NOVEL SINGLE SCREW ELONGATIONAL COMPOUNDER FOR THERMALLY SENSITVE MATERIALS

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Abstract

At Antec 2007, a new single screw compounder (SSE) was introduced. The mixing elements along the screw had axial flutes with elongational mixing (AFEM). In some process conditions, such a mixer can also have upstream axial flow with additional elongational and distributive mixing. The Recirculator [1], hereafter AFEM, demonstrated effective compounding of immiscible blends to 1 micron and particulate mixing to the 500 nanometer scale. [2]

An AFEM processing with upstream axial mixing, while particularly useful in the tested applications, is a potential liability for thermally sensitive materials as they may degrade from extended residence time.

By twisting the AFEM into a spiral, a new mixer was created—the spiral fluted elongational mixing (SFEM). The SFEM does not have upstream axial mixing so a potential source of degradation is removed.

The SFEM was tested on three thermally sensitive materials. Pelletized rigid polyvinyl chloride (RPVC) was processed at a very high screw speed of 96 rpm and produced at stock temperature of only 196C. Multi-layer reclaim containing EVOH was processed in the SFEM at 225C without the degradation seen above 196C in the AFEM but while retaining mixture integrity. Cellulose acetate was successfully processed in the SFEM without the smoke, bubbles, and low melt strength when using a conventional screw.

Introduction

It is well known that elongation is preferred over shear for mixing [3]. The SFEM contains a series of simple mixing elements along an SSE screw. Like the AFEM, the barrel has a smooth bore barrel and the screw turns but does not reciprocate. There are no barrel pins.

At first glance, the AFEM resembles a UC mixer (Fig. 1) in that it is a fluted mixer and so has channels. The UC mixer's resistance zone (RZ) is a barrier or restriction to flow. Conceptually, the UC mixer's inlet channel, C1, dead ends so that all input material is forced through the (RZ) for shearing between the resistance zone of the mixer and the barrel. Leaving the RZ, material then flows into a filled C2 channel. This requires high upstream pressure at the C1 inlet to force material into C1, over the RZ and out of C2.

Conceptually, the AFEM mixer has a C1 channel that is open ended for low pressure (Fig. 2). This distinction is critical because, the adjoining clearance, instead of being a RZ, becomes a pump, P1. When the drag flow capacity of P1 is greater than the pressure flow entering C1, then C1 partially empties. Once this is the case, then flow can enter C1 from the downstream end creating upstream (or reverse) axial flow. This results in secondary elongational and distributive flows within C1 and C2, Fig. 3, a flat view of one group (a group is one complete arrangement of C1, P1, C2, P2, C3).

Structurally, the AFEM mixer is also different from the UC mixer because, upon leaving the shear region of P1, material flows over, but not into, an empty channel, C2 because it adheres to the barrel but is no longer restrained by the P1 surface. This is a powerful region of elongation. The elongation is generated because the velocity at the surface of P1 is close to zero and the velocity at the barrel is much higher. When leaving P1, the material stretches very quickly (Fig. 4). Material then enters C3 and is pumped from C3 by P2.

Upstream axial flow is very useful for some mixing problems particularly when dealing with very small scale nano particulates and small melt domains. For example, immiscible polymer blends show domains to about 1 micron [2] and this compares favorable with twin screws [4]. In particulate mixing, 45nm ceramic spheres and single wall carbon nano tubes were mixed to 500 nm scale [2].

However, the upstream axial flow of the AFEM may also allow the possibility of degradation (when the AFEM is operated such that the C1 pressure flow is less than P1 drag flow). Since the AFEM achieved such positive results, this catalyzed the concept of designing a screw that retained the elongating features of the AFEM but without the possibility of upstream axial flow (recirculation).

By twisting the AFEM into a spiral and connecting flights at entry and exit, an SFEM is created that retains the elongational regions without upstream axial flow. It does have, and for the same reasons as AFEM, elongational flow in C1, shear flow over P1 and the powerful elongation leaving P1 and stretching over C2 before entering C3.

It is the purpose of this paper to report on initial tests of thermally sensitive materials in the SFEM and, in one test, to report on a direct comparison of the SFEM to the AFEM.

Mixer Description/Operation

Superficially, the SFEM element resembles an Egan mixer (Fig. 5). But, just as the AFEM is distinguished from a UC mixer by its structure, so too is the SFEM distinguished from an Egan mixer. The Egan has a spiral group, C1, RV, C2 while the SFEM, has a spiral C1, P1, C2, P2 C3 group. Just as the UC mixer and Egan mixer are high pressure devices, the AFEM and SFEM are very low pressure devices. Vents can even be advantageously place over them operating at near zero pressure [5].

