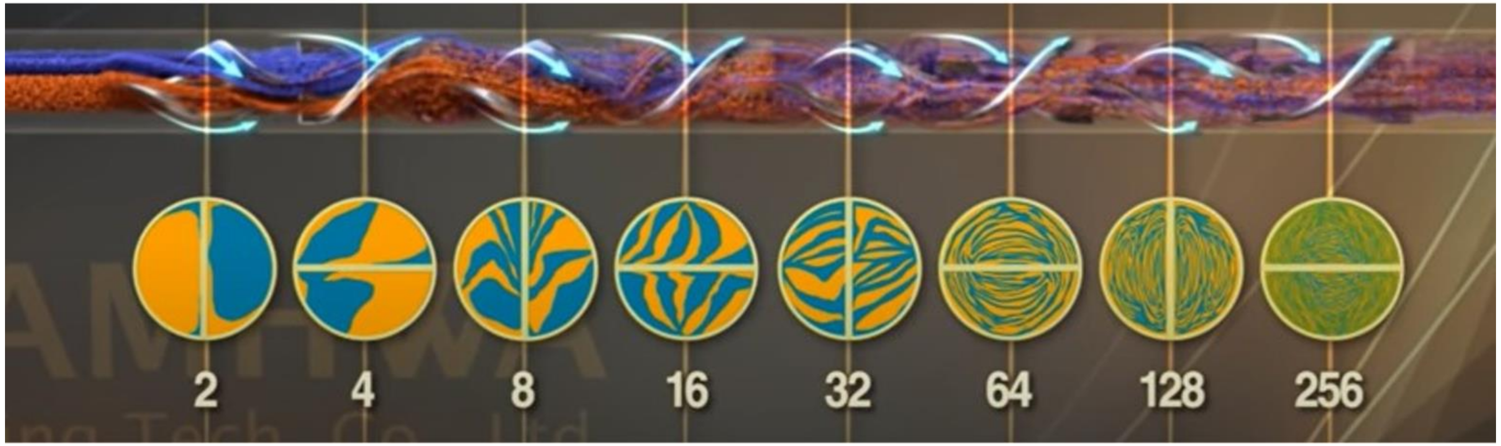
To calculate the total number of layers, use a multiplier of 2^n.

LAYERING IS DISTRIBUTIVE MIXING

Static Multiplicative Mixing



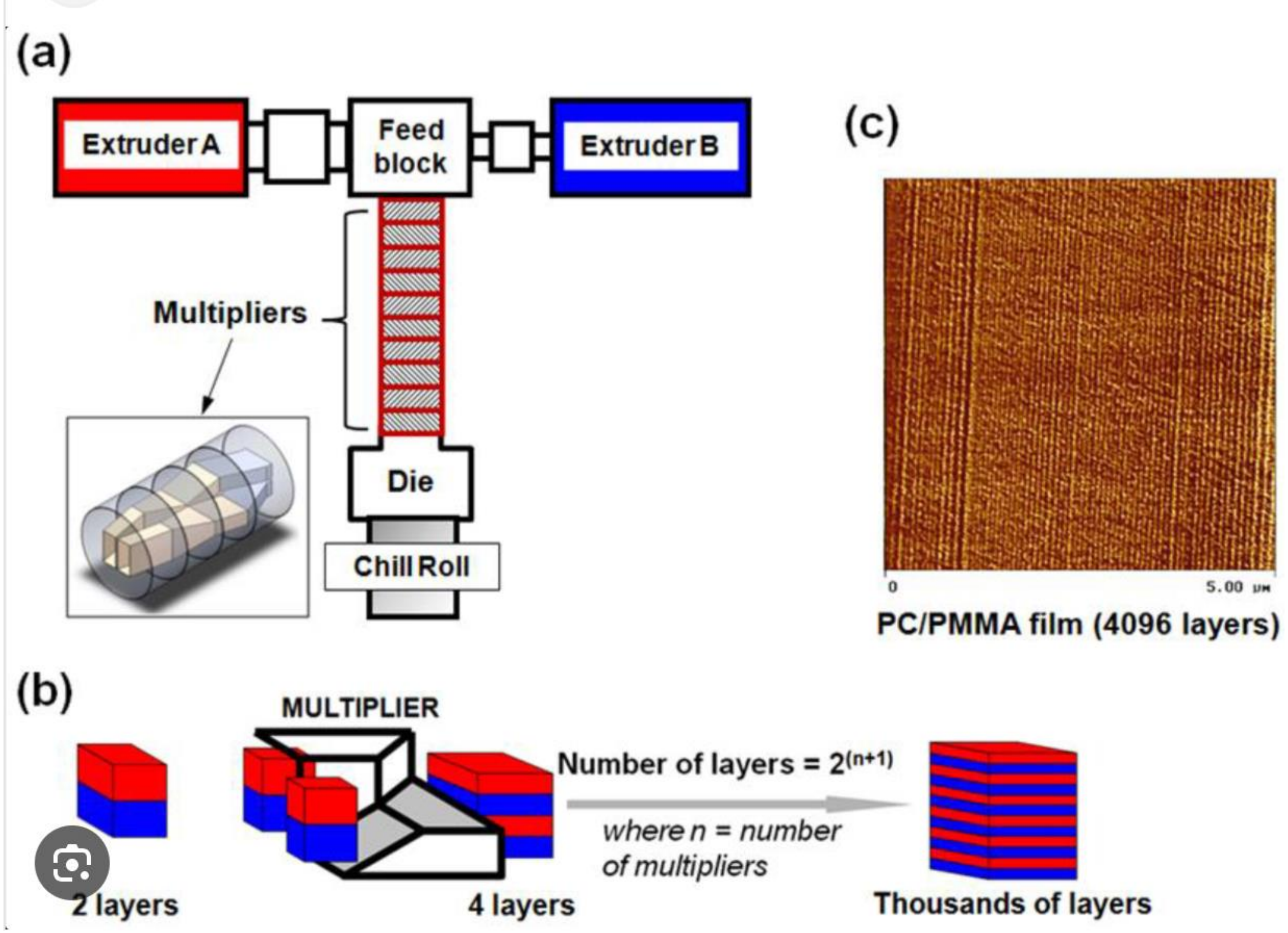
Twisted Ribbon Type Static Mixer



Also known as "Motionless Mixers" the layering created here is 2^n where n= 8 for 256 layers.

The mixture distribution is 256 times better.

