A single-screw extruder provides a simplified production process for many compounding applications. It is a conventional method which helps small volume production with continuous process. It is also a flexible process for compounding a diverse range of products and raw materials. Single-screw compounding has a number of advantages. However, it is important to have a better understanding of mixing limitations and the basic requirements for achieving dispersive and distributive mixing in particular [1, 2].

4.1 Single-screw Extruder

Single-screw extruders are commonly used for the conversion of polymers into products such as pipe, cables, film and so on. It is used for compounding with a modification of the screw, feed zone and mixing zone. The compounding operation can be synchronised with product extrusion in a single operation.

In a single-screw extruder, a screw is rotated inside a cylindrical barrel. The feed may be in the form of a pre-blend or dry blend, pellets or in the form of viscous melt in melt extrusion. The extruder acts as a pumping and mixing device. The extruder performs the additional functions of conveying and melting and also performs compounding and devolatilisation functions.

To incorporate flow and mixing mechanisms in a conventional screw, the ideal screw length for operations of material transport, melting and melt pumping would be excessively long with regard to both
cost and mechanical aspects. The overall performance of single-screw compounding is based on the homogenisation of compounding materials which enter in the die. Improved melting screws in single-screw compounding machines are used with barrier flight and pinned stirring-type screw tips [3, 4].

With single-screw extruders, melting and pressurisation of materials are of primary importance. For single-screw compounding, plasticating extruders are the choice. However, the choice is based on economy, simplicity of operation and the ability to generate pressure. In compounding, the temperature kept in the machine (extruder) is expected to discharge the homogeneous compounded material.

Single-screw extruders involve several steps to mix the composition. Therefore pre-mixing or blending before feed into the extruder is essential. Material transport, melting, and pumping functions are added in the screw after understanding the flow and mixing mechanisms. Figure 4.1 illustrates the melting of polymer and additives in a single-screw extruder. Screw length in the single-screw extruder is excessively long based on cost and mechanical requirements. In compounding, to avoid inadequate homogenisation of the polymer, barrier flight and pinned stirring type screw tips are used [5–8].

In comparison with the twin-screw extruder, single-screw extruders provide an economic means of melting, reducing compounding costs with the introduction of melting (mixing) screws. After compounding, this single-screw extruder can combine with product extrusions as part of a synchronised production unit for producing film, pipes, sheet and so on. Mixing screws are advantageous with respect to reducing raw materials costs, scrap disposal and environmental impacts.
Figure 4.1 Melting stages in single-screw compounding extruder
Therefore single-screw extruders for compounding operations are widely used as mixing devices in the polymer industry. A common practice in compounding with single-screw extrusion is to blend granular polymer materials with colourants or other additives. Compounded materials are used to extrude end products such as rod, sheet or tubing. In the extruder, the polymer melts and the other components are distributed through the viscous liquid. In laminar flow systems, the diffusion of soluble additives can assist in the mixing process although the effect is not large [9, 10].

Some compounding is performed in single-screw extruders which, however, frequently cannot provide the required mixing intensity. The single-screw extruder is preferred for compounding generally on an equipment cost basis. However, innovative ideas and screw designs have enhanced the performance of these extruders.

### 4.2 Material Melt Flow

In the single-screw extruder, melt flows through a channel of rectangular cross-section. The material flows into two sides which are leading and trailing surfaces of the flight. The bottom has the screw root and the top is the inside surface of the barrel. Therefore, fluid is conveyed because of the relative motion of screw channel and barrel. While melting, the conveying force is the viscous drag transmitted to fluid in the channel from the barrel surface and creating the motion of the melt. The channel of the screw is shown as uncoiled and laid flat rod. Velocity profiles present in the screw and barrel are considered as parallel plane in the single-screw extruder is as shown in Figure 4.2.

In the transverse plane (Figure 4.3), the barrel surface drags melt towards the leading face of the flight. In the absence of leakage, all the melt must be forced downwards to return across the bottom of the channel in a pressure type flow.
Compounding: Single-screw Extruder


4.3 Compounding

Single-screw compounding is the most commonly used even though it has processing limitations. The process is simple and relatively inexpensive. Pre-blend material without compounding leads to non-homogeneous compounds with wear problems. Feeding of additives or other chemical ingredients is usually carried out in a downstream operation into the melt. Single-screw compounding is illustrated in Figure 4.4.

Figure 4.4 Single-screw compounding

Gravity feed is an unacceptable method of production due to the potential problem of material plug. The screw is designed in such a way that the flight channels are partially filled to accommodate additional material being fed downstream. Depending on different velocity flows, two- or three-stage screws are employed in compounding. There might be a problem in
conveyance when changing processing conditions or the material characteristics. Large quantities of liquid additives such as plasticisers are injected into the melt and conveyance of the melt might be upset preventing practical operation. Compounding intensity is highly dependent on die pressure. The higher pressure leads to better compounding.

In single-screw compounding, melting starts in the compression zone. A fragile mass of polymer and additives is formed against the barrel surface and spreads inwards to the full channel depth of the screw within several turns. While flowing into the compression zone, the material semi-melt appears similar to the usual melting behaviour of the rolling melt pool which starts at the rear of the screw channel [12, 13].

The melt then steadily grows in width until the channel is full. The channel did not fill with melt mass. However, the separation of polymer granules from one another by the additives’ coating resulted in polymer which deforms under heat and pressure. Hence the compressed melt continues through and is compacted and subjected to high compaction forces which further form agglomerates. Due to additives’ coating, the formation of agglomerate results in preventing the melting polymer from wetting the barrel and screw. At the same time, the polymer melt receives further heating via conduction heat from the heater band, causing it to become increasingly molten and with a normal cross-channel circulating flow. The agglomerates are entrained within the melt through the die and the compounded material extrudes from the extruder [14, 15].

Dispersion and distribution are quite different in the single-screw compounding operation, each having different mixing conditions. Dispersion is achieved with high shear forces. Distributive mixing is achieved by mixing in a stirring mixing process. This process is part of the dilution stage and could be considered as a second compounding stage since it is often carried out during production processes such as extrusion, injection moulding and so on. However, in some
cases, both operations are carried out in one single compounding machine [16, 17].

Advantages:

- Combination of extruder and compounding is economic.
- Cheap replacement of worn out screws, feed devices and so on.
- Widely available new or used machines.
- Resistant to rough handling and mistreatment.
- Few process variables so easy to operate.
- Increase in back pressure is not significant and can be controlled without degradation.

Disadvantages:

- Single-screw compounding is intrinsically very limited in both dispersive and distributive mixing.
- Good dispersion cannot be achieved without proper mixing during compounding.
- Single-screw extruders do not achieve good dispersions due to fine additives interfering with the melting of the polymer.

4.4 Summary

- Polymeric materials have high melt viscosities during melting.
- Mixing of compound with single-screw extruders is economic and attractive.
Compounding: Single-screw Extruder

- Saving on capital cost and easy to combine with product extrusion.

- Limitation in single-screw compounding is the difficulty of powder conveying.

- Needs better understanding of the limitations in many formulations before compounding.

- Compounding with single-screw extruders is better with respect to the cost of raw materials, scrap disposal and above all environmental aspects.

- Discharge from single-screw compounding is not homogeneous, so that defects and increases in cost occur.

- The finer particle size interferes with the melting of polymer materials in single-screw extrusion.

- Mixing occurs in all screw extruders and starts while melting.

- With single-screw extruders, there is little mixing in the conveying zone of the extruder.

- With single-screw extruders, the melting is not completed until close to the end of the extruder. This is due to little time being available to mix the material before its discharge into the die.

References


Compounding: Single-screw Extruder


