The Development of CRD Mixing Technology

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Background

The development of CRD mixing technology was based on an analysis of mixing in co-rotating twin screw extruders. Several workers have studied mixing in twin screw extruders, TSE, (1-3) and the mechanism of mixing in TSE is now reasonably well understood (4-6). Erwin and Bigio (xx) found that the mixing action in TSE occurs largely in kneading blocks along the screws. Janssen (x) studied dispersive mixing of liquids and explained how high viscosity polymers can be dispersed in lower viscosity polymers in TSE. Grace (cc) performed an extensive experimental study of the dispersion of liquids. He found that shear flow is not capable of dispersing droplets when the viscosity of the dispersed phase is more than four times the matrix viscosity. However, elongational flow is capable of dispersing droplets up to one thousand times more viscous than the matrix.

When the flow of a polymer melt in a TSE is analyzed it becomes clear that the main dispersive mixing action occurs at the lobal pool at the pushing flank of the kneading disk. When the disk is thin the majority of the material in the pool will bypass the lobe crest since it will take the path of the least resistance. This is illustrated in figure 1. In this case the mixing action of the kneading disks will be primarily distributive. However, when the kneading disk is wide there is little opportunity for the material approaching the kneading disk tip to escape the intense mixing action in the lobal pool and tip clearance. As a result, wide kneading disks provide good dispersive mixing action but little distributive mixing action.

The flow in the lobal pool is to a large extent an elongational flow because the fluid elements are accelerated as they approach the crest of the kneading disk. This mechanism explains why TSE equipped with wide kneading disks are capable of dispersing polymers that are many times more viscosity than the matrix polymer. Many commercial polymer blends are produced on TSE and take advantage of this mechanism.

Using the TSE Mixing Mechanism in Single Screw Extruders

When we analyze the flow in the lobal pools of a TSE an interesting point emerges. The mixing action in the lobal pool has nothing to do with the fact that the TSE has two screws. This is illustrated in figure 2. As a result, it is entirely possible to use the TSE mixing mechanism in single screw extruders. In fact, it is easier to create elongational mixing in SSE than in TSE because the twin screw geometry has a number of severe design constraints if self-wiping action is to be achieved. The geometry of TSE does not suffer these constraints because there is no self-wiping action.

These arguments and considerations led to the development of the CRD mixing technology. The elongational mixing is achieved two ways. One, the pushing flank of the mixing flights is curved or slanted to produce a wedge-shaped pool between the mixing flight and the barrel. This is similar to the lobal pool of the TSE kneading disks. Two, the flights of the mixing section are equipped with slots to achieve efficient distributive mixing. However, the slots are tapered rather than parallel so that the material flowing through the slots is accelerated. As a result, elongational flow takes place within the slots and this accomplishes additional dispersive mixing.

Early Development of the CRD Mixer

The first designs of CRD mixing sections were based on the passage distribution theory developed by Manas-Zlocsower and Tadmor (ccc). The first designs were evaluated by performing a complete 3D flow analysis using the boundary element method (BEM). A 3D BEM flow analysis program was developed at the University of Wisconsin, Madison in the research group of Professor Osswald (BBB) right at the time that the CRD mixer was being developed. This led to cooperation between the two groups and this is how the first CRD geometries were established.

The BEM method has several important advantages. It allows complete 3D analysis of complicated geometries in relatively short time with excellent accuracy in particle tracking. If the analyses had been performed with finite element analysis the work would have taken probably one to two years rather than about 8 weeks. The real advantage of the numerical tools available today is that it is now possible to design a complicated mixing section based on engineering principles and calculations rather than by intuition and trial-and-error.

The first CRD mixer to be manufactured and tested was the CRD4 mixer shown in figure 3 – earlier designs (CRD1,2, and 3) were analyzed theoretically but not produced. This mixer has four parallel flights with tapered slots machined into the flights. Each flight contains both mixing and wiping segments. In the CRD4 one wiping segment is followed by three mixing segments. The placement of the wiping flight segments is such that the entire barrel surface is wiped by the mixing section. This is important for good heat transfer and for support of the screw in the barrel. The results of the first experimental tests were surprisingly positive as described by Rios et al. (FF).

Commercial Applications

The first commercial application of the CRD mixer were in the manufacture of color concentrates (CC) in SSE and foamed plastic profile extrusion. Producing CCs on single screw extruders is one of the most challenging applications because it requires very good dispersive and distributive mixing capability. Very good results were obtained in the CC application. Foamed plastic extrusion is also a very challenging