SUMMARY RESULTS OF A NOVEL SINGLE SCREW COMPOUNDER

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Abstract

A novel single screw mixer is described having multiple elongational flow fields, upstream axial mixing, and thin film degassing. SEMs show high magnification examples of mixing including a PS/PE immiscible polymer blend, ceramic nano particles, and discrete carbon nano tubes. Novel degassing over the mixer is cited using three vents in a 36/1 L/D single screw to process undried PETG.

Introduction

Historically, single screw extruders have been pumps first and compounders and degassers second.

Single screw mixers, or compounders, have lagged because they have lacked the multiple elongational flow fields of multi-screw extruders, simple upstream axial mixing, and the ability to degas during mixing.

As degassers, single screws have lagged because degassing did not occur during mixing and so lacked the superior surface renewal of multi-stage screws. Further, multi-screw twins commonly use multiple vents to sufficiently extract gases. Often one is a coarse vent and two are for fine degassing. But single screws have lagged because the second stage of a two stage screw uses about 12 L/D's (~6 L/D pumping, 1 L/D compression, 4 L/D venting, 1 L/D decompression) of axial length—often practically limiting singles to one vent.

The UC mixer, Figure 1, is typical of a fluted mixer that after melting, pumps material through a shear plane. The design requires a relatively high input pressure to overcome the resistance of the entry flute (since it dead ends) and the resistance of the mixing land.

It is well known that elongational forces are more effective for dispersive mixing than shear [1]. Some attempts have been made to induce elongation in single screw extruders such as by a shaped pin [2].

Upstream axial mixing conveys material from a downstream to an upstream position along the screw such as by a screw within a screw [3] or a downstream flow passageway that leads upstream.

Various methods of venting in a single screw extruder are known [5] as are multiple flights in the extraction section for improved surface renewal [6].

Generally, the level of magnification measures the quality of mixing. Historically, mixing in single screws is judged by eye [7, 8] and optical microscope [9, 10, 11] but not with scanning electron microscope (SEM). The higher the magnification, the finer the mix. Most single mixing to date is done, at best, with optical microscopes at about 400 times magnification.

The goal of this paper is to describe a single screw mixing element that combines multiple elongational flows, upstream axial mixing and degassing during mixing. We then show some of the mixing results using SEM pictures from 3,000 to 50,000 times magnification and a degassing experiment.

Mixer Description/Operation

Figure 2 shows a section of a screw downstream of a flighted section and sectioned along A-A. Two channels, C1 and C2 separate P1 and P2. When rotated, P1 and P2 are drag flow pumps causing flow in the direction of the arrows. Greater drag flow—in the direction of the arrows—is enhanced when axial pressure flow is lessened towards zero in the C1 and C2 channels until all flow is cross axial at zero pressure.

Figure 3 and 3A show a more useful arrangement of channels and pumps in the "Recirculator" [12] (hereafter) mixer. One third of the mixer, circumferentially, is "laid flat" in Figure 3, show between flights and would be duplicated three times. This is useful in that, just as in multiple flights, melting, mixing and degassing benefit from processing in smaller amounts. Conceptually, this particular mixer is shown after melting in the typical downstream position near the end of the screw though typically preceded by 1 to 3 other mixers as in Figure 3A. The flat section is bounded by a tight fitting boundary, B (similar in clearance to a typical flight).

Figure 3 shows an input flow from the flights on the right and flowing to the left as indicated by the arrows. In this case, the input flow is set substantially below the pumping rate of the P1 and P2 pumps either by a separate upstream starve feeder or by screw geometry (such as shallow input channels or narrow pitch) ahead of the mixer.

Flow in the input channel will be a combination of the pressure flow in the axial direction and drag flow in the cross axial direction. The combination continuously stretches the flow as the viscous material is pushed down the channel, where it will flow spirally, and pulled by the pumps. A cold screw pullout shows the angle of lines from a pigmented PP frozen on the screw in Figure 4. The stretching flow in most of the channel may be visualized continually unwrapping a spiral roll of “fluid paper.”

