MAKING THE BREAKER PLATE OF AN EXTRUDER AN EFFICIENT MIXING DEVICE

AntoineRios, Enric Santanach, and Paul Gramann, The Madison Group
Chris Rauwendaal, Rauwendaal Extrusion Engineering, Inc.

Introduction

During the compounding of polymers it is oftentimes desirable to create additional mixing if possible. This generally requires both distributive and dispersive mixing, where the dispersion of materials having widely different viscosities often poses the greatest difficulties. The best method to accomplish successful dispersive mixing is to expose the material to extensional flow. Furthermore, in terms of power consumption, extensional flows are far superior to the shear-type flows found in most mixing systems.

In most liquid-liquid mixing operations coalescence plays an important role (8). Coalescence is the fusing together of discrete droplets of the dispersed phase, thereby, causing a coarsening of the morphology. As a result, it is beneficial to achieve dispersive mixing as close to the die exit as possible. Generally, this involves putting a mixing section at the end of the screw. However, this can be an expensive and time consuming option. Further, after the material leaves the screw and travels to the screen pack/breaker plate and/or die region, sufficient time may exist for coalescence to take place (1, 2). This article discusses a new device that was developed to create efficient mixing during this critical stage of processing; the Mixing Breaker Plate (MBP) is a device that replaces the standard breaker plate.

Mixing in Polymer Processing

During the processing of polymers it is common to add additional compounds to the melt stream to produce color, enhance properties, or produce a polymer blend. However, these compounds or additives can have widely different properties, e.g. viscosity, which may cause significant mixing problems. Here, mixing demands of the system are significantly increased and the knowledge of what the system can produce is essential. Furthermore, it is often desirable to produce this mixing in the most economical fashion.

In polymer processing, mixing can be distributive and/or dispersive. Distributive mixing involves the increase in spatial distance between solid agglomerates or droplets. Dispersive mixing entails the breakup of these liquid or solid agglomerates to produce a finer level of dispersion. Here, a hydrodynamic force is applied to the agglomerate or droplet by the flow of material as it passes through the system. The type of flow that is created is a major factor in how effective the device will be in creating a dispersive mixing environment. Unfortunately, most of the current generation of mixers rely on shear-type flows. Typically, with these flows, a large degree of shear stress must be created to obtain any level of dispersion. Furthermore, it is well known in the polymer mixing community that dispersion of agglomerates by shear is ineffective at large viscosity ratios (3).

The classic study by Grace (3) showed that when the viscosity of the dispersed phase is greater than four times the matrix viscosity ($\mu_1/\mu_2>4$), simple shear flows cannot overcome the interfacial tension between the compounds, and droplets cannot be broken up. The study also showed that elongational flows are much more effective at dispersive mixing and do not exhibit a limit based on viscosity ratio up to a ratio of 1000:1. Elongational flows can also generate significantly higher stresses to disperse agglomerates. Accordingly, the resulting energy requirement to produce mixing is much lower than with shear flows.

Based on the classic study by Erwin (4) in the 1970's, Figure 1 shows the ratio of energy input requirements for shear and elongational flows to produce a specific dispersed phase size. The graph shows that as the interfacial area of the agglomerates, A, is increased from the initial surface area, A_o, shear flow is an inefficient way to mix. As the figure illustrates, shear flows are always less efficient, i.e. require more energy, to produce an increase in interfacial area than elongational flows. Also readily evident from the figure is the fact that the energy required for elongational flow can be many orders of magnitude *less* than for shear flow.

Given the advantages of elongational flow, some quantitative measures must be defined to numerically evaluate a new mixing device. One such measure, the flow number, has been extensively used by many authors (5-8) to ascertain the type of flow in a given geometry. The flow number, λ, is defined by Eq. 1 in terms of the magnitude of the strain rate tensor, $\dot{\gamma}$, and the vorticity tensor, ω. The flow number is a measure of the type of flow in the system and varies between a value of 0 and 1. For a flow number of 0, the system is undergoing purely rotational flow and no effective mixing can occur. A flow number of 0.5 denotes simple shear flow, while a value of 1.0 denotes pure elongational flow. In commercial applications, whenever the flow number is greater than or equal to 0.7, the system is thought to be generating effective elongational flow for dispersion.

$$\lambda = \frac{\dot{\gamma}}{\dot{\gamma} + \omega} \quad (1)$$

Equally important as the flow number, is the magnitude of the separation forces that the mixer can impart to the fluid. In simple shear flow, the force that is applied is given by Eq. 2 (1), and for pure elongational flow by Eq. 3.

$$F_{shear} = 3\pi\eta_s \dot{\gamma} r^2 \quad (2)$$

$$F_{elong} = 6\pi\eta_e \dot{\gamma} r^2 \quad (3)$$

Here, η_s is the shear viscosity of the carrier fluid, η_e the elongational viscosity, and r the radii of particles to be broken up. Considering the Trouton relationship, where the elongational viscosity is usually three times the shear viscosity, the equations indicate that elongational flows can generate substantially higher separation forces than shear flows. However, it should be noted that it is generally more difficult to achieve high elongational strain rates than high shear strain rates.

