PVC FLOW STREAMS IDENTIFY ELONGATIONAL FLOW

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Abstract

At Antec 2008, a new single screw compounder (SSE) was introduced with newly designed mixers along the screw. These mixing elements had spiral flutes with elongational mixing (SFEM). The Elongator [1], hereafter SFEM, demonstrated simple processing of RPVC powder with an increased output from the historic limit of 30 rpm to a faster speed of 180 rpm at only 174 °C, vented, starved or flood fed. There was no need for a vacuum hopper or crammer feeder with this simple screw design.

At Antec 2009, continuing work was presented with mixing tests performed with the smaller SSE using a newly designed SFEM (hereafter SFEM-II). Two tests were performed with the RPVC powder, one using 0.5% color concentrate and the other wood flour.

Elongation flow has been shown in single screws to compound to the 500 nanometer level [2]. This paper shows the elongational mixing in cross sections of a mixture of PVC and color on a screw that was stopped and cooled during operation. The boundaries of the flows are visible as well as the progression of mixing.

Introduction

Until recently, SSE's were seldom used to process RPVC powder [3]. Although processing of RPVC powders on SSE's had been possible, it was very difficult and required a variety of special equipment. In order to produce constant feeding, a vacuum crammer hopper was necessary. The vacuum crammer hopper consisted of an upper hopper which pulled the vacuum to remove air and densify the material, and also metered the RPVC powder into the lower hopper. The lower hopper was the crammer feeder portion which had a vertical screw perpendicular to the extruder screw and placed very close to the extruder screw for additional densification, Fig. 1, [3]. The vacuum hopper also provided for a single stage screw with a vacuum seal at the screw shank end which aided in the prevention of air and moisture entrapment in the melt [5].

The startup procedure for use with RPVC powders and the vacuum hopper was unique as stated by R. C. Neuman:

> "Extruder Start-up is done open-head. The screw is started slowly - about 5 rpm – until melt appears at the gate. The vacuum is turned on, and rpm increased to operating speed, typically 35-40 for 114.3mm (4 1/2") or 90mm (3 1/2") extruders. After the melt becomes soft and uniform in appearance, the machine is stopped and the die installed. The screw is again started slowly until melt appears at the lips, then increased to operating speed as the web is fed through the polishing stack and succeeding equipment" [6].

The screws were also bored for cooling, especially at the tip [7, 8].

Today, conical counter-rotating twin screw extruders (TSE) dominate RPVC powder extrusion. They are excellent at feeding powders [9, 10], have high outputs at low screw speeds [10], and provide low temperatures [11]. Conical TSE's are also used for processing RPVC powders because of their low shear characteristics Fig. 2, [12, 13, 14].

The SFEM series is well known for compounding. Mixing is fundamentally important to extrusion. So, an SSE that can process RPVC powder, generate high, stable pressures *and* compound becomes a very interesting device. Additional compounding results investigate the actual mechanisms of mixing of the SFEM II frozen screw pullouts and simple model. [15]

Purpose

The purpose of this paper is to show the elongational mixing capabilities of the SFEM-II by viewing cross sections of a mixture of RPVC and color on a screw that was stopped and cooled during operation

Mixer Description

The SFEM is a spiral, fluted mixing element, as shown in Fig. 3, 4, and 5.

It is well known that elongational forces are more effective for dispersive mixing than shear mixing [16] and it is important to understand how this mixing element used in the SSE generates elongational flow. The first mixer is placed within a few L/D of the water cooled feed section of the barrel. In this version, the flow is split into two C1 channels and each channel feeds an elongating screw mixer. The elongating screw mixer is composed of three channels (C1, C2, C3 and two intermediate pumps P1, P2). Material is pushed into C1 by upstream flights. P1, by means of drag flow, pumps material from C1. The combination of pressure flow up the channel and drag flow perpendicular to pump inlet flow, produces an elongating flow in the approach to P1. This can act to mix and/or melt depending on the state of the material in C1.

Experimental

Materials

The polymer that was used in this study was a natural, extrusion grade, RPVC powder E3106N-000DB provided by Colorite Polymers, Ridgefield, NJ. The virgin RPVC powder was extruded and pelletized. The SAN color concentrate (styrene acrylonitrile) for Rigid Vinyl, 25:1 Green #55437, was provided by Coloron Plastics of Somerville, NJ.

