ATYPICAL TWIN SCREW EXTRUSION COMPOUNDING SYSTEMS FOR POLYOLEFINS

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Abstract

Plastics is a major worldwide industry that plays a role in all facets of modern life, from health and well-being, nutrition, shelter and transportation, to safety and security, communication, sports, and leisure activities. Almost every polyolefin based polymer has been processed at some stage on a twin screw extruder to mix materials to impart desired properties into products such as packaging films, fibers for carpets, car interiors and windshields, structural decking, conductive parts, and synthetic wine corks. These are all high-tech products!

Introduction

Developed almost 100 years ago, twin screw extrusion (TSE) is now the industry standard to perform mixing, devolatilization and reactive extrusion processes for polyolefin and other polymer based formulations. The vast majority of TSEs make pellets. Some are configured to directly extrude continuous shapes or “parts”. In both instances, TSE technologies are being applied to non-traditional operations to manufacture a variety of new products.

The high speed co-rotating intermeshing twin screw extruder is the most prevalent device for continuous compounding applications. The intense inter-screw mixing associated with the short mass transfer distances inherent with a TSE and the possible use of low or high screw speeds (i.e., 1000+ rpm) makes the TSE a highly efficient and versatile mixing device. Entrapped air, moisture and volatiles are also removed via venting.

The TSE process is dependent upon the rotating screws contained within barrels to impart energy into the materials being processed. Screws are segmented and assembled on high torque shafts. Screw designs can be made shear intensive and/or passive. Mixing elements may be dispersive, distributive, or a balance of each/both. *(Fig. 1)*

Process control parameters include screw speed (rpm), feed rate, barrel/die temperatures, and vacuum levels. Typical readouts include melt pressure, melt temperature, and motor amperage. Monitoring these values ensures what’s being produced is consistent and repeatable.

A metering system sets the rate to the TSE. Feeders utilize various delivery mechanisms, including: vibratory trays, single screw and twin screw augers. Loss-in-weight (LIW) feeders maintain a constant mass-flow rate to the TSE by adjusting the feed mechanism based on materials usage from the hopper that is situated on a load cell. Liquid feed streams use various types of pumps (i.e., piston or gear pump) depending upon the viscosity of the liquid. Crammer feeders can also be used for highly filled and/or low bulk density materials.

The TSE is referred to as “starve-fed” because the TSE screw rpms are independent from the feed rate. The pressure gradient along the length of the TSE process section (barrels/screws) is primarily influenced by the selection of screws. Flighted screw elements are strategically placed so that the screw channels are not filled, which results in a zero-pressure underneath feed and downstream vent/feed sections, facilitating strategic sequential feeding and preventing vent flooding. (Fig. 2)

The addition of materials into the melt stream of a TSE is often facilitated by a side stuffer. A side stuffer is a twin screw auger that “pushes” material into the process melt stream to minimize screw/barrel wear, residence time and shear exposure for sensitive materials. Liquid injection into the process section is also possible. In some cases, sequential feeding may eliminate the need for premixing of feedstocks.[1]

Downstream systems size and cool the extrudate, with a multitude of high-tech equipment options available to make high-quality, precision parts. Pressure generating devices, such as a gear pump or screw pump can also be mated to the twin screw extruder to help manage melt pressure and temperature.

In the context of the above discussion the following statements generally apply to co-rotating, intermeshing twin screw extruders:

- Recycling is an area where TSEs have not been widely used due to difficulties/limitations associated with processing contaminated feedstocks
- The starve fed TSE is a better mixer than a pump, as compared to a single screw extruder (SSE)
- TSEs tend to run at much higher screw speeds than SSEs
- Almost every TSE integrates venting/ devolatilization into the process, with multi-stage venting being common
- Most TSEs make pellets where dimensional tolerances are a secondary concern as compared to achieving a homogenous mix (without degrading the product)
- TSEs, compared to SSEs, are low pressure machines, rated for operation at less than 3500 psi and very seldom operated above 2000 psi
- Probably 99% of TSEs are the only extruder in the system, as opposed to part of a tandem or co-extrusion system
- Almost all TSEs process plastics, as compared to rubbers, due to torque and cooling limitations

In the context of the above the following are examples of TSEs that have been integrated into atypical system configurations.

