Mixing of Pigmented Polymers in a Co-rotating Twin-Screw Extruder

L. Cong and M. Gupta

Michigan Technological University, Houghton, MI 49931, USA

Abstract

Simulation results for mixing of two different polymers in a co-rotating twin-screw extruder are presented. Velocity distribution predicted by a three-dimensional simulation of the flow is used to predict the change in the distribution of initially segregated particles. The predicted particle distribution is used to estimate the increase in Shannon entropy along the extruder channel.

Introduction

Twin-screw extruders are commonly used to mix polymer compound together with additives such as stabilizers and flame retardants. In the present work, quality of distributive mixing [1] in a co-rotating twin-screw extruder is estimated by evaluating the distribution of particles with two different colors, which are initially segregated in the two halves of the co-rotating extruder.

Shannon Entropy of a Mixture

Following the approach of Manas-Zloczower and co-workers [1], in the present work a color homogeneity index based on Shannon entropy [2] is used as a measure of the quality of mixing.

$$\text{Color homogeneity index} = -\left(\sum_{j=1}^{M} P_j \sum_{c=1}^{2} (P_{c/j} \ln P_{c/j})\right) / \ln(2) \qquad (1)$$

where M is the number of equal-sized bins formed by dividing the flow domain at each cross-section, P_j is the probability of finding a particle (irrespective of color) in bin j, c represents the particle type, $P_{c/j}$ is the probability of finding a particle of color c conditional on bin j.

Simulation of Distributive Mixing in a Twin-Screw Extruder

In the present work, PELDOM^{TM} software [3] was used to simulate the flow in a co-rotating twin-screw extruder. The geometry of the 30 mm diameter twin-screw extruder (Fig. 1) used in the flow simulation are the same as that of extruder used by Shah and Gupta [4]. For the flow simulation, the screws were rotated at 60 RPM. A Newtonian fluid with a constant viscosity was used for the simulation. Fig. 2 shows the predicted velocity distribution at one cross-section of the extruder. The velocity distribution predicted by the PELDOM software was used to trace the path lines of various particles in the twin-screw extruder. It should be noted that in a stationary frame of reference, the geometry of flow domain in a twin-screw extruder is time dependent. Therefore, in a stationary reference frame, the predicted velocity distribution shown in Fig. 2 cannot be used to trace the path lines. However, the geometry of the twin-screw extruder is time independent in the reference frame moving along the axial direction with a constant velocity $V_r = LN$ towards the exit, where L is the screw lead and N is the rotational speed in revolution per second. In this moving frame of reference, the predicted velocity was used to trace the path lines of 1,000 particles in the co-rotating twin-screw extruder. The periodic nature of the flow after each screw lead of the twin-screw extruder was also exploited to trace the particles beyond the domain used for the flow simulation. Starting with the blue and red particles segregated in the two halves of the twin-screw extruder at the entrance (z = 0), at five locations along the axial direction, the predicted particle distribution is shown in Fig 3. It is noted that starting with red and blue particles in the left and right lobes, respectively, at z = 40 mm the left lobe has more blue particles, whereas the right lobe has more red particles. That is, a major portion of the fluid in the two lobes at the entrance has been swapped to the other lobe by z = 40 mm. At z = 80 mm, the particles distribution in the twin-screw extruder in Fig 3 (e) is quite uniform.

To determine the color homogeneity index (Eqn. 1), the outer bounding rectangle at each cross section was divided into 10, 100, 500 and 1000 equal size bins. Only the bins which partially or fully lie in the flow domain were used for color homogeneity calculations. The predicted evolution of color homogeneity index along the screw axis is shown in Fig 4. As expected, the uniformity of particle distribution, and therefore, the color homogeneity index increases along the axial direction. Also, for the same particle distribution, the homogeneity index decreases as the number of bins is increased, which is reasonable since the color homogeneity is expected to decrease as the area of observation is refined.