Mixing Devices

Some common high shear mixing devices that are used in the polymer processing industry are the Maddock (LeRoy) fluted mixer, the blister ring, Egan mixing section, and various barrier screws (1). These are all dynamic mixing devices that are part of the screw. Because these devices generate a large amount of shear, degradation of the polymer and a high temperature increase must be taken into account. Recently, a new mixing device, named the CRD, was developed to generate elongational flows by incorporating tapered flights and wedge shaped slots (9). This device has been very successful in the dispersive mixing of difficult materials, while reducing the overall melt temperature (10).

Another type of mixer that is common in polymer processing is the static mixer. This device is not attached to the screw, and as the name suggest, it is a stationary object. Because the flow of material creates the only relative motion between the mixing device and the polymer, the type of flow created is extremely important when considering dispersive mixing. Fluids entering a static mixer are typically divided by baffles and mixing occurs by the continual splitting and recombination of flow streams.

The current state of the art of static mixers for the polymer industry can produce an extremely uniform mixture for materials with nearly equal viscosities. However, when mixing incompatible compounds with large viscosity ratios, the current generation of static mixers is often unable to sufficiently disperse the secondary phase material. Common static mixers are the twisted tape, SMX and the Ross ISG (1).

The mixer described in this paper attempts to alleviate many of the shortcomings of current mixers by providing both distributive and dispersive mixing capabilities, while being relatively easy to incorporate in an existing extrusion line.

The New Mixing Breaker Plate

With the aforementioned requirements and caveats, a new mixer, patent pending, has been developed that improves dispersive mixing while providing distributive mixing as well. By taking advantage of the strengths of elongational flows, this new mixer has shown excellent promise in generating effective dispersive mixing.

The present invention replaces the standard breaker plate with one that generates both distributive mixing and dispersive mixing. The main purpose of the standard breaker plate is to support the screen pack and reduce screw beat. The Mixing Breaker Plate (MBP) is similar to the standard breaker plate in that it is stationary in the extruder, can hold a screen pack and also reduces screw beat. However, this new device is designed to created strong elongational flows for dispersive mixing by incorporating a series of wedge shaped slots, Fig. 2. The arrangement of the baffles is such that all fluid elements experiences elongational deformation. Further, all material passing through the mixer is exposed to high elongational stresses required to achieve breakup.

A number of geometries have been developed for specific processes to help setup streamlines while creating elongational flow, Figs 3-5. The MBP shown in Fig. 3 is typical for sheeting, while Fig. 4 shows the design for the processing of pipe. Because the MBP replaces the same space occupied by the standard breaker plate, which is at the end of the extruder, it is ideally positioned to provide mixing at the latest time in the process before entering the die. As mentioned earlier, this gives the advantage of reducing or eliminating coalescence. Further, the MBP is relatively easy to incorporate into an existing system giving the processor a simple method to increase the overall performance of the extruder.

Given that the MBP is stationary in the extruder it is considered a static-type mixer. To increase both the dispersive and distributive mixing of this device a number of MBPs of similar or different design can be placed in series. The modularity of this mixer makes it quite powerful for designing the mixing that will take place, i.e. number of high elongational events the material will experience. Placing different MBPs in series will help achieve a random mixing situation while the number of high stress exposures and splitting events will be increased. When placed in series, this device is called the Dispersive/Distributive Static Mixer (DDSM), patent number 5,971,603 (11), shown in Fig. 6.

Another advantage of this mixing section is that its design was made to be relatively inexpensive to manufacture. Also, stagnation zones are significantly reduced compared to conventional breaker plates. Each baffle has a continuous tear drop shape, which creates the streamlined elongational flow. The gap between the baffles can be made according to the size of the dispersed phase needed and the pressure available. An important advantage of this device is that the angled surfaces of the wedges lend themselves to be cleaned easily. In many cases, each hole of the standard breaker plate needs to be cleaned by hand.