Using the TSE to purposely increase the MFI of HDPE

In virtually every process the goal of the TSE is to mix materials together with minimal degradation and maintain mechanical properties. Too much shear often results in degradation. However, the TSE can be purposely used to “intensively” mix the polymer and increase the MFI in a controlled and purposeful way to match its’ flow properties to a subsequent process.

For example, a fractional melt HDPE scrap material from an in-house process can be ground and metered into a TSE that will operate at very high speeds (800+ rpm) with elevated temperature set points (i.e., 100°C higher than normal). The screw design will include high energy input neutral and reverse kneading elements to maximize the energy imparted by the rotating screws and motor. The resulting melt temperature might be 100°C above what’s typically deemed optimal. (Fig. 3)

By using the TSE in this process as described a fractional melt HDPE scrap was modified into a molding grade MFI so that the materials could be reused in a molding process, facilitating close to 100% utilization of the raw materials coming into the facility.

Integrating a TSE into a coextruded foamed profile

TSEs can be used to mix supercritical fluids with PE and PP to produce foamed parts. The screw design will integrate a dynamic seal prior to the injection of sCO_2 at high pressure. High pressures necessitate the use of a one-piece barrel or modified barrel flanges. Once the supercritical fluid is mixed and dissolved, the TSE screws pump and cool the melt. Near the end of the screws, high-distributive rate mixers are used to thermally homogenize the melt prior to discharge.[2] (Fig. 4)

Unlike most high speed TSEs, for this application screws are operated with filled screw channels and at lower speeds (200 rpm or less). The TSE barrels are used as a heat exchange device to cool and condition the melt and maintain viscosity into the die. For rates below 200 kg/hr, the TSE may be able to directly pump into the die.

Customized coextrusion dies may be specified to accept melt streams from single screw extruders to facilitate unique multi-layer structures. For instance, a thermoplastic elastomer might be added as an external layer of a coextruded structure to facilitate texture and printing capabilities.

The usage of a TSE in this example is unique because: the TSE is both mixing and serving as a high-pressure pump to make a precision part, and is also being integrated with a SSE to make a unique, multi-layer structure.

Recycling and devulcanization of tire rubber with in-line Thermoplastic Vulcanizate (TPV) production

A patented thermo-mechanical devulcanization process, with no chemical agents, was developed for recycled ground tire rubber using a TSE.[3] Ground tire rubber particles are metered into a TSE and conditioned via shear prior to injection of sCO_2 that acts as a plasticizer to facilitate and complete the devulcanization process. The resulting devulcanized rubber can then be processed/revulcanized.

By extending the length of the TSE process section to 60/1 L/D, a second extruder can meter a molten PP feed stream into the TSE process section to prepare a TPV material. Resulting volatiles are controlled and removed via multi-stage venting, and the TSE is now be mated to a traditional downstream system to make a profile, sheet or pellets.

This system as described is unique for a number of reasons: TSEs are generally not used to process rubber formulations, the process as described has never been done before and the extended L/D facilitates its' integration as part of an in-line TPV compounding system. (Fig. 5)

High level filler compounding of Post Consumer Reclaim (PCR)

Processing of HDPE, PE and PP Post Consumer Reclaim (PCR) materials present particular challenges for a TSE. The materials must be thoroughly washed and dried. Metals must be removed from the feed stream as severe damage will result if these are metered into a closely meshing, high speed TSE. Residual moisture from the washing step can be problematic from a processing perspective.

In every instance, filtration will play a key role in making a good product, which often requires high pressures. Accordingly, it may be preferable to use a SSE to melt and pump the PCR feedstock through a screen changer prior to mixing the fillers in the TSE. A gear pump would then be mated to the exit of the screen changer to "meter" a specific rate of the "clean" melt to the twin screw extruder. The TSE will mix fillers (up to 80%) and additives with the polymer and the TSE can pressurize an underwater pelletizer.

