NOVEL SINGLE SCREW FOR RPVC POWDER THAT COMPOUNDS

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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.

This paper presents scale up work that was performed on a 2.5" extruder with the RPVC powder. The new SSE processed RPVC powder with an increase in screw speed to 70 rpm and output temperature of only 191 °C, non-vented, with screw cooling, and flood feeding.

This paper also presents 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.

Introduction

Until recently, SSE's were seldom used to process RPVC powder [2]. 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 [4].

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" [5].

The screws were also bored for cooling, especially at the tip [6, 7].

Today, conical counter-rotating twin screw extruders (TSE) dominate RPVC powder extrusion. They are excellent at feeding powders [8, 9], have high outputs at low screw speeds [9], and provide low temperatures [10]. Conical TSE's are also used for processing RPVC powders because of their low shear characteristics Fig. 2, [11, 12, 13].

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. [16]

Purpose

There are two purposes of this paper. The first is to show that the screw can be scaled up from a 1 inch to a 2.5 inch and still process RPVC powder. The second is to demonstrate the mixing capabilities of the SFEM-II with regards to RPVC powders.

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 [14] 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 SAN color concentrate (styrene acrylonitrile) for Rigid Vinyl, 25:1 Navy 60176, was provided by Coloron Plastics of Somerville, NJ.

Equipment

The scale up tests were performed on a 2.5” NRM extruder at 24:1 L/D with a 55 horsepower AC motor with a maximum screw speed of 100 rpm. The screw was equipped with two SFEM mixers, Fig. 5. There was a pressure transducer before the die. The extruder was flood fed. The extruder was equipped with a 6 hole strand die.

For the mixing tests, a 1” extruder at 36:1 L/D was selected with a 5 horsepower AC motor with a maximum screw speed of 180 rpm. Two atmospheric vents over the second and third mixers were used. There was a pressure transducer in the die and another pressure transducer just over the first mixer. The extruder was equipped with a 4 hole strand die. The extruder was flood fed using the SFEM-II screw.

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 is 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 1 – Scale up: RPVC powder was processed. The maximum screw speed for RPVC pellets in large single screw extruders is well known. It has remained constant at about 30 rpm for many years. At faster speeds, yellowing or browning occurs as the temperatures rise above 200 °C—the typical maximum threshold prior to significant degradation. The RPVC powder was processed at various rpm’s where 70 rpm with a melt temperature of 191 °C produced the highest output of 68 kg/hr.

Experiment 2 – Output Test: SFEM-II: RPVC powder was processed. We have not found data for a 1 inch extruder processing RPVC powder, so we don’t have a proper control for an output comparison. However, the output of a 25 mm (1 inch) extruder processing RPVC pellets is known—about 2.3 kg/hr at 30 rpm [15]. This output was increased during tests on the SFEM to 8.5 kg/hr at 95 rpm, Fig. 7. It is well known that the SSE for pellets of RPVC is limited to slow screw speeds, typically about 30 rpm. Thereafter the temperature rises and degradation occurs. Unfortunately, the RPVC pellets cited [14] are not the same composition as the dry blend and this lessens the quality of the comparison. The output achieved for the RPVC powder using the SSE with the SFEM mixers was nevertheless 13.2 kg/hr.

The same RPVC powder was processed on the new SFEM-II screw at a maximum of 180 rpm with a melt temperature of 185 °C and produced an increase in output of 15.8 kg/hr over the original SFEM screw. There was no vent flow from the two atmospheric vents used over the second and third SFEM.

Experiment 3 – Mixing Tests, SFEM-II: Two separate compounding tests were performed with the RPVC powder, one with wood flour and the other with blue color concentrate.

Experiment 3a - RPVC powder and wood flour. The wood flour was dried at 65.5 °C for 12 hours. We compounded 25% wood flour in the Colorite E3106N-000DB RPVC powder. At 180 rpm the output was lower than desired, 3.9 kg/hr, however the wood flour was mixed throughout the strand, Fig. 8. The flexibility of the wood flour compounded strand was sufficient to make a loop about four inches in diameter without any surface fracture, Fig. 9.

Experiment 3b - RPVC powder and color concentrate. We compounded 0.5% of SAN (styrene acrylinitrile) for rigid vinyl, 25:1 Navy 60176 color concentrate in the Colorite E3106N-000DB RPVC powder. We processed the color concentrate at the maximum screw speed of the extruder of 180 rpm with a melt temperature of 185 °C and produced an output of 15.8 kg/hr.