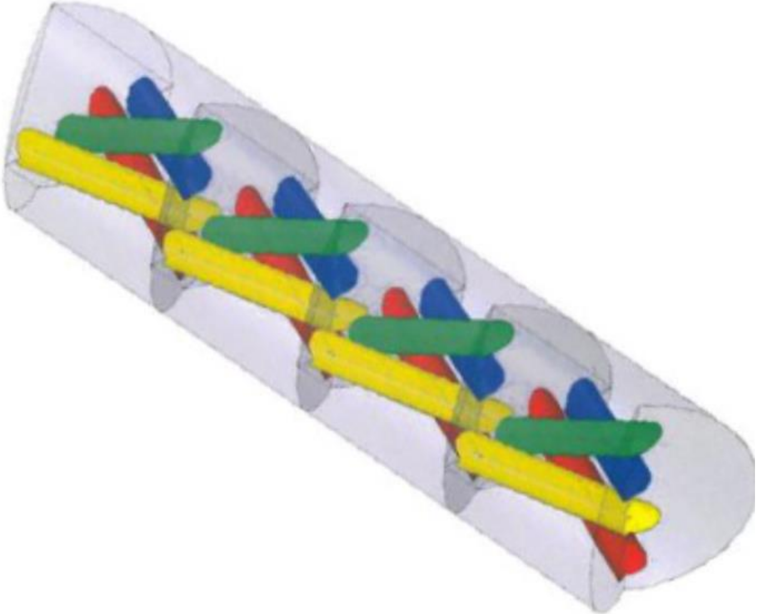
Static Multiplicative Mixing



Total layers created are also 2^n. Here n= 12 for 4096 layers. The mix distribution is 4,096 times better.

Static Multiplicative Mixing

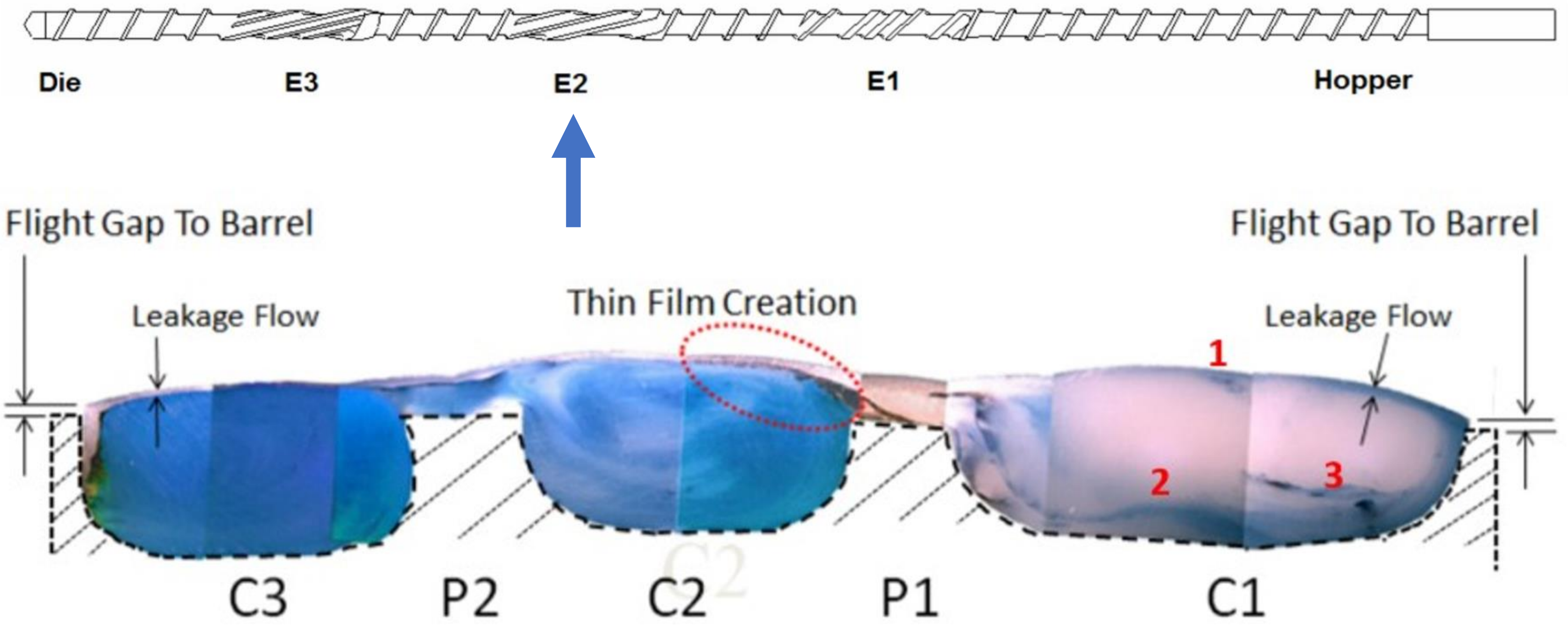
Static mixers can have other multipliers besides 2^n. For example, ISG mixer** below, is 4^n* for >2 million layers in 10 elements**:



*See Rauwendaal, *Polymer Extrusion*, p. 383, Hans Gardener 2001, for multiplier numbers and pros/cons static mixers.
** https://www.mixers.com/resources/mixing-technology-reports/choosing-the-right-static-mixer-design-for-viscous-mixtures/

Dynamic Multiplicative Mixing (DMM)

Section of Frozen Melt In Randcastle's E2 (Elongator 2) Mixer



Elongators generate pressure so no loss of output.

There are 2.5 layers (or striations) in C1. The mixing mechanism creates at least 25 layers from C1 to C2 or a 10^1 mixture improvement. From C2 to C3, for the same reasons, the mix improves 10^1 times more.

So, the total improvement for mixing element E2 is 100 times. *The multiplier for each E (Elongator) mixing element is 100.*

In this schematic, the Elongator screw with 2 functional mixing elements (E2 and E3) is 100^2 or distributive layering of 10,000 from E2 to E3.