The key to the mixer is its multiple elongational flow fields at low pressure. Fig. 6 shows a complete SFEM screw studied and groupings along its length. Fig. 7 shows is a typical first SFEM element on the extruder screw. For this study, the first SFEM was placed within four L/Ds from the water cooled feed section of the barrel. There were two groups (C1, P1, C2, P2, C3) in the first mixer and three groups on downstream mixers. Once material enters the inlet channel, C1, by upstream pressure flow, then pump P1—by means of drag flow—will drag material away from C1. The combination of pressure flow up the channel and drag flow perpendicular to channel flow, produces an elongating flow especially at the approach to P1. This elongating flow can act to melt, drain melt or mix depending on the state of the material in C1. Ideally, pressure flow into C1 is less than the drag flow of P1 so that C1 can partially empty and complete elongation will occur. Pressure flow can be limited by upstream screw geometry (such as initially wider flights or an initially shallower root) or by starve feeders. Very low pressure is also beneficial as mixers that require a high pressure drop also tend to reduce output and increase temperature. Starve feeding, however, does not necessarily reduce output because screw rpm can be increased substantially (i.e. Experiment 1.)

In the first SFEM mixing element, pellets may enter the channel, C1. Any melted material, such as from contact with the hot metal barrel, will reach P1 by drag flow and separate from the solid remains of the pellet (since pellets are too large to flow over P1. This action is similar to the many well known barrier screws where melt is separated from solids to promote melting. The difference is that melt is dragged at low pressure to P1 rather than forced at high pressure flow over the RZ.

A different type of melting can also occur in C1 from elongation itself. For example, a softened pellet may be captured at one end between P1 and the barrel but still pushed down C1 by pressure flow and the spiral geometry of P1. This extension at very high viscosity beneficially combines melting with mixing. It is important to remember that dispersive mixing is best done at the highest possible viscosity (because the most force can be exerted when pulling on a highly viscous material whereas, by comparison, only a small force can be exerted on a low viscosity fluid).

When the pressure flow into C1 is less than P1 drag capacity, *all* of the material will experience extensional flow in approaching P1. This is unlike some twin screws where pellets or melted material may bypass the kneading block intersection. Similarly, in the SFEM, all of the material can be extended in the powerful extending region leaving P1 over the C2 empty channel just as described for the AFEM screw where the P1 restrains material while the barrel drags it forward allowing for sudden acceleration (Fig. 4 is the same for the AFEM and SFEM mixer).

So, within a single grouping, *all* the material flowing into C1 can experience elongation in C1, followed by *all* the material experiencing shear mixing in P1, followed by *all* the material experiencing elongation in P2. It should be realized that the shear flow in P1 reorients the material prior to its extension leaving P1. Reorientation is between elongational cycles is beneficial. The entire process occurs for each subsequent SFEM mixer. To date, as many as four mixers have been constructed within one screw.

Proceeding from P2, the material will enter C3. The material is constrained by the flighted boundary and will flow from the mixer aided by the spiral design. It may then move to additional mixers for additional compounding.

Experimental Apparatus

A 25mm horizontal, 36/1 L/D extruder was equipped a 5 HP drive with a maximum screw speed of 96 rpm. For experiment 1, an adjustable depth thermocouple was installed to measure stock temperature. The SFEM screw had three SFEM mixers along its length, a P1 to barrel clearance of 1mm. For experiment 2, the AFEM screw, also with 1 mm P1 to barrel clearance, also had three AFEM mixers along its length. For experiment 3, a conventional 3:1 apparent compression ration screw, equally divided between feed, compression and meter along its length was used and then followed by the SFEM.

Experiment 1

RPVC pellets were processed. The maximum screw speed for RPVC pellets in single screw extruders is well known. It has remained virtually constant at about 30 rpm for many years. At faster speeds, yellowing, browning or burning occur as the temperatures rises above 200C—the typical maximum threshold prior to significant degradation.

Colorite 1317 clear E-G4J1 4F SK1 pellets were processed at 182C on all the extruder temperature control zones. The screw rpm and melt temperature were recorded. It was found that the maximum screw speed was 96 rpm with an output 8.5 kg (Fig. 8) at a maximum stock temperature of 186C (Fig. 9). Such a high screw speed and such a high output from a 25mm SSE at such low temperatures was previously unknown.

Experiment 2

Sheet feedstock was ground for reprocessing. The sheet was made of polypropylene (PP), a tie layer and ethylene vinyl alcohol (EVOH). This is generally very difficult to reprocess because 1) the EVOH is thermally sensitive; 2) the EVOH has already had one process history when it was made into sheet and 3) the low viscosity (compared to the PP) EVOH blooms to the die surface as it coalesces. This is readily seen either as die drool of EVOH or separation of the EVOH that accumulates for a time on the die surface.