Discussion

In experiment 1, we were able to scale up the RPVC powder processing from the original SSE to the 50 mm SSE with an increased output, low melt temperatures and no visible signs of degradation. Additional tests to are planned.

In experiment 2, the SFEM-II increased the output of the RPVC Powder processing from the original SFEM while still providing low melt temperatures and no visible signs of degradation.

In experiment 3, the superior mixing of the SFEM-II is responsible for the uniform color dispersion of the color concentrate and the dispersion of the wood flour resulting in a strong product with a more wood-like appearance. The compounded material was a uniform color and thoroughly mixed without streaks or specks of color, Fig. 10. The color distribution is particularly surprising given the very low percentage of color 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 screws used in these studies permitted RPVC powder processing at high screw speed and high output at reasonable processing temperatures. Venting was effective and two vents, while uncommon, have clear potential for better degassing. Because this is a single screw extruder, it can generate high, stable pressure. These earlier work with lab sized extruders scaled up production scale. The SFEM II provided excellent, even surprising compounding. This means that processors of RPVC powder now have a choice of production tools. Clearly, single screw extruders are less expensive and require less maintenance than conical twins making the SFEM superior in many applications.

Acknowledgements

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References

1. K. Luker, U.S. Patent 6,962,431 B1 (2005)
2. Friedhelm Hensen, *Plastics Extrusion Technology*, Hanser Publishers, New York, pp 57, 225 (1988).
3. Paul R. Schwaegerle, *"The Extrusion of Thin Gauge Transparaent Rigid Vinyl Sheet Part I: Equipment Requirements,"* SPE Antec (1982)
4. Dr. Demosthenes Kyriacos, *"PVC Extrusion,"* http://www.gen-chem.net/PHP/machinerytse.html, pp 11 (2007)
5. R. C. Neuman, *"The Extrusion of Thin Gauge Transparaent Rigid Vinyl Sheet Part II: Raw Material and Operating Requirements,"* SPE Antec (1982)
6. Friedhelm Hensen, *Plastics Extrusion Technology*, Hanser Publishers, New York, pp 375 (1988).
7. Dr. Demosthenes Kyriacos, *"PVC Extrusion,"* http://www.gen-chem.net/PHP/machinerytse.html, pp 9 (2007)
8. Friedhelm Hensen, *Plastics Extrusion Technology*, Hanser Publishers, New York, pp 225 (1988).
9. Dr. Demosthenes Kyriacos, *"PVC Extrusion,"* http://www.gen-chem.net/PHP/machinerytse.html, pp 12 (2007)
10. Alan L. Griff, *Plastics Extrusion Technology*, Robert E. Krieger Publishing Company, New York, pp 68 (1976).
11. Dr. Demosthenes Kyriacos, *"PVC Extrusion,"* http://www.gen-chem.net/PHP/machinerytse.html, pp 12 (2007)
12. M. J. Stevens, J. A. Covas, *Extruder Principles and Operation*, Chapman and Hall, London, pp 349 (1995).
13. Friedhelm Hensen, *Plastics Extrusion Technology*, Hanser Publishers, New York, pp 485 (1988).
14. C. Rauwendaal, Polymer Extrusion, Hanser Publishers, New York, pp 386-398 (2001).
15. Keith Luker, *"Novel Single Screw Elongational Compounder for Thermally Sensitive Materials,"* SPE Antec (2007)
16. K. Luker, T. Cunningham, *"Investigation Into A High Output Polypropylene Screw And Its Mixing Mechanism,"* SPE Antec (2009)

Keywords

RPVC powder, mixing, elongating, SSE.