DMM SFEM Mixing is Primarily Elongational

Progress in creating elongational flow—the primary mixing flow of twin-screw extruders (TSE)—was made by Rauwendaal with the CRD mixer. In 2011, Dow Chemical wrote* about the Elongator:

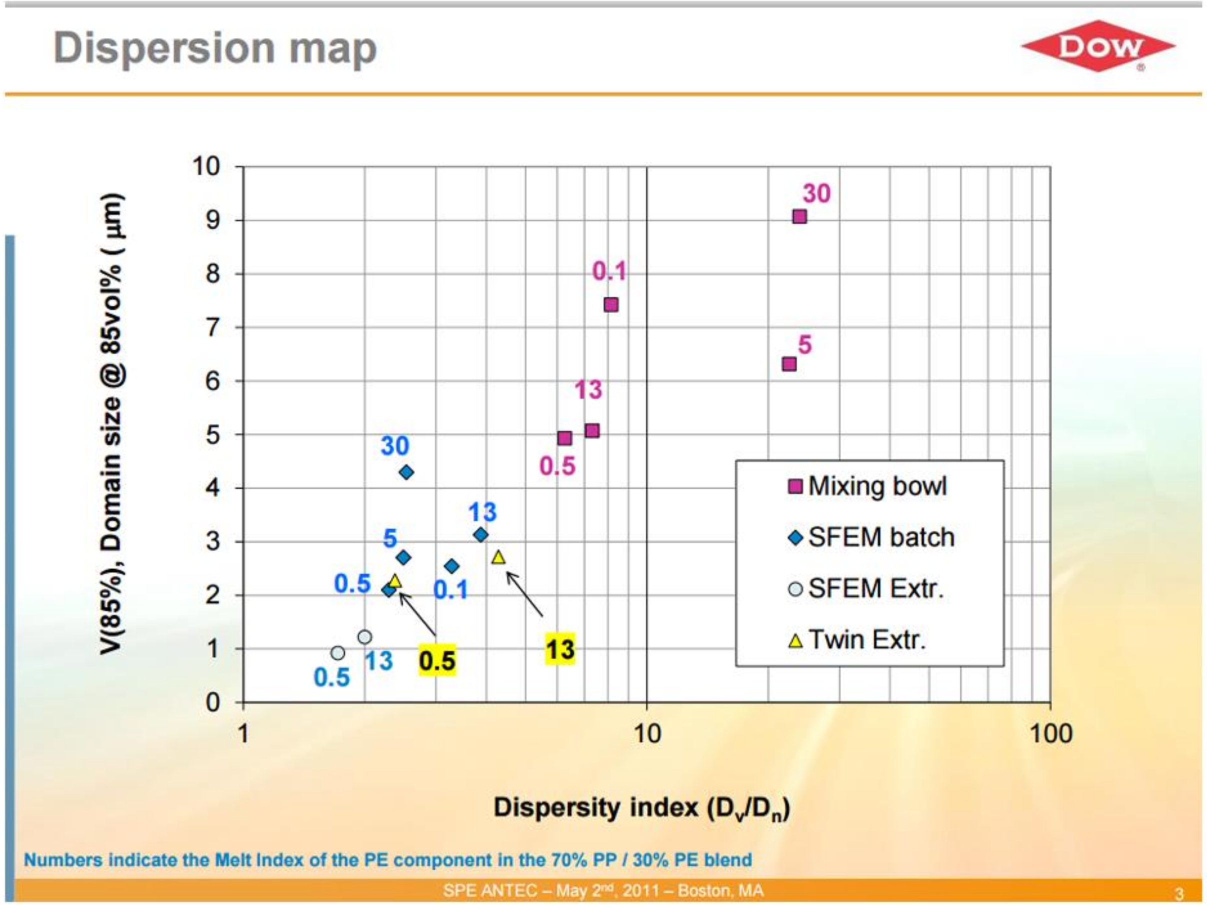
> It is confirmed that the SFEM's primary deformation mode is elongational, which also contributes to limiting shear heating effects.

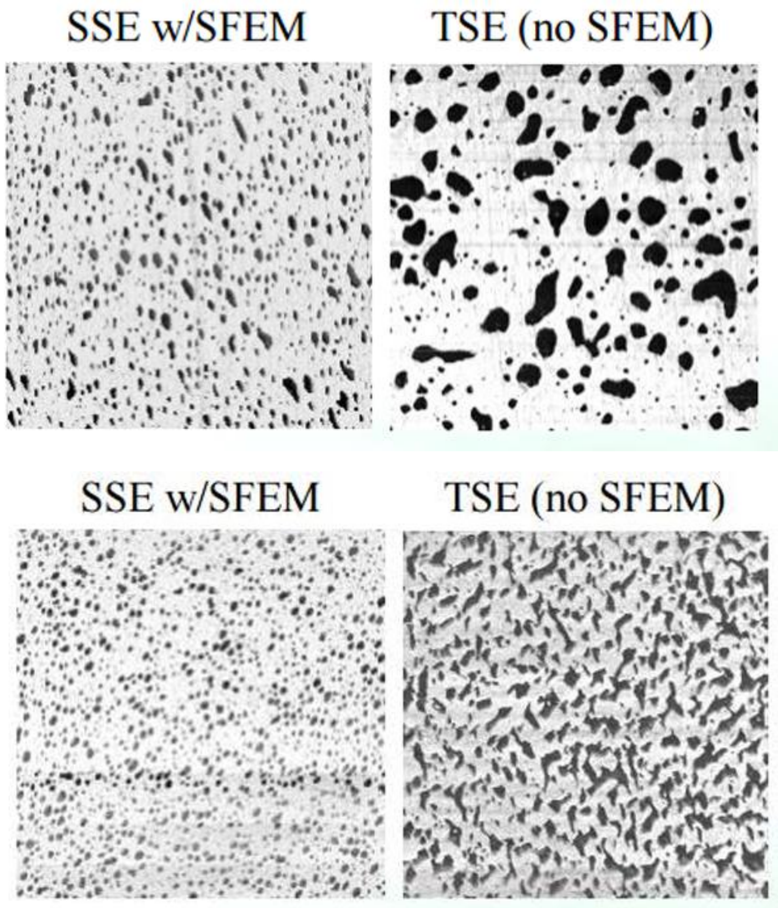
And,

> This technology is suitable for single-screw extrusion of TPOs and other immiscible blends.

FACILE TPO DISPERSION USING EXTENSIONAL MIXING Stéphane Costeux, Mark Barger, Keith Luker, Anand Badami, Kim Walton The Dow Chemical Company, Midland, MI (U.S.A.) *Randcastle Extrusion Systems, Inc., Cedar Grove, NJ (U.S.A.)