Flow Simulation

To investigate the type of flow generated in this system the boundary element simulation program BEM*flow* (11) was used. Using this program, the geometry of the mixer can be quickly modified to help pursue the optimized geometry — one which gives high dispersive mixing with distributive mixing effects. The flow number was used as the mixing index to quantitatively measure its dispersive mixing ability. Figure 7 shows the calculated particle tracking though a circular MBP. Figure 8 shows the calculated flow number for several particles as they travel through two openings of the mixer. A flow number of 0.7 and higher indicates strong elongational flow (dispersive mixing), which is illustrated in yellow and red, respectively. It is clearly evident that this mixer produces extremely high elongation flows, which are not found in most mixing devices used in industry today, especially, static mixers. Mixing sections that are typically used are shear dominate and have a flow number in the range of 0.5. The figures demonstrate how the converging baffles continually expose the fluid to an elongational flow — assuring that the material goes through the HSR multiple times and is exposed to high forces long enough for dispersion to occur. The mixing that is produced by the staggered baffles, creates a distributive mixing effect similar to the twisted tape static mixer.

Conclusions

The current state of the art mixing devices that are now used rely on large shear stresses to create dispersive mixing. It is well known that the elongational flows are extremely more effective and efficient for reducing the dispersed phase. The new Mixing Breaker Plate (MBP) and Dispersive/Distributive Static Mixer (DDSM) shown in this paper was designed to create a high degree of elongational flow and assure that all material passes through the high elongational region.

The streamlined design of this mixer reduces stagnation, makes it relatively inexpensive to manufacture, and easy to clean. Further, since the MBP is designed to replace the existing standard breaker plate incorporating it into the extruder is very easy, giving the processor a simple method to increase the overall mixing of the system.

References

1. "Polymer Mixing, A Self-Study Guide," C. Rauwendaal, Carl Hanser Verlag, Munich (1998).
2. S.T. Balke, J. Hu, S. Joseph, A. Karami,, R. Salerni, M. Planeta, J. Suhay, and H. Tamber, "Polymer and Particle Separation during Extrusion," ANTEC (1998).
3. Grace, H. P., "Dispersion Phenomena in High Viscosity Immiscible Fluid Systems and Application of Static Mixers as Dispersive Devices in Such Systems," *Chemical Engineering Communication,* **14**, 225 (1982).
4. Erwin, L, "Theory of Laminar Mixing,*" Polym. Eng. Sci.*, **18**, 1044 (1978).
5. Cheng, J. and Manas-Zloczower, I., "Hydrodynamic Analysis of a Banbury Mixer," *Polym. Eng. Sci.*, **11**, 701 (1989).
6. Davis, B. et al., "Computer Modeling and Optimization of Polymer Processes Using the Boundary Element Method," Winter Annual Meeting of ASME (1994).
7. Rios, A., Gramann, P. and Osswald, T., "Comparative Study of Mixing in Co-Rotating Twin Screw Extruders Using Computer Simulation," *Advances in Polymer Technology*, **17**, 2, 107 (1998).
8. Peng, F. et al, "Computer Simulation of Melt Flow in Wave Screws," ANTEC (1998).
9. Rauwendaal, C., T.A. Osswald, P.J. Gramann and B.A. Davis, "A New Dispersive Mixer for Single Screw Extruders," ANTEC 1998.
10. Rauwendaal, C., "New dispersive mixers based on elongational flow", *Plastics Additives & Compounding*, p. 21-23 (1999).
11. Gramann, P.J., B.A. Davis, T. A. Osswald, C. Rauwendaal, "A New Dispersive and Distributive Static Mixer for the Compounding of Highly Viscous Materials" ANTEC Conference – New York, (1999).
12. BEM*flow*, Boundary Element Fluid Dynamics Simulation Program, The Madison Group: PPRC.