As the flow in C1 approaches P1, it starts to resemble the flow preceding lobal kneading discs. Figure 5 shows lobal kneading discs superimposed over a cross sectional view of the mixer. In all mixing elements, the flow is divided into smaller masses for better processing. In all mixing elements, the material approaches a “lobe” in twin screw terms or a “pump” in this mixer’s terms. In all mixing elements, the flow is a combination of pressure flow and drag flow.

Proceeding from the input channel entry flow, Figure 3, material sticks to the barrel as it is pumped over channel C1 as a film between P1 and P2 with a continually renewed surface and additional elongation.

Proceeding from P2, Figure 3, material enters C3. The material is constrained by the boundary, B, and flows to the left (pushed by the P2 pump).

Upon leaving the C3 channel, material can move in two axial directions. Material arriving on the downstream flight, to the left, will advance downstream. However, material may also enter the C2 and C1 channels flowing axially upstream, from right to left. In each case, the flow will again elongate and stretch (as previously described at the entry to C1 but now flowing upstream) for additional mixing and surface renewal.

Upstream axial flow may be increased, compared to the input flow. It is even possible that the upstream axial is greater in volume than the input flow, as in Figure 6, by additional starve feeding. This is particularly useful in cases where extreme distributive mixing is required and the polymer is not sensitive to degradation.

Alternatively, upstream axial flow can be reduced to zero if the polymer is sensitive to degradation by decreasing the starve feeding, or by flood feeding, as in Figure 7, or by reducing the length of the mixer.

As on multiple-screw extruders, kneading blocks can be placed far upstream. Likewise, one mixer was placed 7 L/D’s from the water cooled feed section and the screw rotated to 250 rpm. There is little chance that the material will have completed melted before the mixer. Because the inlet channel is open downstream, it does not act as a barrier to flow. Whole pellets can enter the inlet channel and begin to melt. Since hard unmelted material cannot flow over P1, whatever melt exists is believed to drain over P1, leaving the solids in the C1 channel. We believe that this acts similarly to a melt separation screw. Once the solids soften sufficiently within C1, then they can pass over P1. If the pellets do not soften sufficiently, then the pellets exit C1, and enter C2 moving upstream for additional melting opportunities or move downstream.

Figure 8 shows a cold pullout of an upstream mixer. Natural PP pellets and yellow color concentrate were fed by a starve feeder (from right). Incoming pellets are clearly visible. Unfortunately, the cold pullouts within the mixer are fragile and tend to break during removal. The empty area was originally further downstream (to the left). Figure 9 (a larger view of Figure 8) shows partially melted pellets in C1 indicated by the arrows.

Since the mixers have empty regions, the pressure is near zero. This has three advantages. First, vents may be placed over the empty regions and a vacuum will communicate with the various flows within the mixers—especially the film between P1 and P2. Second, the lower the pressure consumed by a mixer, the less heat generated. Third, the empty regions dampen surges by acting as accumulators.

Results

Previous results have described the mixer for distributive compounding of up to 40% wood flour and LDPE pellets; elastomer compounded with LDPE, color mixing and vinyl processing [13].

Yu et al [9] studied various PS/LDPE 95/5 blends and achieved average domains of between 6 and 11 microns. Rauwendaal [14] studied a dry blend of high density polyethylene and polystyrene in 60:40 by weight ratio. Using an optical microscope, he found that one-third of the outer part of the extruded strand (approximately half the strand volume) was substantially coarser than the inner material and measured about 20 microns. The inner region reportedly measured about 4 microns. A somewhat similar dry blend, Figure 10, of high density and polystyrene, in a 80/20 by weight ratio, was processed using three of the mixers in a 5/8 inch, 50/1 L/D extruder. The outer boundary is negligible and the SEM shows PS domains of about 1 micron.