Equipment

A 25mm extruder at 36:1 L/D was selected with a 5 horsepower AC motor with a maximum screw speed of 180 rpm. No atmospheric vents were used. There was a pressure transducer in the die, another pressure transducer between the first and second mixer, and another pressure transducer between the second and third mixer. The extruder was equipped with a single hole strand die. The extruder was flood fed using the SFEM-II screw. Melt temperature was taken with a hand held Minolta/Land Cyclops 330S at 95 emissivity, monitoring peak, mean, minimum temperature.

The SFEM-II was designed to maximize output. It is a flood fed design and is shown schematically in Fig. 6. The 25mm screw had a feed channel depth of 4.6 mm, a meter channel depth of 2.3 mm, and the clearance over P1 was 1 mm. The lengths of the various sections can be judged by the drawing which is to scale. The SFEM-II can be seen to differ from the SFEM particularly in the pitch of the first melting/mixing element. Another difference is that the first melting/mixing element has a single group (C1, P1, C2, P2, C3) while SFEM has two groups. The second melting/mixing element in the SFEM-II is the same as the SFEM first melting/mixing element.

Testing Procedures

Experiment – Mixing Test, SFEM-II: The compounding tests were performed with the pelletized RPVC and the green color concentrate.

We compounded 0.5% of SAN (styrene acrylinitrile) for rigid vinyl, 25:1 Navy 60176 color concentrate in the RPVC pellets compounded from the Colorite E3106N-000DB RPVC powder. We processed the color concentrate at a screw speed of 60 rpm with a melt temperature of 194 °C and produced an output of 6.7 kg/hr. The residence time for the green was 115 seconds. We discovered that the color distribution was particularly surprising given the very low percentage of color. The compounded product was very light in color making it very difficult to see the flow patterns in the cross sections of the channels once the screw was pulled.

We therefore performed a second test and increased the percentage of color to 3.5% of the same color concentrate. We processed the new formulation of color concentrate at a screw speed on the extruder of 60 rpm with a melt temperature of 194 °C and produced an output of 5.6 kg/hr.

Results

When we pulled the screw, we observed that the RPVC was fully melted and fused in the metering section and in the third mixer. However, we found that the fusing of the RPVC was still taking place just before the third melter though Fig. 7, 8. This shows that the SFEM-II screw is a late fusion device. Fig. 8 also shows that the C1 inlet channel is empty and shows a thin film over the empty channel further downstream in the mixer with the C2 and C3 output channels completely full.

Starting at the beginning of the screw, the first L/D’s are empty as they contained unmelted pellets which fell off the screw upon removal from the barrel, Fig. 9. Fig. 10 shows the beginning of the solid bed formation and color development as the color pellets began to melt.

Entering the first SFEM-II we see both the RPVC and color pellets beginning to melt and deform at approximately half way through the mixer, Fig. 11. A fully developed melt, shown by the green color, fills about half of the C2 and C3 output channels. In the second SFEM-II, we do not see any more natural RPVC, Fig. 12. We do however see that the RPVC is still cold and mostly fused; while very little material was found in the C1 channels. It is just prior to the third SFEM-II that the RPVC was still not fully fused, Fig. 7. Melting improves during the third mixing element and is uniform thereafter in the metering section, once again showing that the SFEM-II screw is a late fusion device, Fig 13. We can see in the cross section of the first SFEM-II (Fig. 11) that as the material enters the C1 inlet channel the material is dragged by the barrel rotation over the P1 land into the C2 output channel, and then over the P2 land into the C3 output channel., Fig. 14. As the material is pumped over the lands into the output channels down the length of the mixer the solids are eventually melted and the material is mixed completely, as shown in Fig. 13 of the third SFEM-II and in the metering section of the screw, Fig. 7.

Discussion

In the experiment, the superior mixing of the SFEM-II is responsible for the uniform color dispersion of the color concentrate. The compounded material was a uniform color and thoroughly melted without streaks or specks of color, while still providing low melt temperatures and no visible signs of degradation.

The color distribution of the 0.5% blend is particularly surprising given the very low percentage of color, and is particularly gratifying for several reasons. Generally, all single screw extruders have problems making a uniform color with such a small percentage of color. Small extruders are notoriously poor mixers, compared to larger extruders. This is because, first, they have lower shear rates than large extruders. Second, the number of color concentrate pellets per flight is much reduced compared to large extruders. A large extruder can have, for example, a color concentrate pellet every L/D while the same mixture in a small extruder may have a color concentrate pellet every six L/D's. From a scale up point of view, this means that better mixing is very likely with increases in diameter.