DMM With Elongation: 8 Times Better Than Twin Screw





Melt Index 13

Melt Index 0.5

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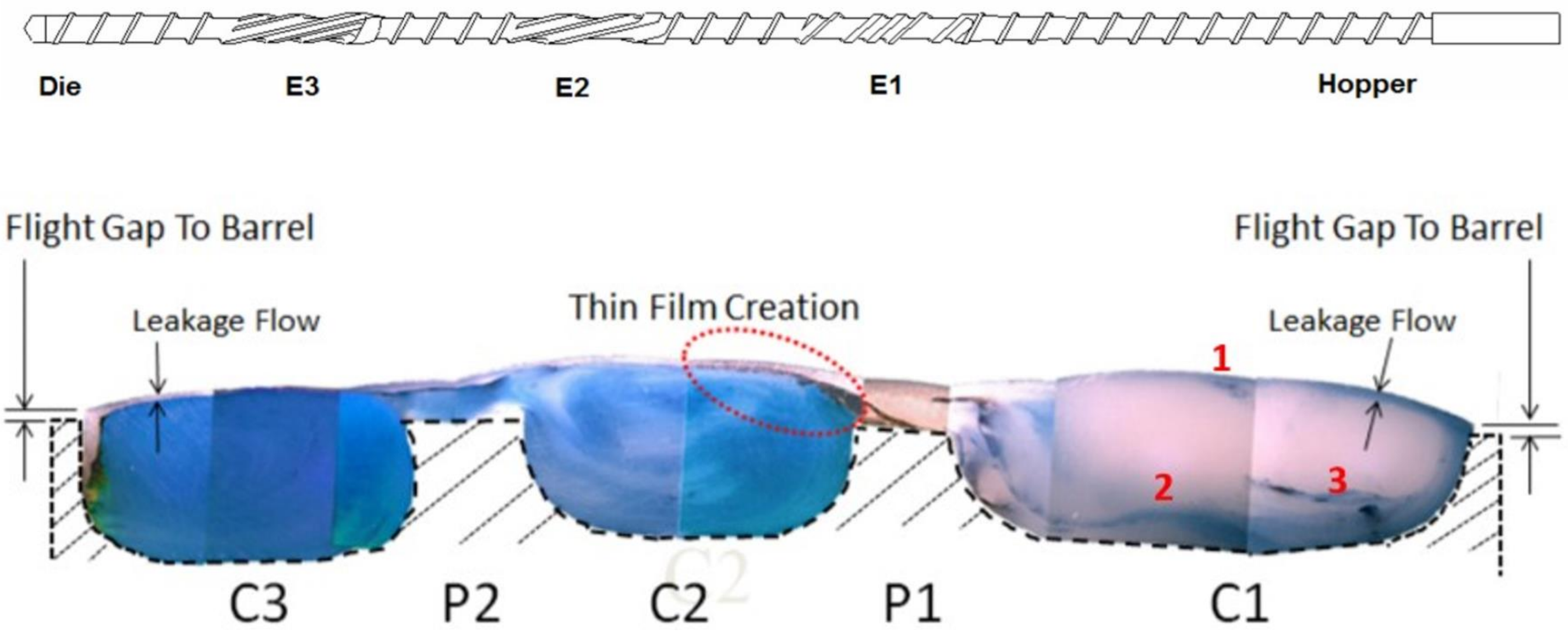
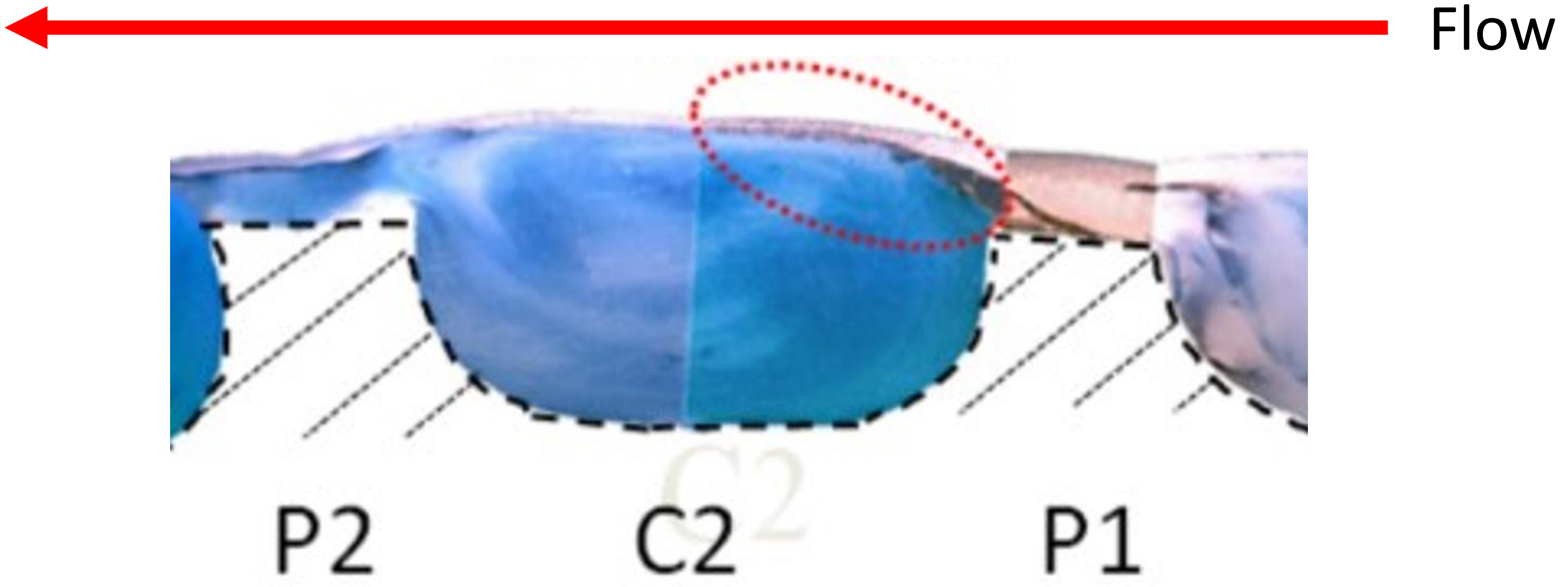
Elongation In A Dynamic Multiplicative Mixer (DMM)