Ceramic particles in the 30 to 60 nanometer range were processed using the same 3 mixer extruder above. Figures 11, 12, and 13 show SEM at 5000 X, 10,000 X and 50,000 X where it is possible to distinguish individual and slightly agglomerated particles.

In a very brief experiment (25 grams of carbon nano tubes and 475 grams of PMMA) were processed in same extruder above but with 4 mixers and a low output screw. Figures 14, 15, and 16 show SEM at 1,000 X, 3000 X and 10,000 X where individual, apparently unentangled, carbon nano tubes are visible.

A 1 inch 36/1 extruder with three vents centered over three mixers processed undried PETG into 5 mil film. Using an optical microscope, no bubbles were found. This does not imply that a loss of IV from hydrolysis was prevented but only that three vents were practical and removed sufficient water to make a bubble free film.

Discussion

Two broad mixing categories are polymer blends and particulate mixing. Of these, two difficult mixing areas include the immiscible polymer blends and nano particulate mixing.

The mixer is unique in its combination of properties within single screw technology. In addition to the specific properties described, this remains a single screw extruder and retains the ability to readily generate high, stable pressures without a gear pump.

Conclusions

This mixer shows a surprising degree of mixing. Prior magnification judged the quality of mixing from 0 to about 400 times magnification. This mixer can be judged by its 3,000 to 50,000 times magnification.

Together with the earlier work cited, the mixer is a flexible processing tool for many different materials. The mixer can combine multiple elongational flows, upstream axial mixing, and venting in a unique single screw extruder that is still capable of high pressure development and stable pressures. The combination adds a powerful tool for the polymer processor. To use multi-screw terminology, it is a direct compounder.

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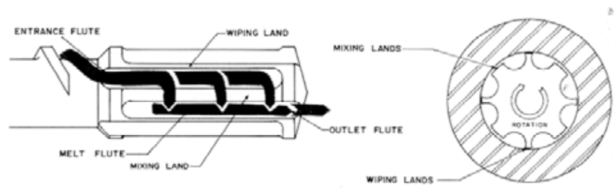
Key Words

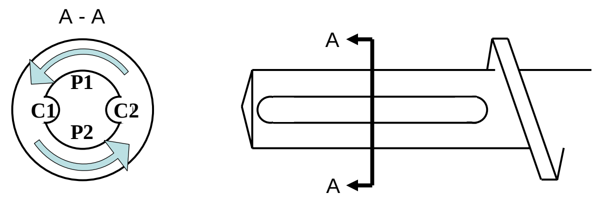
Mixing, Elongation, CNT, venting

Figure 1: Union Carbide Mixer



The entrance flute dead ends at the wiping land. Pressure, generated upstream, forces material over the mixing flute where the material is sheared. The higher the pressure, the higher the heat generation.

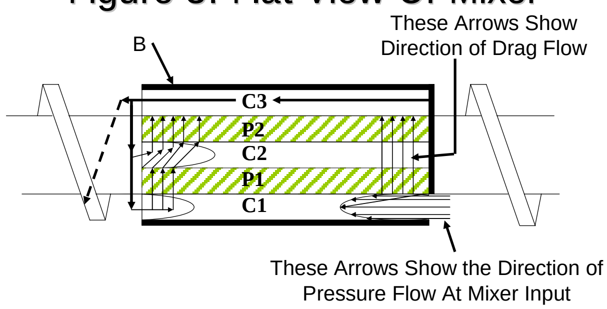
Figure 2: Pump and Drag Flow



P = PUMPS C = CHANNEL

P1 and P2 will pump (rather than act as a barrier to pressure) when the pressure in the channels is low.