It was found that the AFEM could prevent this effect when processing at 182C on all barrel zones. It was also found that if any temperature zone on the extruder was raised to 185C, black specs were produced in the reprocessed sheet. It was thought that the upstream axial flow of the AFEM was degrading the EVOH.

The SFEM screw was installed and tested with the same reclaim material so that a direct comparison could be made between the two screws. Starting with all process zones at 182C, sheet was made on the SFEM. No black specs were seen. The temperatures were then raised on all zones in 10 degree increments until reaching 226C. No black specs were visible at any temperature. Mixing appeared the same. No die drool occurred. No visible EVOH separated from the mixture or stuck to the die surface. No bubbles occurred in the extrudate.

Experiment 3

Cellulose pellets were dried at 90C in a desiccant drier and then processed a conventional screw (no mixer) and made into extrusion cast film as a control. The screw was then exchanged with the SFEM.

The control was extruded at the recommended temperature of 240C on all extruder zones into a film. The film had bubbles in it (Fig. 10). A substantial visible gas was produced at the die exit. Melt strength was low and the film required compressed air pinning at the edges to hold the film to the chill roll. Otherwise, the melt strength was so poor that the film varied greatly in thickness. In an attempt to increase melt strength and decrease degradation, temperatures were reduced incrementally to 232C but without any apparent effect on melt strength, bubbles or smoke.

The SFEM was installed and the cellulose again extruded at 240C. The film had no visible bubbles. The melt strength increased. There was no need to pin the film to the chill roll using compressed air. To maintain a constant thickness. The visible gas was much reduced. There was no need to reduce the temperatures.

Discussion

In experiment 1, the historic limit was of RPVC pellet processing speed was substantially surpassed as the allowable rpm was increased from a typical 30 rpm to 96 rpm. Yet, the temperatures remained below the degradation threshold of RPVC. This is an extremely gratifying result.

In experiment 2, coalescence of the EVOH was not seen at the die face while the processing range of the mixture was extended from 182C to 226C—a significant improvement without apparent disadvantage. Such processing latitude has obvious utility.

In experiment 3, the superior mixing is responsible for lack of bubbles, increased melt strength and lack of smoke—all typical indications of degradation using the conventional screw—but more likely caused by large domains of the oil from poor mixing.

Conclusion

All the experiments showed that thermally sensitive materials could be processed in the new screw. In addition, the SFEM showed very important processing attributes such as increased output, increased processing flexibility and showed good mixing. There were no obvious drawbacks. The SFEM represents a useful new tool to process thermally sensitive materials [6] with excellent mixing [7] and potentially increased output.

Acknowledgements

To Colorite for their generous donation of RPVC.

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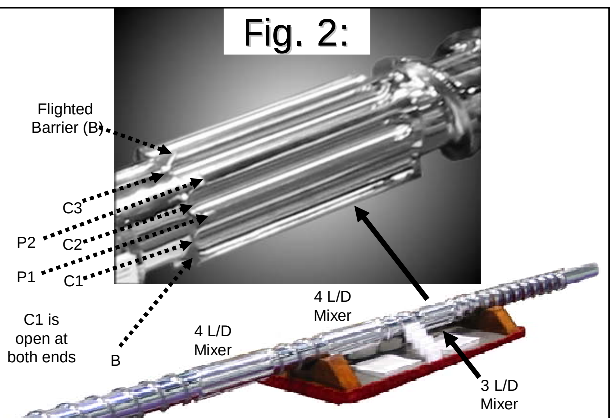
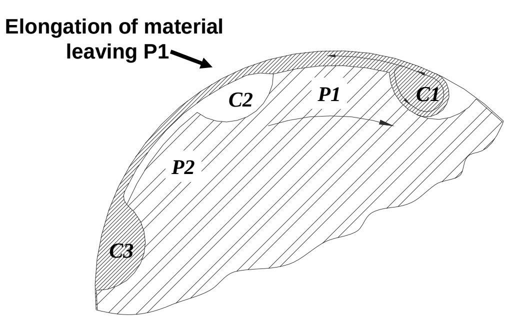
Key Words

