# ***CRD Mixing Technology***

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## Introduction

It has been known (1, 2, 8) for some time that mixing generally occurs more efficiently in elongational flow than in shear flow. Studies on mixing were often performed on small laboratory devices, e.g. the four-roller apparatus. For many years these results were not applied to actual extrusion operations because it was not known how elongational flow can be created effectively in screw extruders. Recently, REE developed mixing devices capable of generating strong elongational flow in single and multi-screw extruders (3, 4, 5, 12); these mixers are called CRD (Chris Rauwendaal Dispersive) mixers. The introduction of these patented mixers (6, 7) has opened up exciting new possibilities for single screw extruders; these will be described in more detail.

## CRD Mixing Technology

CRD mixers create elongational flow two ways, see figure 1. One method is by forcing material over a mixing flight with a slanted or curved active flight flank, see figure 1 left. As the material is forced over the mixing flight the material accelerates because of the narrowing of the gap and this creates strong elongational flow. The other method is by using tapered slots in the flights. The narrowing of the slot increases the fluid velocity as it flows through the slots and thus creates elongational deformation. The dashed arrows in figure 1 indicate the screw velocity; the solid arrows indicate the melt velocity relative to the screw.

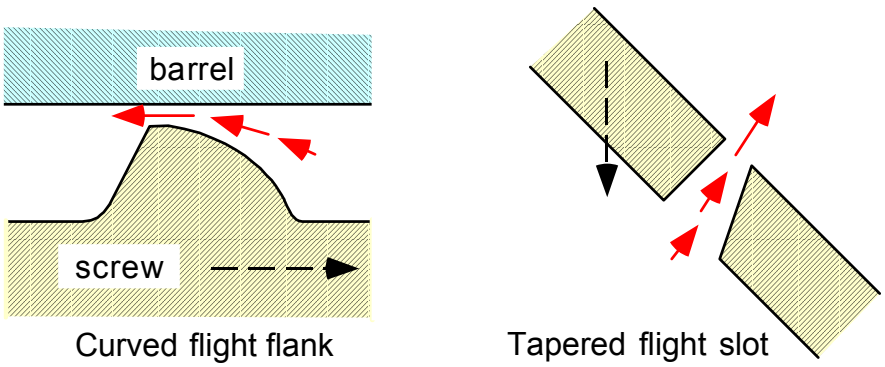


Figure 1, Two methods of creating elongational flow in the CRD mixer - the dashed arrows indicate the screw velocity; the solid arrows indicate the melt velocity relative to the screw

The tapered slots in the flights serve to increase distributive mixing as well as dispersive mixing. If the material is not distributed and randomized in its passage through the mixer, only the outer shells of the fluid will be dispersed leaving the inner shells undispersed. Therefore, it is critical to incorporate both distributive and dispersive mixing ability within the mixer.

Figure 2 shows a CRD6 mixer with an illustration of the breakup of droplets that occurs when the material flows over the mixing flights and through the tapered slots in the flights.

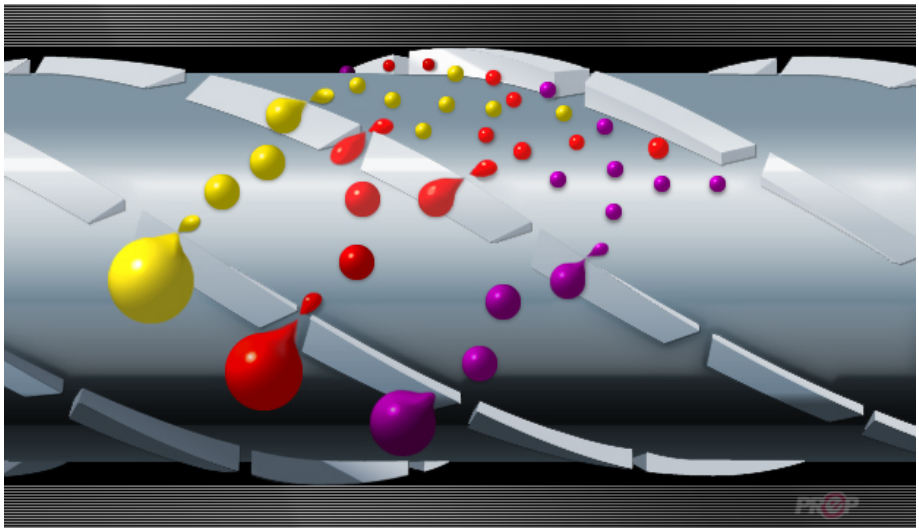

Figure 2, Illustration of the dispersive mixing action in the CRD mixer

Elongational flow achieves better mixing than shear flow and generates less viscous heating, resulting in lower melt temperatures. While most dispersive mixers do little distributive mixing, the CRD mixer is designed to provide both dispersive and distributive mixing. In cooperation with The Madison Group we have successfully extended this technology to static mixers and breaker plates (9).