The process as described is different from a traditional TSE compounding system for a number of reasons. The melting and filtration of the PCR materials are performed upstream of the TSE. A gear pump then functions as a metering feeder, pumping into the TSE feed zone. The TSE can now use a shorter L/D and smaller horsepower motor because of the upstream melting and filtration unit operations being performed before the melt enters the TSE. The TSE now only needs to complete traditional mixing and devolatilization functions.[4] (Fig. 6)

Conclusion

Twin screw extrusion is a battle hardened, well proven, manufacturing process that has been validated in 24 hour/day industrial settings for more than half a century. The superior mixing characteristics inherent to a co-rotating intermeshing twin screw extruder has resulted in this device being the preferred manufacturing methodology for polyolefin and plastics compounds. The dominance of the TSE in this capacity has spawned intensive machine development efforts and extensive industry research, which is responsible for the current level of understanding and experience with TSE mixing technology. The continued expansion of TSE technology as part of atypical extrusion systems will help improve manufacturing efficiencies in a wide variety of new applications that benefit from the consistent and less costly TSE in-line mixing process.

References

1. C. Martin, *Twin Screw Extruders as Continuous Mixers for Thermal Processing: a Technical and Historical Perspective*, **AAPS Pharm SciTech** (2016)
2. W. Thiele, C. Martin, *Extrusion Equipment for Foam Processing*, **Pharmaceutical Extrusion Technology**, **10**, 293 (2007)

3. Tyromer Patent # US20130023595 A1, Method and Apparatus for Regenerating Vulcanized Rubber, (2013)
4. C. Martin, presentation "*Integrating Compounding Twin Screw Extruders Into PCR/PIR Reclaim Systems*", SPI Refocus Recycling Summit & Expo, Orlando, FL (April 25-27, 2016)