Cross-Sectional Elongation In Dynamic Multiplicative Mixer

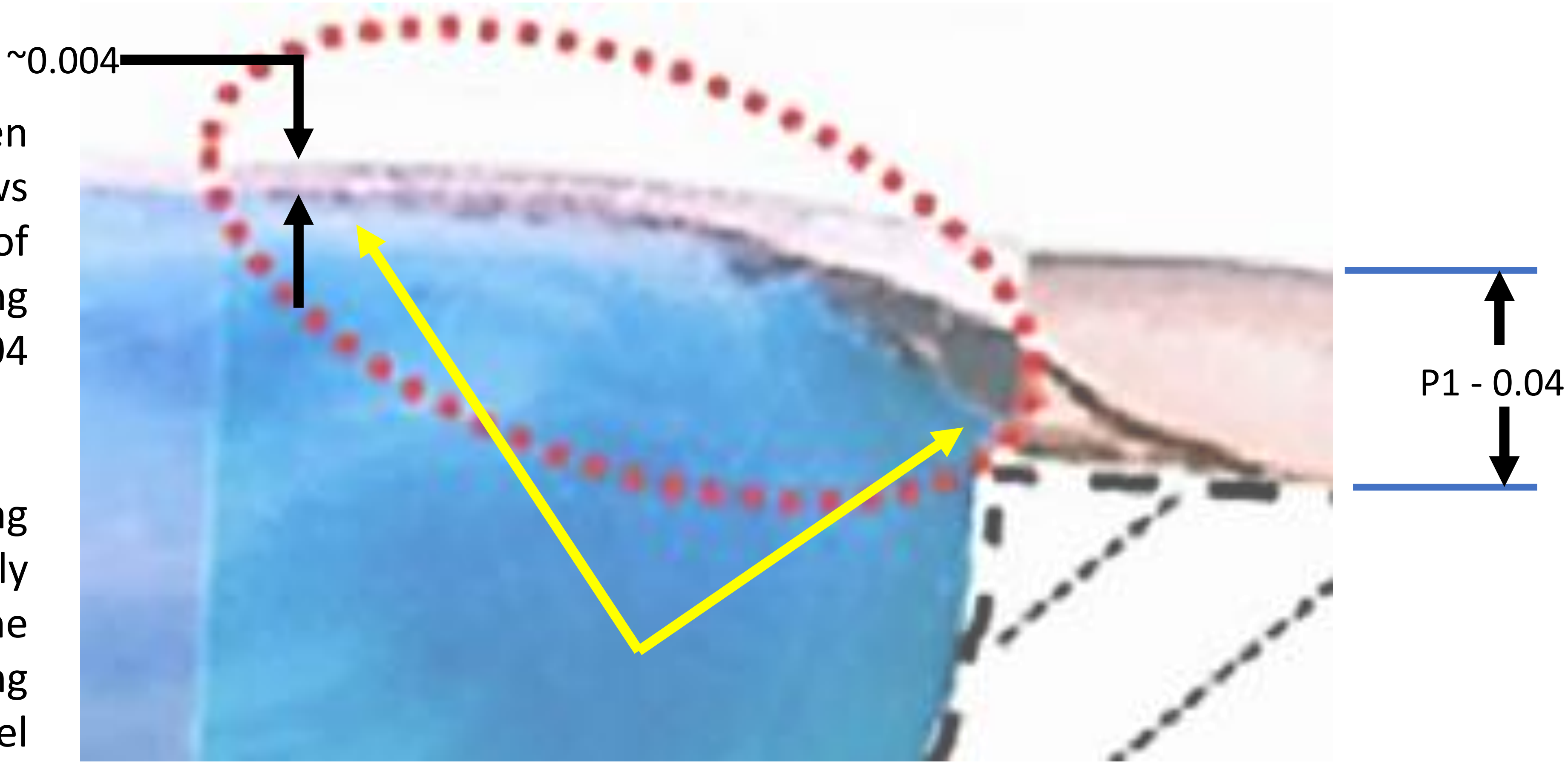


Conventionally, the flow in an extruder is thought of as a stationary screw and the barrel is moving (red arrow) causing right to left flow in the E2 (Elongator) mixing element.

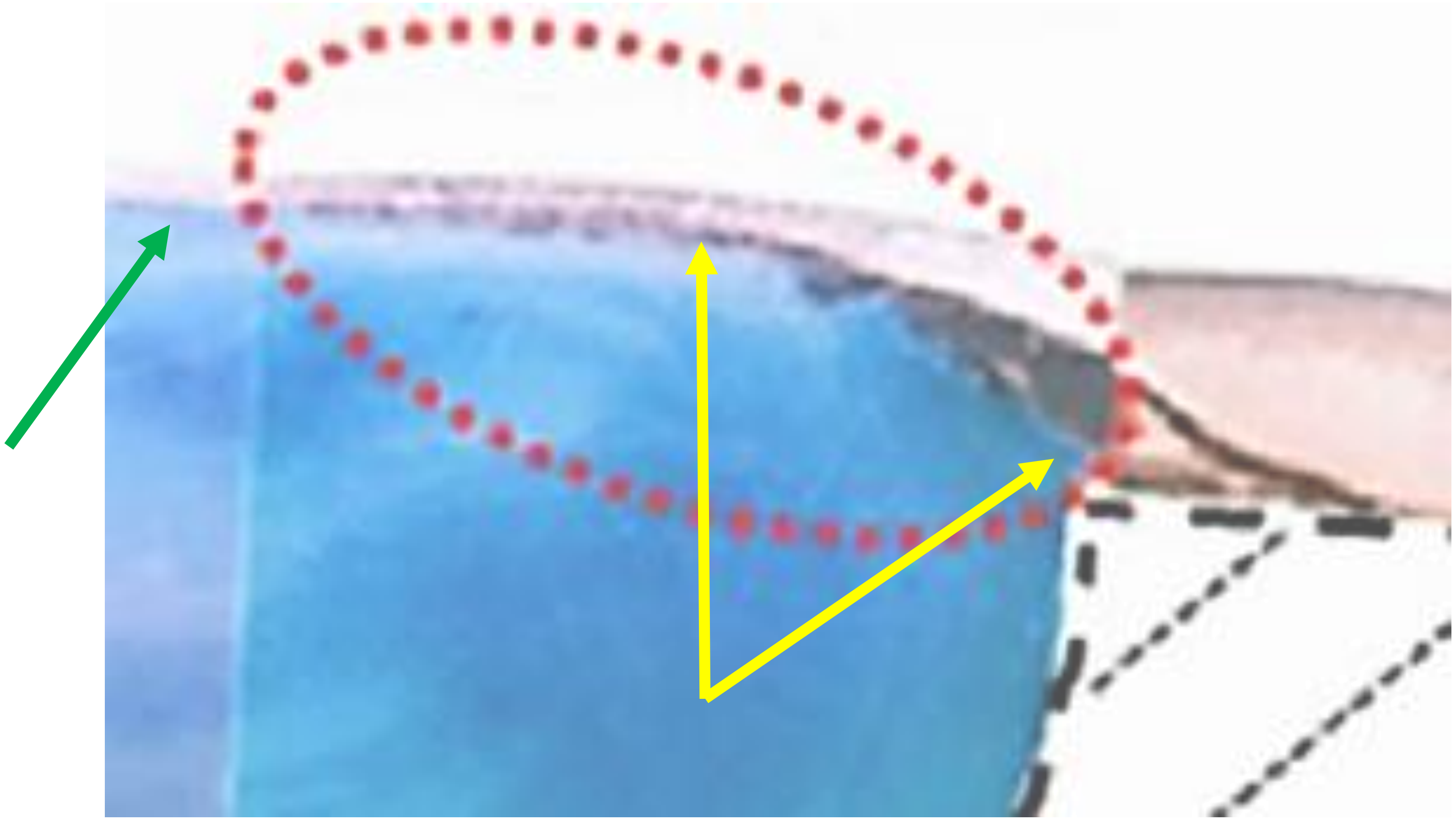
Cross-Sectional Elongation In Dynamic Multiplicative Mixer

