COMMERCIALIZATION OF SOLID-STATE SHEAR PULVERIZATION: A NOVEL POLYMER PROCESSING TECHNOLOGY

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Abstract

Zzyzx Polymers, a startup company located in Allentown, PA, has commercialized the solid-state shear pulverization (SSSP) process. The initial technology was developed at Northwestern University, but had not been demonstrated on a commercial scale due to several key scaling issues: energy cost, throughput, and machine wear. Researchers from Zzyzx have demonstrated, with a wide range of polymers from polyolefins to polyesters, that they can achieve continuous throughputs of over 180 kg/hr at an energy cost of ~$0.05-0.07/kg on a 70 mm SSSP machine. This cost is in line with conventional melt twin-screw extrusion technologies.

Introduction

Key Questions Surrounding SSSP

There were several key questions that limited the commercialization of the SSSP technology:

1) Throughput is too low
2) Specific energy is too high
3) High shear will break screws, shafts, gear box

1) At a the laboratory scale, researchers at Northwestern University, including the corresponding author, were only able to demonstrate a few grams an hour for heat sensitive polymers like poly(lactic acid) [1] to a few kilograms an hour for polyolefin-like materials [2]. It was this low throughput that limited the practicality of the technology on a large-scale.
2) A specific energy of 0.4 kw*hr/kg or more would limit commercial application. On a small-scale, researchers from Northwestern calculated specific energy values of 0.7 kw*hr/kg up to 10 kw*hr/kg [3]. Again, it was the high calculated specific energy values that limited commercial interest in SSSP.
3) A major concern around the SSSP technology is that the high shear will wear down/break screws, shafts, and gear box much faster than melt-state extrusion technologies. On a small scale, one way to combat this was to run the extruder at low throughputs as to not take motor load higher than 25-30%. This strategy is not practical for large scale processing.

In this paper, it will be demonstrated for the first time, the commercialization of the solid-state shear pulverization technology.

Equipment

A key difference in the SSSP apparatus and conventional twin-screw melt extruders is that the SSSP extruder is maintained at a temperature below the glass and/or melt transition temperature of the polymer through a circulating cooling system. This allows for repeated fragmentation and fusion steps in the solid state without the limitations of thermodynamics, viscosity, and degradation often encountered in melt processing of polymers. Figure 1 gives a schematic of the layout.

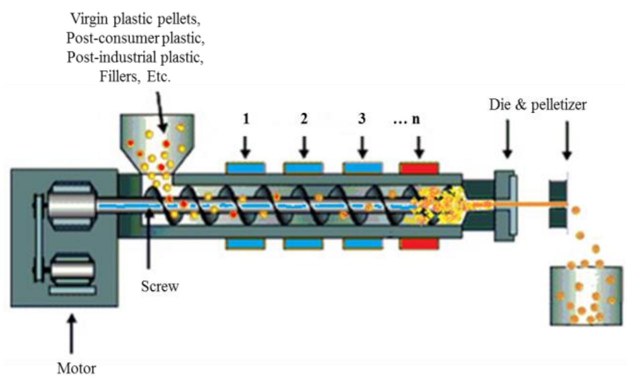


Figure 1. Schematic of SSSP apparatus

Materials

Polyethylene (PE) (MFI = 120 g/10 min at 190 ^{o}C) and Ultra-high molecular weight polyethylene (UHMWPE) was purchased from Marval Industries. Post-consumer recycled (PCR) laminated film and polyvinyl chloride (PVC) mixed waste was sourced as from a local recycler in Pennsylvania.

Results and Discussion

Throughput of the commercial SSSP process

At the small 25-mm scale, the throughputs of the SSSP process were from a few grams an hour to several kilograms an hour depending on the material [1]. Compared to conventional melt twin-screw extrusion, this throughput is 10 to 100 times lower, which ultimately deterred interest in the commercialization of the SSSP technology.

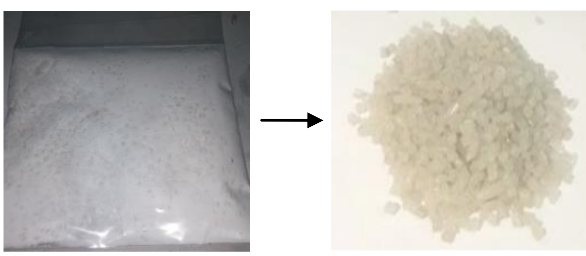
Several key trade secrets have been implemented around the large scale process, which couldn't be applied to a small scale SSSP apparatus, to overcome many of the issues facing small-scale production. These trade secrets have enabled throughputs of over 180 kg/hr on a 70 mm extruder at 200 rpm for certain materials. Table 1 shows common polymeric materials with calculated throughputs and specific energy values.