Figures

Figure 1: Co-rotating intermeshing twin screw extruder screws

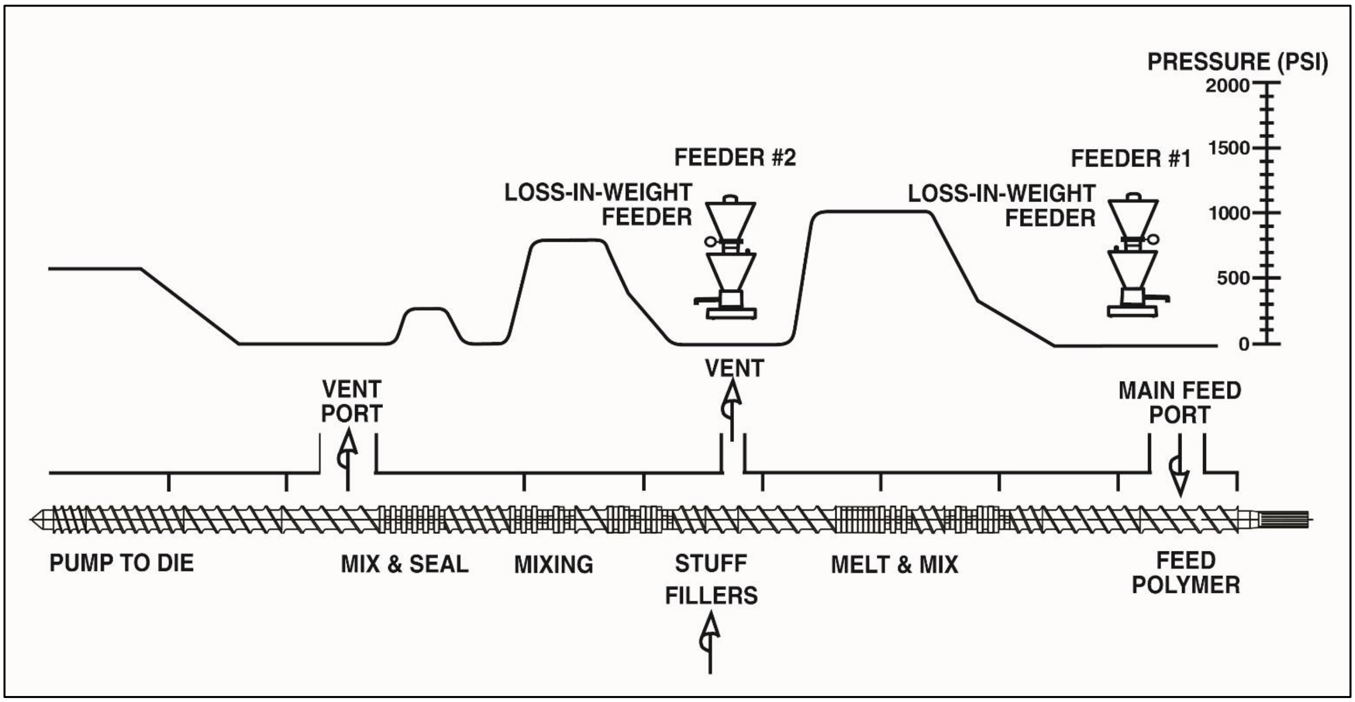

Figure 2: Pressure gradient in a typical twin screw extruder system

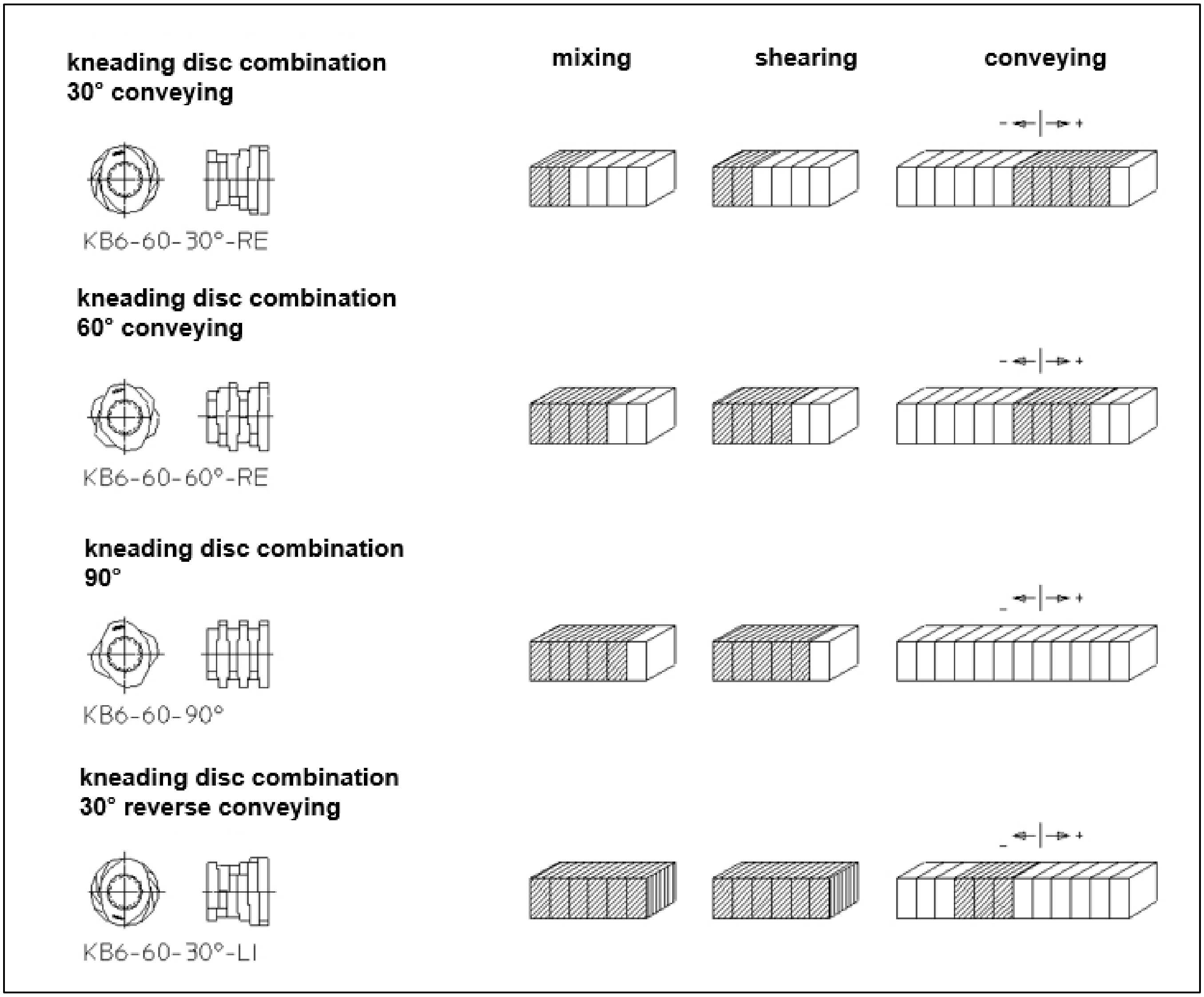