Conclusions

The screw used in this experiment provided gradual and uniform melting throughout the screw which resulted in low processing temperatures and a uniformly mixed blend of RPVC pellets and color concentrate. The fusion of the RPVC occurred late in the screw yet provided a completely melted and mixed product. Further experiments to increase the output for color compounding will continue.

Acknowledgements

Meg Henke, Colorite Polymers for supplying the RPVC Powder.

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Keywords

RPVC powder, mixing, melting, elongating, SSE, SFEM, SFEM-II.

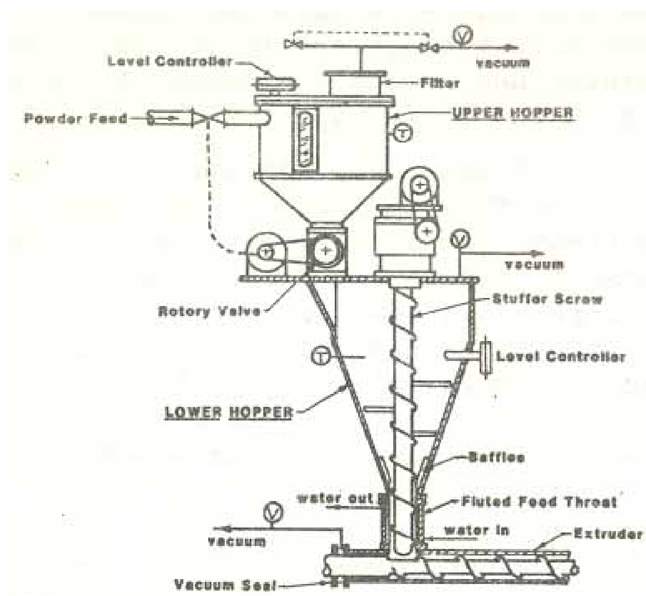

Figure 1. - Vacuum Feed System for Vinyl Sheet from Powder

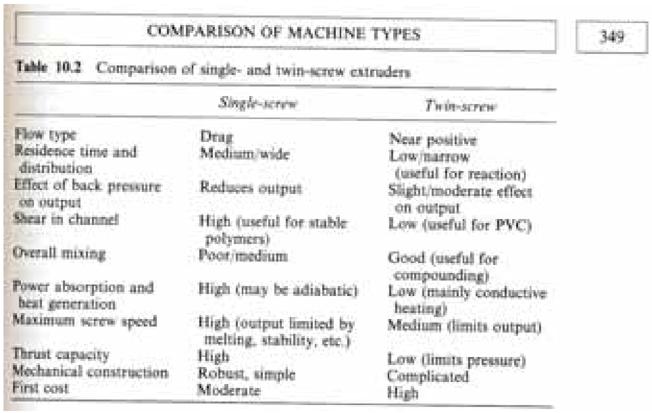

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Table 10.2 Comparison of single- and twin-screw extruders

	Single-screw	Twin-screw
Flow type	Drag	Near positive
Residence time and distribution	Medium/wide	Low/narrow (useful for reaction)
Effect of back pressure on output	Reduces output	Slight/moderate effect on output
Shear in channel	High (useful for stable polymers)	Low (useful for PVC)
Overall mixing	Poor/medium	Good (useful for compounding)
Power absorption and heat generation	High (may be adiabatic)	Low (mainly conductive heating)
Maximum screw speed	High (output limited by melting, stability, etc.)	Medium (limits output)
Thrust capacity	High	Low (limits pressure)
Mechanical construction	Robust, simple	Complicated
First cost	Moderate	High