Table 1. Throughputs and calculated specific energy for several different materials processed on the commercial SSSP apparatus

Material	Throughput (kg/hr)	Specific Energy (kw*hr/kg)
A) PE/UHMWPE	180	0.26
B) PCR laminated film	145	0.35
C) PVC mixed waste	100	0.40

Figures 2a-c shows the final output of the abovementioned polymers listed in Table 1. It is evident that SSSP process can successfully process a wide variety of materials into standard pellets.

A)



B)

C)

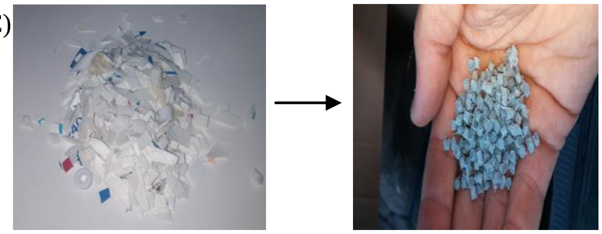


Figure 2. Images of input consisting of a) Polyethylene (PE) and ultra-high molecular weight PE (UHMWPE), b) post-consumer recycled (PCR) laminated film, c) Polyvinyl chloride (PVC) mixed waste and the final product.

Specific Energy Calculation

One of the major issues with the laboratory scale SSSP processing was the high energy costs. It was calculated that the energy needed to process a pound of plastic could be anywhere from ~ 1 kw*hr/kg to over 10 kw*hr/kg depending on material and properties needed for final product [1,3]. On a large scale, the specific energy needed to yield similar property enhancements demonstrated on the small-scale SSSP apparatus has been calculated to be almost a tenth (~0.25 to 0.40 kw*hr/kg). The reason for such a dramatic decrease in energy is due to several trade secrets that have been implemented to large scale SSSP apparatus.

The key to understanding and optimizing the SSSP process has been the ability to measure and control key processing parameters including coolant flow rate, coolant temperature, and heat removal. Essentially, a nine thousand pound calorimeter was built, which enables the understanding of everything that is happening during the SSSP process; something that was not available at Northwestern University. This fundamental understanding of the SSSP technology has been made possible by a SBIR grant from NSF. Zzyzx is currently in the second year of the program.

In order to show a rough estimate of the specific energy, a reading was taken of the energy meter at the Allentown plant during production of laminated film pellets. It is seen that over a 4 hour period of production, there was a peak energy rate of ~54 kw*hr. Therefore, over one hour the total energy consumption is ~54 kw. Over that same hour, the throughput rate was ~150 kg/hr. This coarse measurement shows the specific energy calculated to be ~0.36 kw*hr/kg, which is similar to conventional melt-compounding.

Overall, it has demonstrated that the energy costs of the SSSP technology fall within what is reasonable acceptable for commercial compounding technologies

Wear of the screw/shafts and gear box

Another major concern with large-scale SSSP processing of polymeric materials is the wear on the machine. More specifically, the screws, shafts, and gear box. Due to the implementation of several key trade secrets, these issues have been eliminated. Despite running many challenging proof of concept materials and worst case load tests, there have been no issues with screw/shaft replacement or excessive wear. In fact, during production most materials run anywhere from 25-45% load on the motor, which is below standard practice. This also demonstrates that we are not processing at the technologies full capacity and higher throughputs can be achieved.

Conclusions

Solid-state shear pulverization is a novel, commercial polymer processing technique. This technology has been researched on a small scale since the late 1990's at Northwestern University and late 2000s at Bucknell University. Due to several limitations on the small scale machine, this technology was assumed to be too expensive for commercial applications. In January 2015, the first-of-its-kind manufacturing facility was opened around the SSSP technology (see Figure 3). Zzyzx Polymers has proven its viability on a large scale for the first time.

Figure 3. Schematic of the first-of-its kind facility around SSSP technology

Acknowledgments

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References

1. Brunner, P.J. Ph.D. Thesis, Chapters 3-7, Northwestern University, 2013.
2. Brunner, P.J.; Clark, J.T.; Torkelson, J.M.; Wakabayashi. K. *Polym. Eng. Sci.* 2012, **52**, 1555-1564.
3. Masuda, J.; Torkelson, J.M. *to be submitted to Polym. Eng. Sci.*, 2016.