The CRD mixers are also designed to expose all the material to multiple high stress events to achieve a fine dispersion. Conventional mixers, like the Maddock, expose the material to only one high stress event, thus limiting the mixing efficiency. Another advantage of the CRD mixer is that it is designed to have forward pumping capability. As a result, incorporating a CRD mixer does not compromise the output capability of the extruder. The following benefits result from the use of the CRD mixer:

1. Better dispersive and distributive mixing than conventional mixers
2. Reduced melt temperatures (less chance of degradation)
3. Gels can be dispersed; shear based mixers cannot disperse gels
4. CRD mixer have pumping capability; therefore, little or no pressure drop

These benefits result in reduced pressure and melt temperature fluctuation, which leads to improved output stability, dimensional control, and product appearance.

Applications of CRD mixers

The CRD mixers have been commercially available since 1999 and found rapid acceptance in the industry. Hundreds of extruders now use CRD mixing screws in a variety of applications, such as sheet and film extrusion, tubing and pipe extrusion, blow molding, and injection molding. Some of the most demanding applications for single-screw extruders are foam extrusion and compounding, in particular the production of color concentrates. CRD mixing screws have been particularly successful in these applications because of the special benefits that the CRD mixers offer.

Injection Molding

Injection molders are increasingly using the injection molding machine (IMM) to mix color concentrates (CC) with virgin polymer to produce custom colors right at the machine. This eliminates a separate compounding step and reduces the cost of the compound. Obviously, in-line blending requires good mixing capability in the plasticating unit of the IMM. CRD mixing devices can be used in injection molding screws just as in regular extruders.

The mixing capability of IMM can be further increased by incorporating mixing capability in the non-return valve (NRV) at the end of the screw. REE has developed several non-return valves that incorporate CRD mixing elements (11). Figure 3 shows an example of a CRD-NRV.

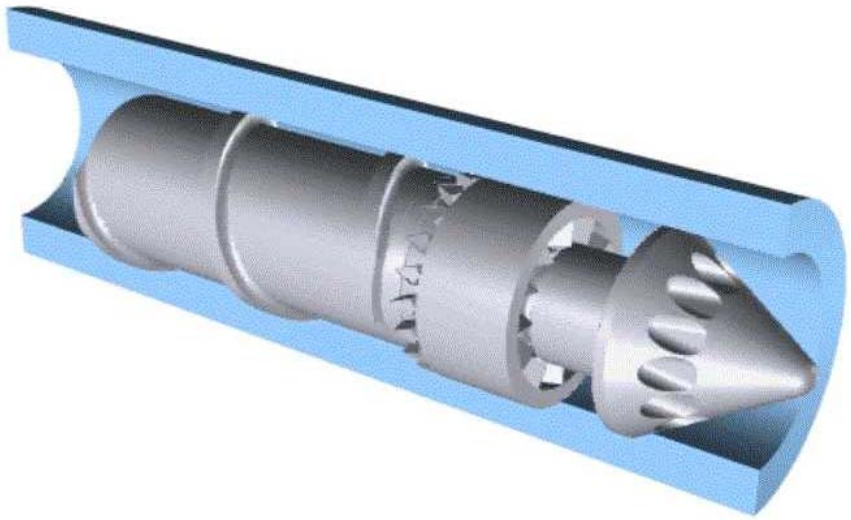

Figure 3, Example of a CRD non-return valve for injection molding

The CRD-NRV fits in the same space as a regular non-return valve and can be installed quickly and easily. As a result, the CRD-NRV provides a simple and quick method to achieve substantial improvement in mixing in an IMM. REE has recently developed a third generation mixing NRV that further enhances mixing capability (13). This new VIP mixer will become commercially available early 2003.

Foam Extrusion

The extrusion of foamed plastics poses special challenges over and beyond conventional extrusion operations. In foam extrusion the dispersive and distributive mixing capability of the screw has to be excellent to achieve a finely dispersed foaming agent with a very uniform distribution throughout polymer matrix. Melt temperature control is extremely important in foam extrusion because excessive melt temperatures can lead to premature activation of the foaming agent.

CRD mixing screws have been successfully used in numerous foam extrusion operations both with chemical and physical blowing agent. Details of the application of CRD mixing screws in foam extrusion were presented at the Foams 2002 Conference in Houston, Texas (10). The success of the first commercial application of a CRD mixing screw in foam extrusion resulted in this company now running 50 extrusion lines with CRD mixing screws.

Compounding on Single Screw Extruders

Even though twin screw extruders are commonly used in compounding there are many companies that use single screw extruders (SSE) for compounding. One of the important benefits of SSE is their relatively low cost, ease of operation, and low maintenance requirements. The use of SSE in compounding has been limited by lack of efficient mixing elements. With the use of CRD mixer the SSE can now perform compounding jobs that were only possible with twin screw extruders (TSE) in the past.