Stretching between yellow arrows shows about an order of magnitude thinning (elongation) from 0.04 to ~0.004 inches.

This very strong elongation is partly the result of some material flowing down the C1 channel limiting P1 output.



Dispersive Example From Elongation In DMM



The large agglomerates, while they look black, can be seen breaking up (dispersed) between the yellow arrows.

Eventually, just to the left of the ellipse at the green arrow, they are finally small enough to look blue.

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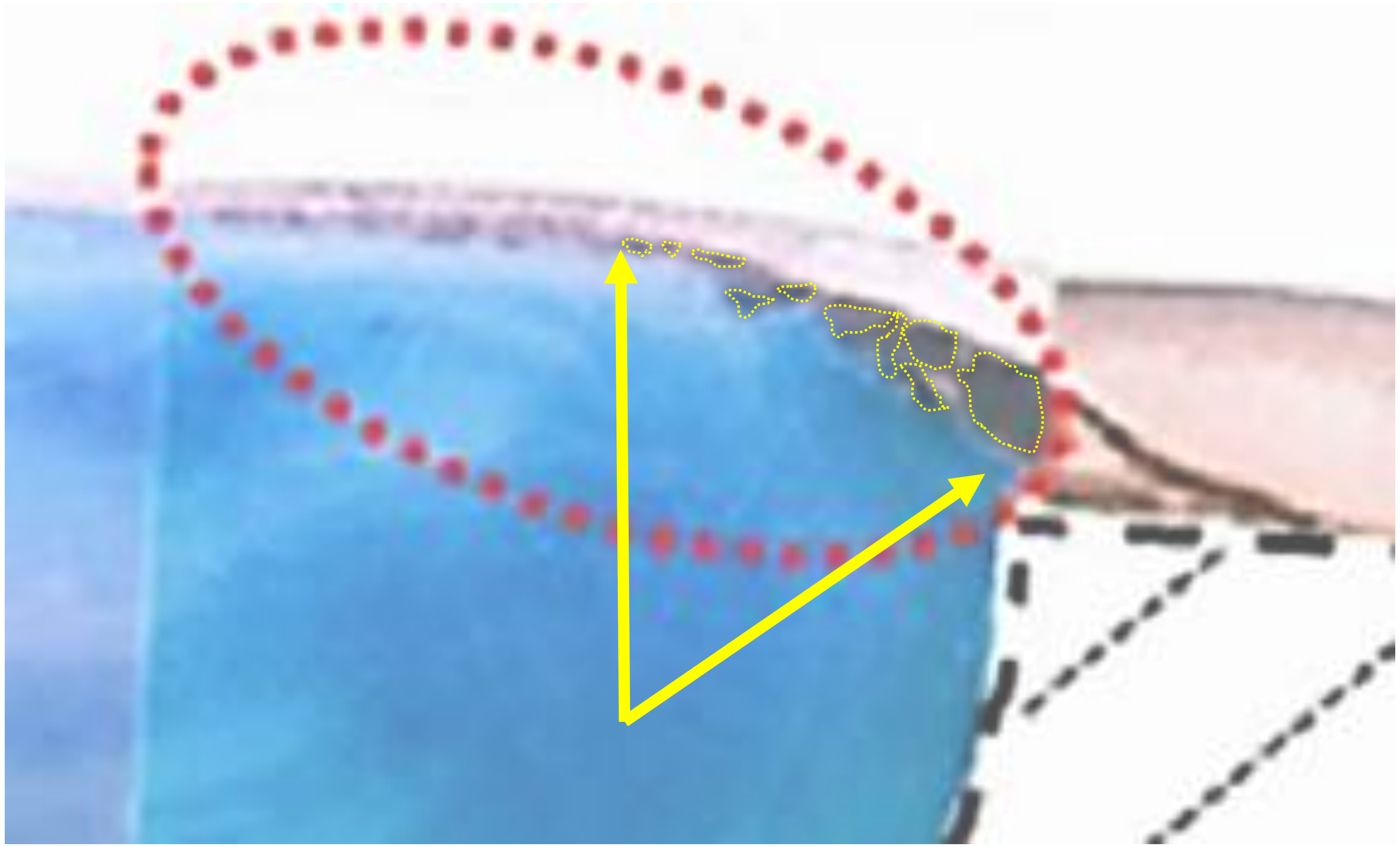
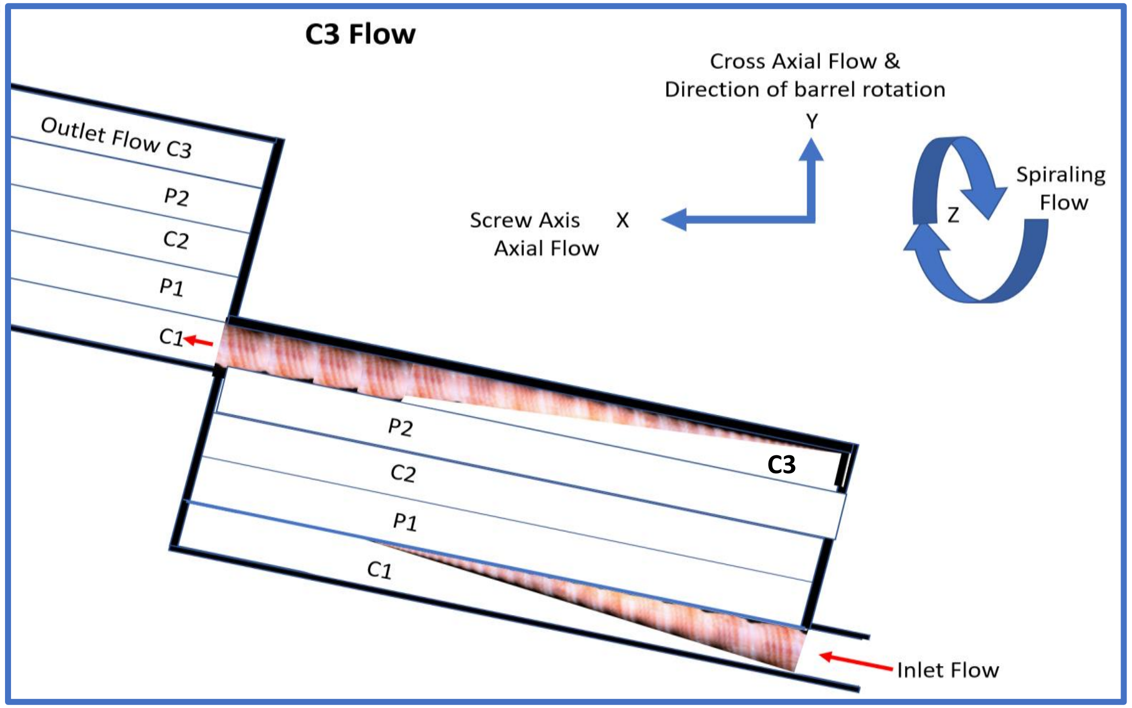
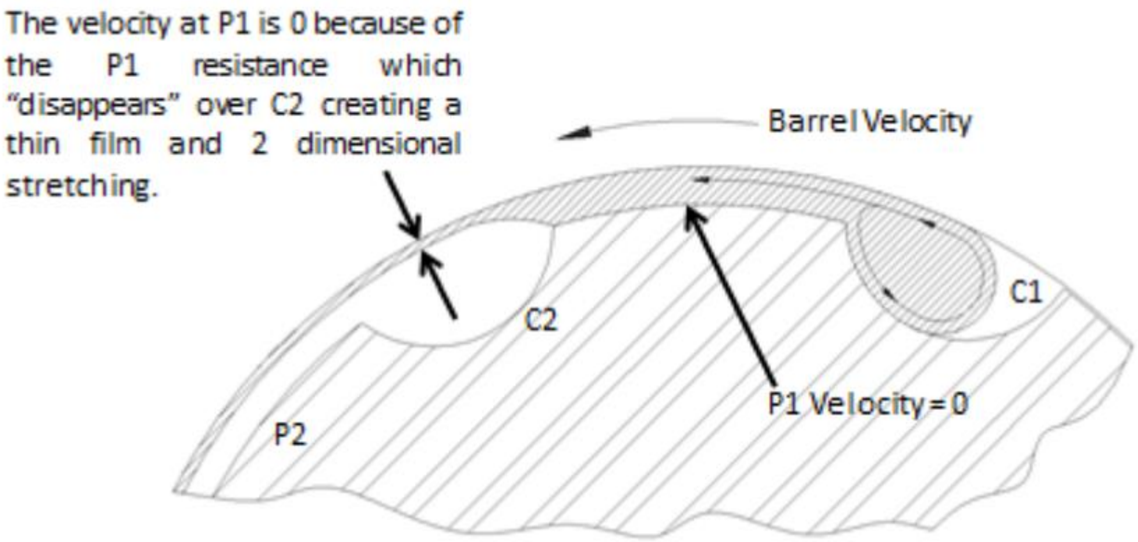