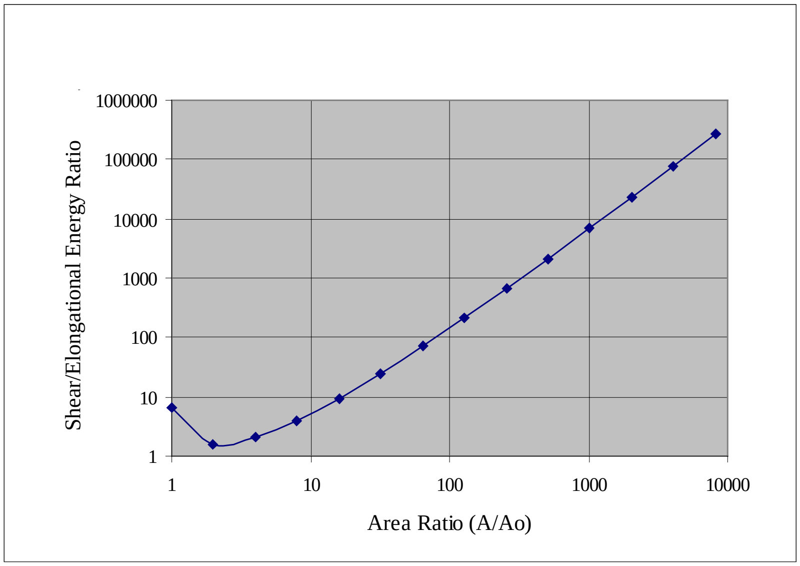

Figure 1 - Energy ratio (shear/elongational) required to produce dispersed phase of a specific size.

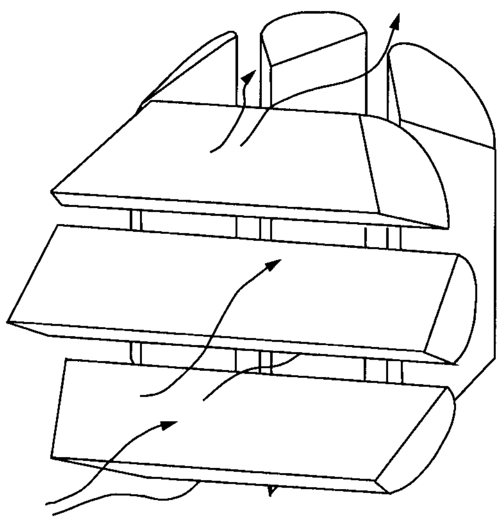

Figure 2 – General shape of converging wedges that create elongational flow.

Figure 3 – Parallel slotted MBP with guide holes for stacking plates in series.

Figure 4 – Circular slotted MBP with guide holes for stacking plates in series.

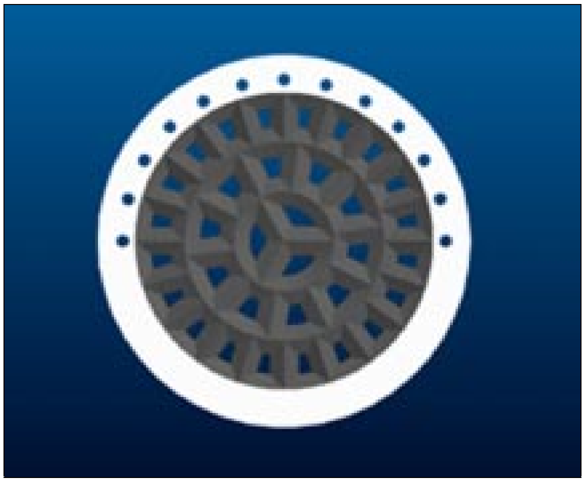

Figure 5 – Radial slotted MBP with guide holes for stacking plates in series.