One of the most demanding compounding jobs is the manufacture of color concentrates (CC). A substantial number of CC producers now use CRD mixing screws on SSE to produce high quality concentrates even with colors that are notoriously difficult to disperse such as phthalate blue. The success of CRD mixing screws in these applications has led to the development of a new single screw compounding extruder.

New Single Screw Compounding Extruder (SSCE™)

Rauwendaal Extrusion Engineering has cooperated with Machinefabriek de Rollepaal B.V. of Dedemsvaart, the Netherlands to develop a new SSCE™ based on the CRD mixing technology. To successfully use a SSE for compounding a number of conditions have to be met:

1. The SSCE must be longer than conventional SSE
2. The SSCE must be equipped with multiple downstream ports
3. Starve feeding must be used for optimal mixing and process control

Since the melting in the SSE is generally less efficient than in the TSE the length of the SSE has to be about 5D to 10D longer than a corresponding TSE. Obviously, the increased length of the SSE and the additional ports along the barrel will increase the price of a SSCE

relative to a conventional SSE. However, a compounding SSE offers a number of significant advantages over TSE:

- Lower purchase cost
- Lower operating cost
- Better pressure generating capability
- Can operate without gear pumps

A schematic representation of a SSCE is shown in figure 4. This SSCE is designed with multiple downstream addition ports for processing high levels of fillers, up to 50-60 percent. The screw is a multi-stage screw with a mixing section (shown in blue) in each stage of the screw.

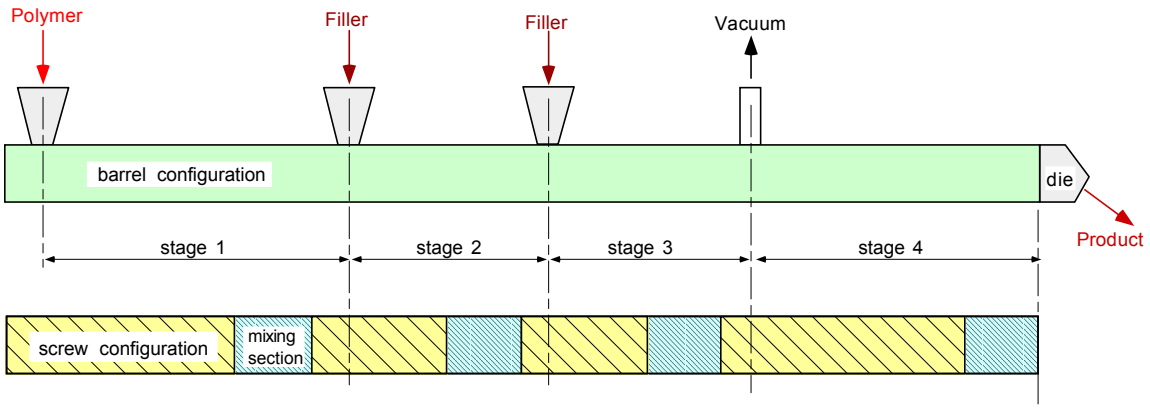


Figure 4, Schematic representation of single screw compounding extruder (SSCE)

The SSCE will offer special advantages in direct extrusion; this is the combination of compounding and final product extrusion in one step. Since the SSCE has better pressure generating capability than a TSCE it can be used in direct extrusion without a gear pump; twin screw extruders generally require a gear pump in direct extrusion. It is interesting to note that the advantages of the SSCE can be applied equally well to injection molding. By using the principles of the SSCE it is possible to manufacture a single screw compounding injection molding machine (SSCIMM) that will be capable of performing direct injection molding. Clearly, this would be more difficult and more expensive with a twin screw compounding extruder.

Obviously, compounding extruders have to be equipped with good feeders. Gravimetric feeders are necessary when the bulk density of the feed stock is variable. When the bulk density of the feed material is quite low it is beneficial to use single- or twin-screw feeders (side stuffers) directly coupled to the extruder barrel. This allows efficient addition of solid fillers at higher levels than conventional feeders. A four-stage SSCE shown in figure 4 is able to handle filler levels up to 50-60 percent.

Outlook

The CRD mixing technology has changed the way extruders are used. Single screw extruders and injection molding machines can now achieve substantial mixing performance and be used in applications that were not possible only a few years ago. Conventional extruders can now handle tough compounding tasks and injection molding machines can blend virgin polymers with color concentrates right at the machine. The new single screw compounding extruder, SSCE, can be used in heavy-duty (high filler loadings) compounding and direct extrusion.

Single screw extruders with CRD mixers can be used in direct extrusion and, in fact, several machines are already used in direct extrusion. The excellent results achieved thus far combined with significant economic benefits make direct extrusion with single screw extruders an attractive option that deserves serious consideration. In the near future it can be expected that direct injection molding can be achieved with plasticating units similar to the SSCE.

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