The largest of the agglomerates are outlined as they break up.

Axial Elongation/Inverse Flow In Starved DMM CSFEM





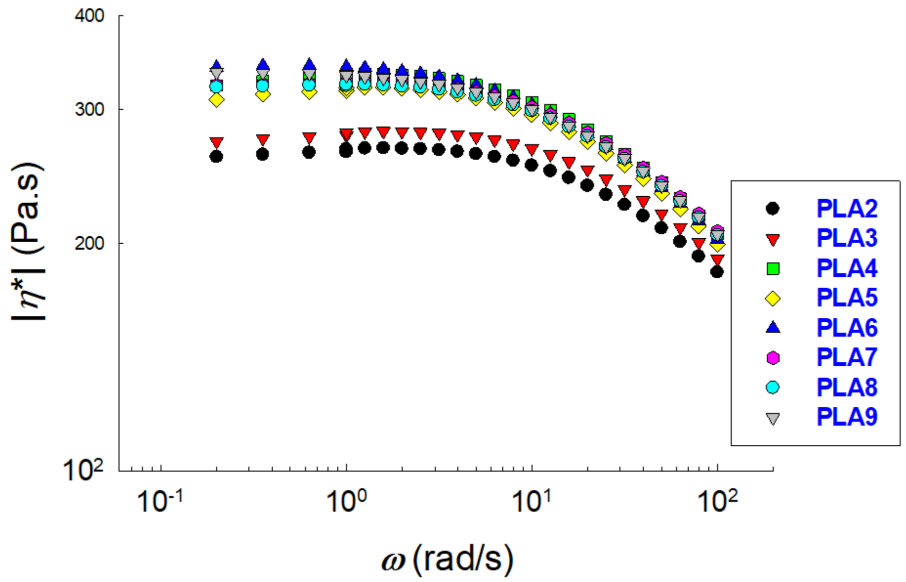
Left, flow in the **Continuous Spiral Fluted Elongational Mixer (CSFEM)** is right to left at the inlet. Axial flow is created when P1 pulls the outer viscous, sticky, material away from the inlet towards Y while the inside flow is pumped towards x. Note that the outermost flow in C1 becomes the innermost flow in C3. In other words, mixer turns the flow inside out. Note that the CSFEM is a continuous mixer because C3 of the first mixing element becomes C1 in the next mixing element.

The Continuous Spirally Fluted Elongational Mixer (CSFEM)

The multiplier of the SFEM mixing element is 100. Above, each of the seven mixing elements has a multiplier of 100 so the total number of "layers" is 100^7 or 100 trillion "layers". The number of dispersive flows per elements can be at least five per element or 35 total. All the material flows thru the 35 dispersive zones (unlike a twin) for unmatched dispersive and distributive mixing uniformity.