mixing, elongation, PVC, EVOH



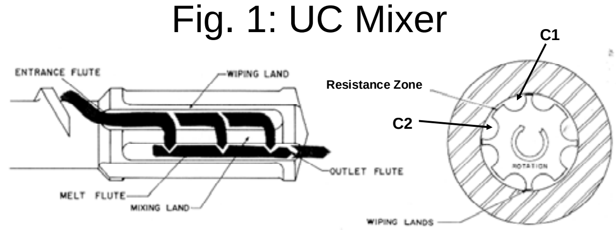
Three Mixer Screw

Fig. 4: Elongation After P1



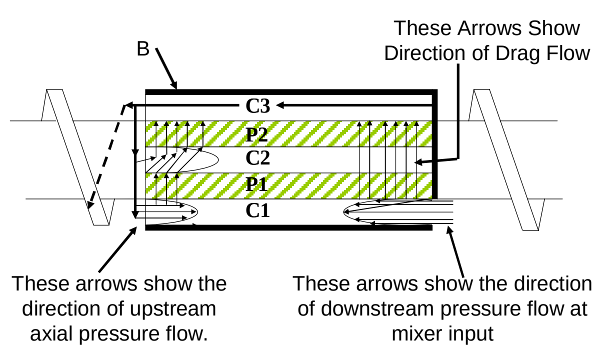
Material is in shear flow between P1 and barrel. Upon exiting P1, velocity at P1 is near zero while the velocity at the barrel is high so the material extends over empty C2.

Fig. 1: UC Mixer



The entrance flute dead ends at the wiping land. Pressure, generated upstream, forces material over the resistance zone (mixing zone) where the material is sheared. The higher the required pressure, the higher the heat generation and the lower the output tendency.

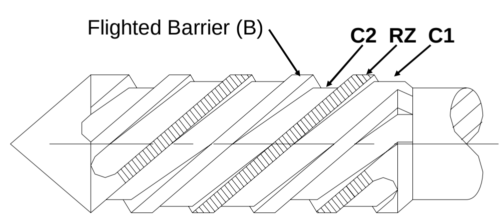
Fig. 3: Flat View Of Mixer



Mixer Flow With Input Below Pumping Capacity of P1 and P2

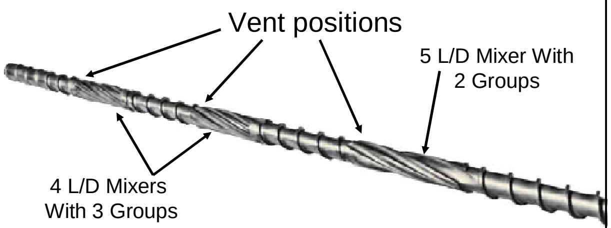
Fig. 5: Egan Mixer

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.

Fig. 6: 36/1 SFEM Screw



A "Group" is composed of the sequence of channels and pumps such as for this study, C1, P1, C2, P2, C3. Each group is axially bound by a flighted clearance.

Fig. 7: SFEM

Mixer Nomenclature/Cross Section Is The Same For Both AFEM and SFEM

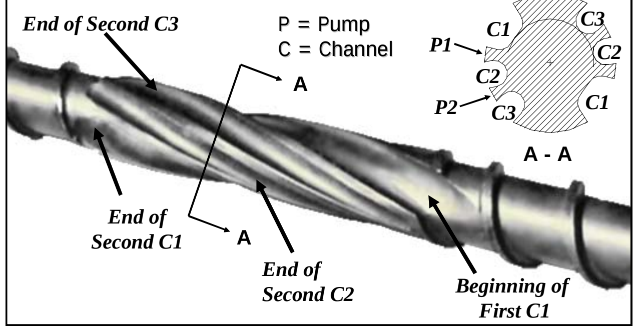


Fig. 8: Output RPVC Pellets

25 mm 36/1 L/D SFEM Extruder

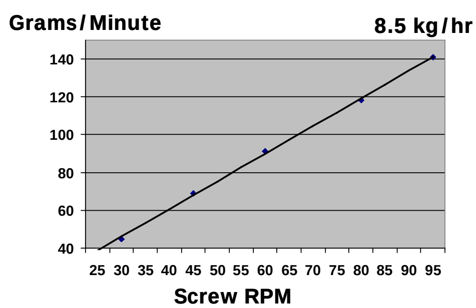


Fig. 9: Stock Temperature

RPVC Pellets 1 Inch 36/1 Extruder

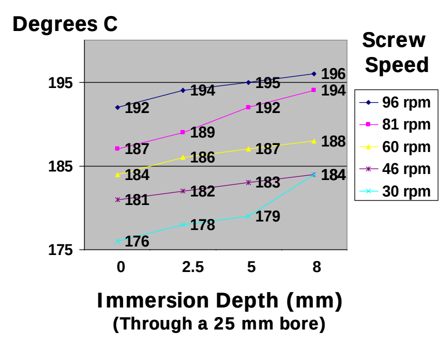


Fig. 10: Cellulose

3.5 mil thick films (both films are clear but shaded for contrast)

General Purpose Screw SFEMr

The plasticizer oil forms bubbles with the typical screw, left, but the SFEM keeps the oil mixed to make better film.