Figure 2. - Comparison of Single and Twin Screw Extruder features

Fig. 3: Three Mixers On 36/1 Screw

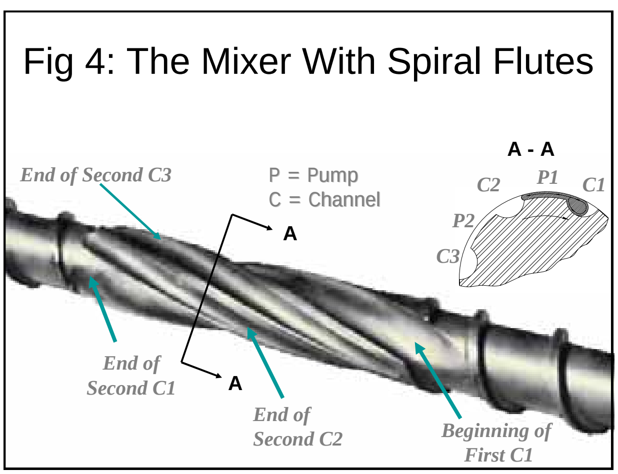
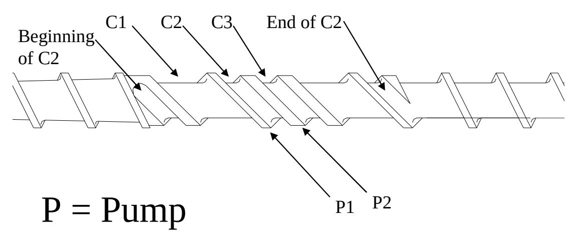


Figure 5. – 2.5” NRM SSE with SFEM Shown

SFEM-II



P = Pump

C = Channel

Figure 6. - SFEM-II Description

Figure 7. – Screw pull of RPVC and Green color concentrate, metering section and third SFEM-II.

Figure 8. – Screw pull of RPVC and Green color concentrate, third SFEM-II.

Figure 9. – Screw pull of RPVC and Green color concentrate, feed section.

Figure 10. – Screw pull of RPVC and Green color concentrate, solid bed formation.

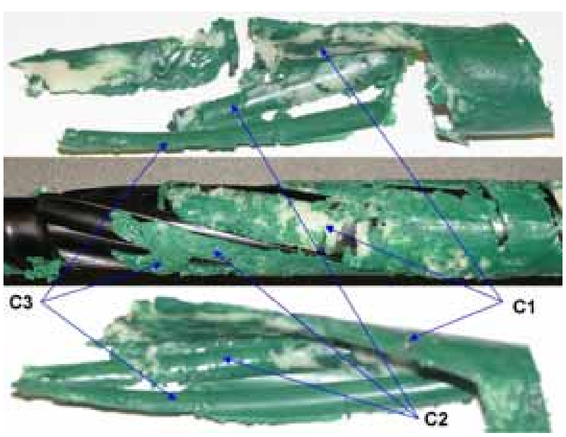


Figure 11. – Screw pull of RPVC and Green color concentrate, first SFEM-II.

Figure 12. – Screw pull of RPVC and Green color concentrate, second SFEM-II.

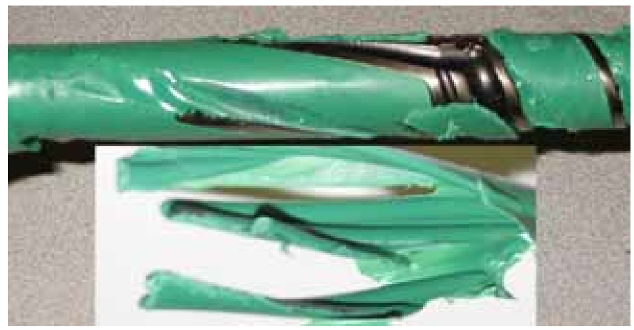


Figure 13. – Screw pull of RPVC and Green color concentrate, third SFEM-II.

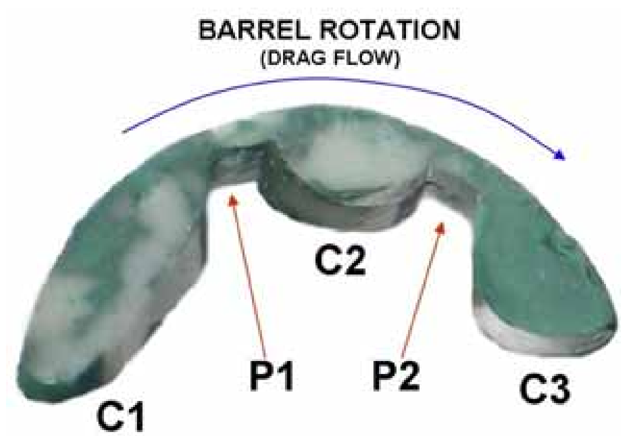


Figure 14. – Cross section of screw pull of RPVC and Green color concentrate, first SFEM-II.