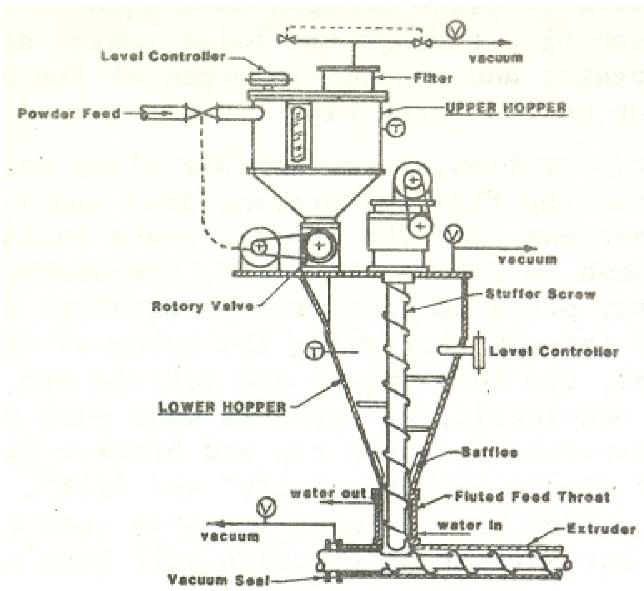


Figure 1. - Vacuum Feed System for Vinyl Sheet from Powder

COMPARISON OF MACHINE TYPES 349

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

Fig 4: The Mixer With Spiral Flutes

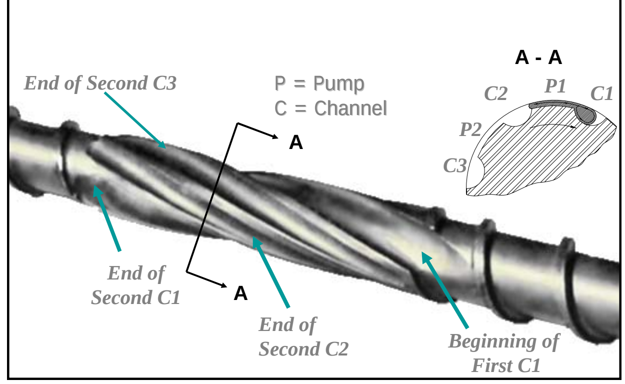
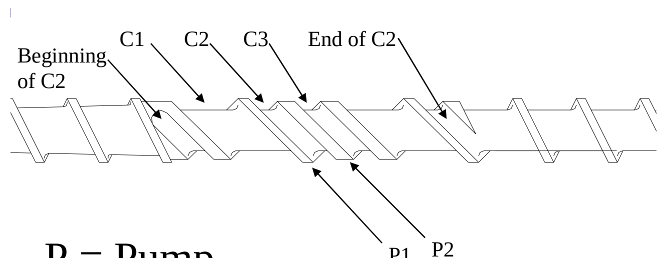


Figure 5. – 2.5" NRM SSE with SFEM Shown

SFEM-II



P = Pump

C = Channel

Figure 6. - SFEM-II Description

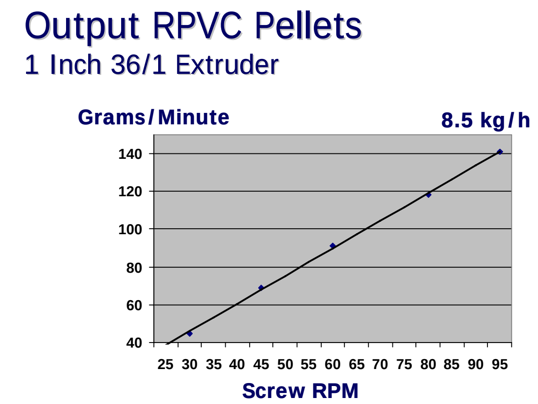


Figure 7. – Graph of RPVC Pellet Output on 1 Inch Extruder

Figure 8. – Compounded RPVC and wood flour mixed throughout the strand with moderate melt strength.

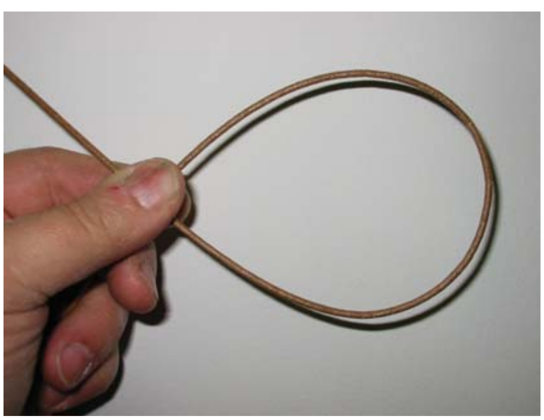


Figure 9. - Flexibility of the compounded RPVC and wood flour compounded strand making a loop without any surface fracture.

Figure 10. – Compounded RPVC and 0.5% of SAN 25:1 Navy 60176 color concentrate.