Figure 3: Examples of forward, reverse and TSE mixing elements

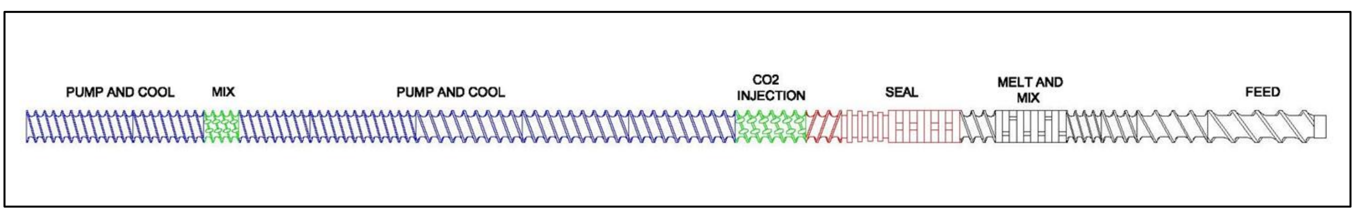

Figure 4: Screw design for sCO2 injection for direct profile extrusion

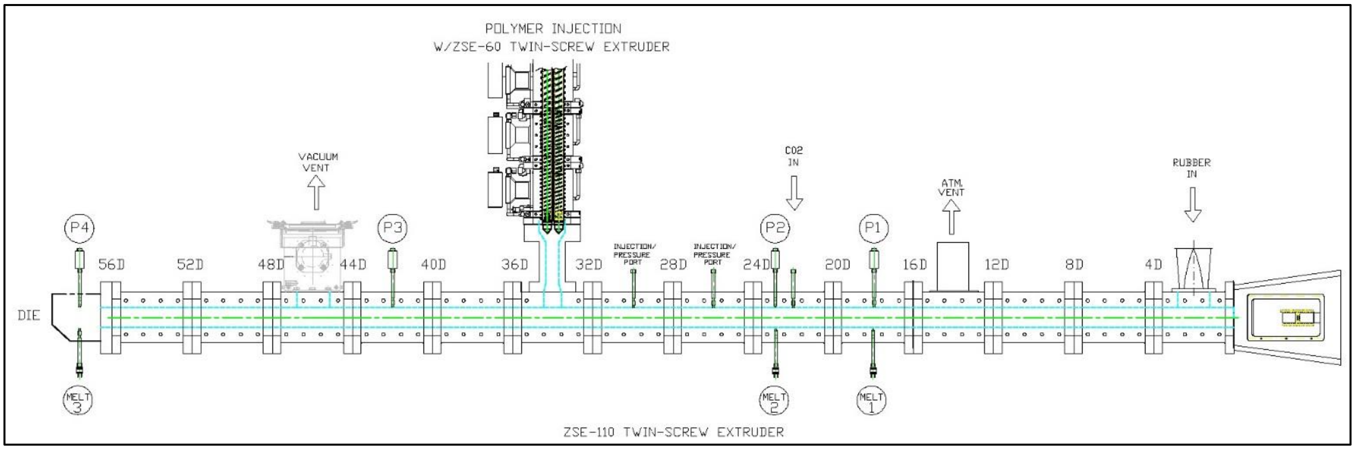