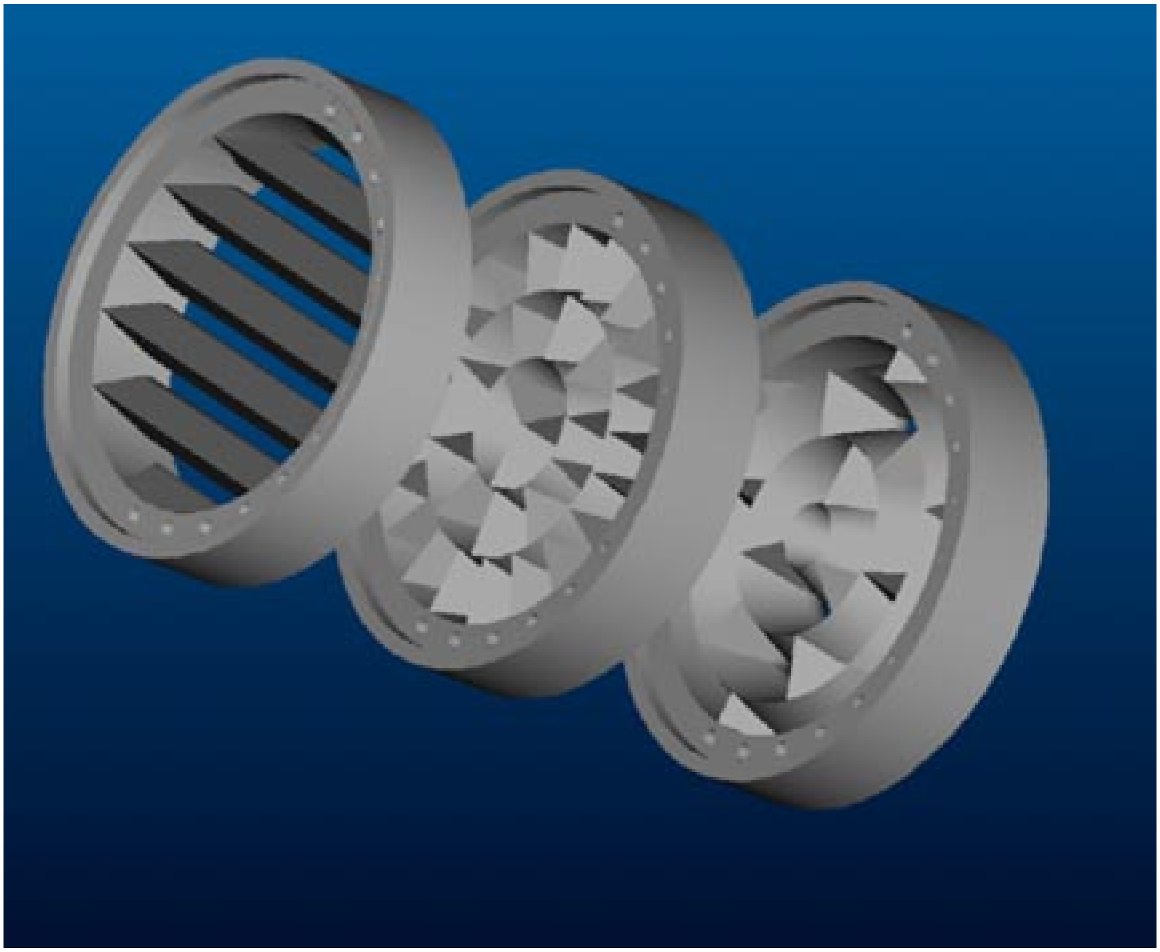

Figure 6 – Parallel, radial, and circular MBPs placed in series to create the dispersive/distributive static mixer (DDSM).

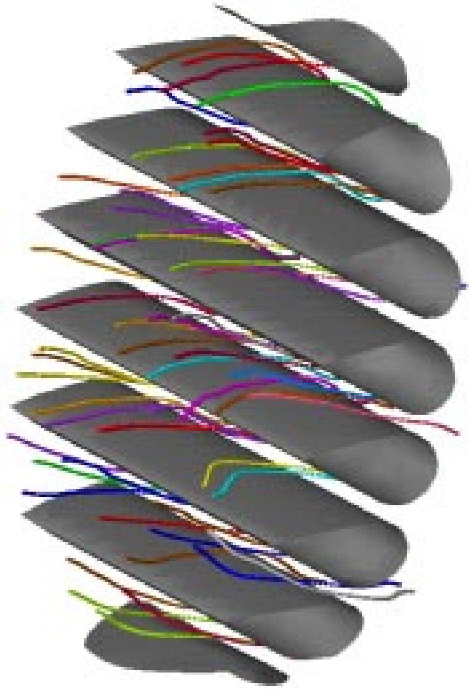

Figure 7 – Calculated particle tracking through the MBP.

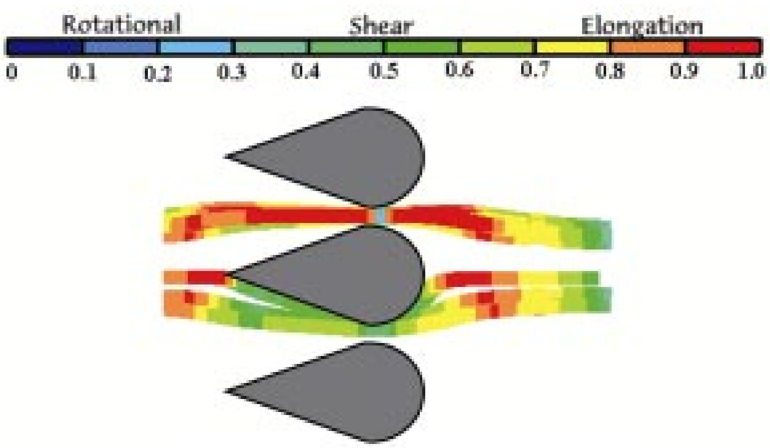

Figure 8 - Calculated flow number for particles tracked through they Mixing Breaker Plate (MBP).