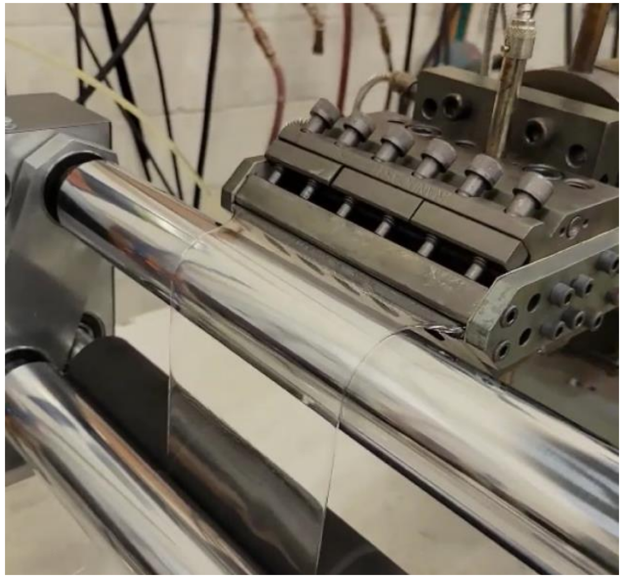
Results: The Continuous Spirally Fluted Elongational Mixer

With distribution levels of 100 trillion layering combined with uniform dispersive flows, the CSFEM should create interesting and sometimes surprising results. Below, a feedstock of 50% undried PLA and 50% undried recycle has the same curve as the virgin material—*an interesting result for a sustainable material:*



Results: The Continuous Spirally Fluted Elongational Mixer

With distribution levels of 100 trillion layering combined with uniform dispersive flows the CSFEM should create interesting and sometimes surprising results. Here, there's no sign of bubbles—*and we expect bubbles in undried material.*



PMMA

Undried, Unvented PMMA: We extruded ***undried*** PMMA through an ***unvented*** Molecular Homogenizer (CSFEM) screw making thin film. The clarity is excellent (see wiring through the film); it is smooth and glossy showing no trace of bubbles even at the edges where the path through the die is longer giving bubble agglomerates more time to expand.

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PMMA

Dried PMMA was processed through the CSFEM screw and pelletized on a Friday afternoon and exposed to atmosphere for a rainy summer weekend in NJ.

On Monday afternoon, these exposed to atmosphere pellets were reprocessed in a conventional (3:1 ACR, feed, compression meter) screw. There were no visible bubbles. Moisture pickup was delayed from about 6 hours to at least 72 hours—*at least a ten-fold reduction.*

After 30 days, in the same conventional screw, there were typical bubbles.

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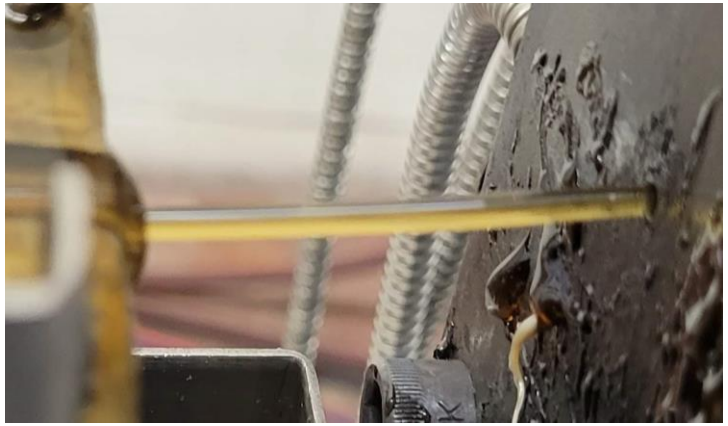
SAN COLOR CONCENTRATE

PVA

PEEK



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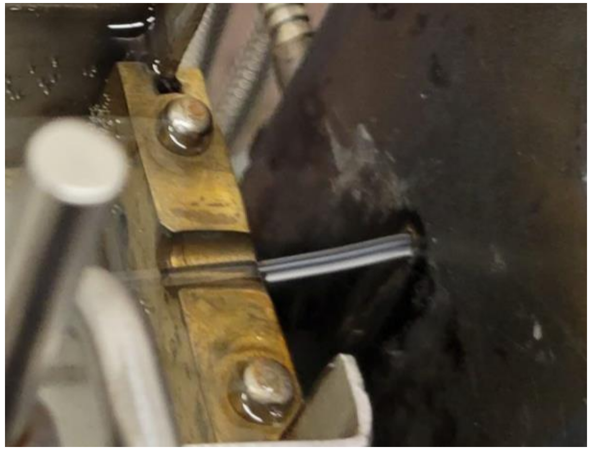
PC



PET

75% Crystal PET 25% Amorphous PET

Results: The Continuous Spirally Fluted Elongational Mixer

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LDPE 5% COFFEE CHAFF

Coffee chaff is hygroscopic and has oils that at LDPE temperatures become gaseous. Yet, bubble free extrudate was produced in a non-vented extruder. Gaseous oils cannot migrate out the hopper as they would lubricate the incoming pellets and solids conveying would stop.

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PVA With 3% Reactive Agent

Estimated conversion to gas 0.38% gas. Gases created along the screw cannot escape thru the hopper.

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- The moisture analyzer reports 0.328% moisture in the feedstock.
- It also reports 0.171% moisture, without visible bubbles, in the extrudate, at 170C for 15 minutes.

It's Better To Think Of 100 Trillion Actions

Multiplication breaks down, in terms of the number of layers created, at some point. If we only think in terms of layers, 100 trillion layers would be about 1×10^{-9} and 1 angstrom is 1×10^{-7}. An angstrom is much smaller than a polymer molecule.

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- Suppose that you wish to mix (distribute) water vapor molecules in a polymer. In that case, such distribution is useful.
- Suppose that you wish to mix the interstitial space between molecules. That space is not even. There are big and small sections that may be mixed to a much finer level.

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- The SFEM Dow Results (dispersion eight times better than Dow's twin and distribution twice as good) is not really surprising. *The CSFEM has four more multiplicative mixers (100^4).* The implication is that first compounding in a twin then making product is unnecessary, advancing sustainability by *saving energy, labor and cost.*

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- Gaseous vapors i.e. coffee oil, reacted PVA, water vapor all without visible bubbles is, at least, unusual.

Thanks!

I owe a great deal to many but especially to Tom Cunningham, Amco Polymers, Charlie Martin, Leistritz, Chris Rauwendaal, Rauwendaal Extrusion Engineering, and George Venturini of Randcastle for their insight, suggestions, assistance and generosity.


Any Questions