Figure 3: Flat View Of Mixer



Mixer Flow With Input Below Pumping Capacity of P1 and P2

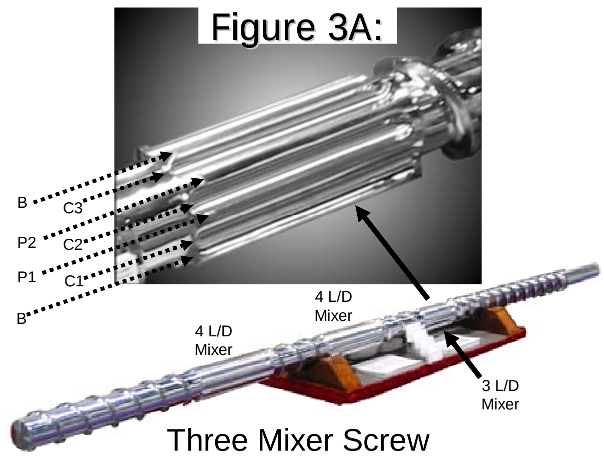


Figure 4: Stretching Flow In Cold Screw Pullouts

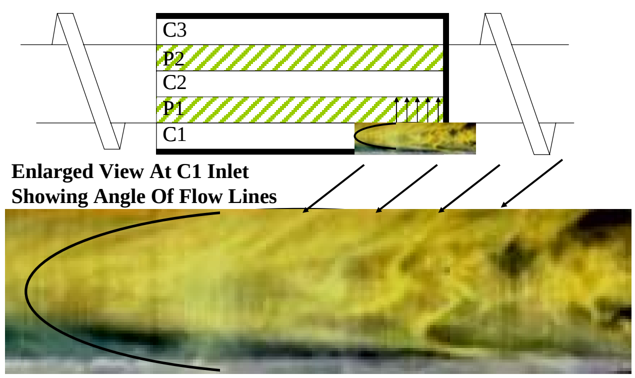


Figure 5: Comparison Lobal Mixers

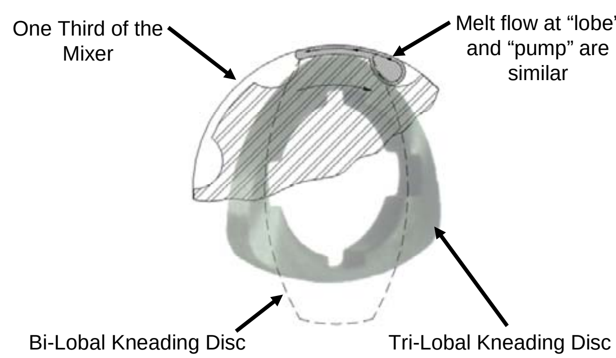
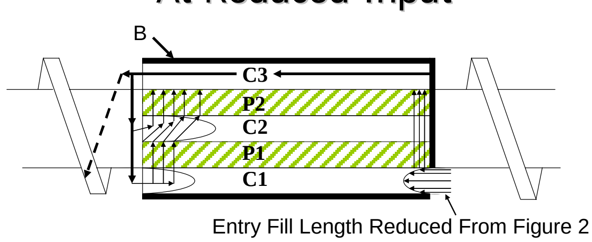
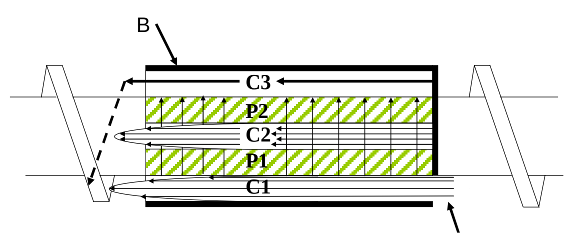


Figure 6: Flat View Of Mixer At Reduced Input



C1 Recirculatory Flow, Left, Greater Than C1 Entry Flow, Right

Figure 7: Flat View of Mixer Flood Fed Input



Upstream flow eliminated by increasing the input flow.