Figure 5: Process schematic for devulcanizing tire rubber and TPV processing

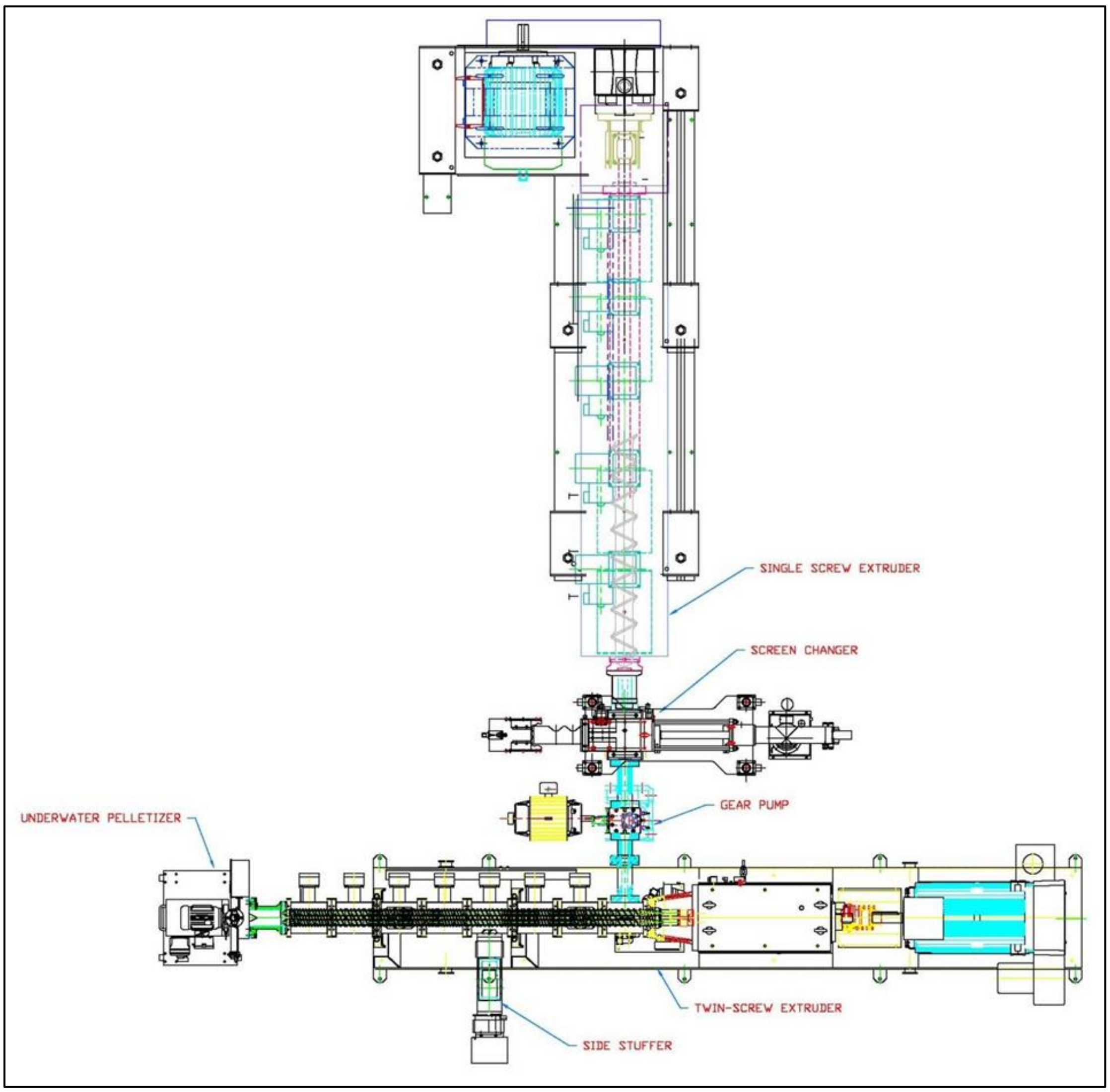

Figure 6: System design for PCR reclaim and high-level filler compounding