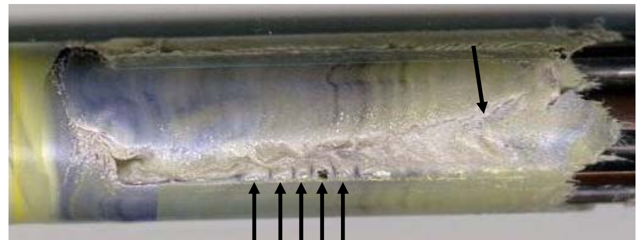
Figure 8: Melting In Mixer Cold Pullout

Pellets about to enter C1.

Note the starve fed channel

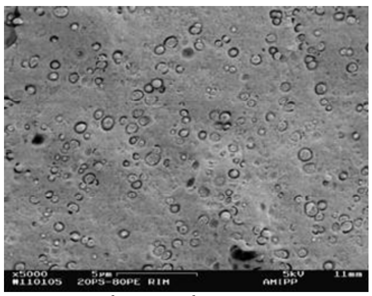
These clear PP pellets were mixed with yellow color concentrate. The fragile sample was damaged during removal. The empty volume in the mixer was further downstream (left).

Figure 9: Melting In Mixer Cold Pullout



These appear to be partially melted pellets

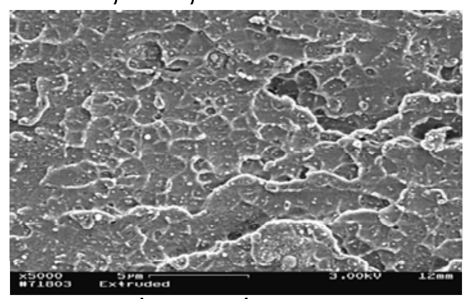
Figure 10: 20PS/80PE



5 microns

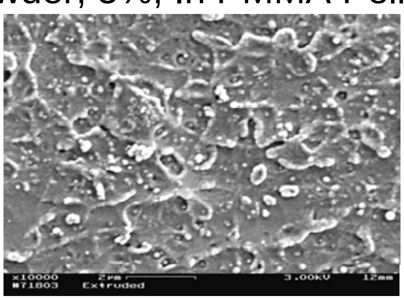
X5000 magnification, shows PS domains ~1 micron and smaller

Figure 11: 30 to 60 nm Ceramic Powder, 5%, In PMMA Pellets



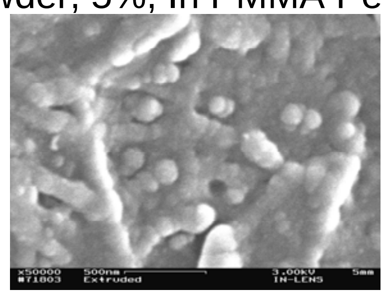
5,000 X 5 microns

Figure 12: 30 to 60 nm Ceramic Powder, 5%, In PMMA Pellets



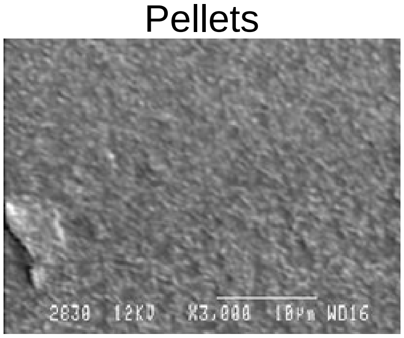
10,000 X 2 microns

Figure 13: 30 to 60 nm Ceramic Powder, 5%, In PMMA Pellets



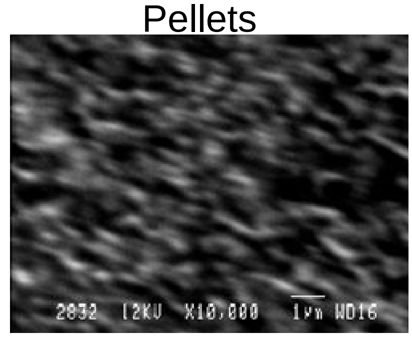
50,000 X 500 nm

Figure 14: 5% CNT and PMMA Pellets



3,000 X 10 microns

Figure 15: 5% CNT and PMMA Pellets



10,000 X 1 micron