References

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3. PELDOM software, Plastic Flow, LLC, Houghton, MI 49931 (www.plasticflow.com)
4. A. Shah, M. Gupta, SPE ANTEC Tech. Paper, **50**, 44 (2004)

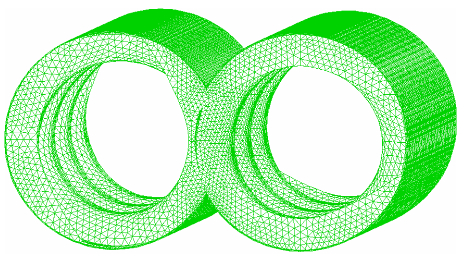


Fig. 1: Finite element mesh used for flow simulation in a co-rotating twin-screw extruder.

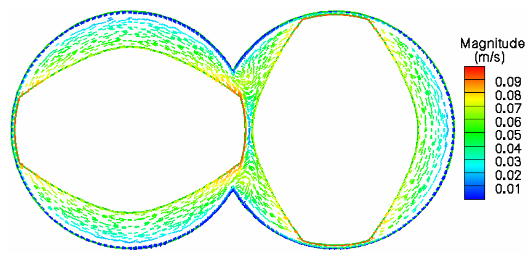
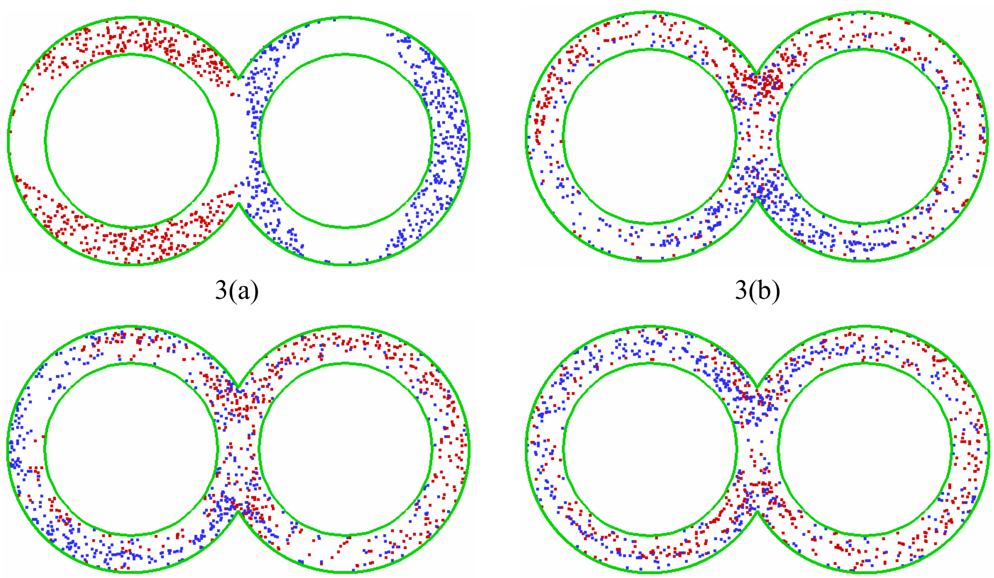
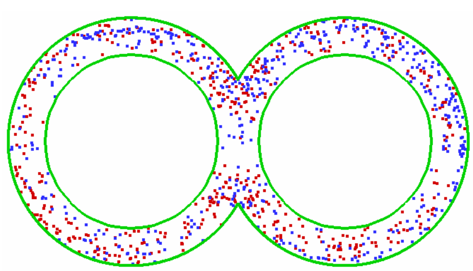


Fig. 2: Velocity distribution in a cross-sectional plane perpendicular to the axis of the twin-screw extruder (z = 22.5 mm).



3(a) 3(b)

3(c) 3(d)



3(e)

Fig. 3: Spatial distribution of particles at different axial locations, z = 0 (a), 20 (b), 40 (c), 60 (d), 80 mm (e).

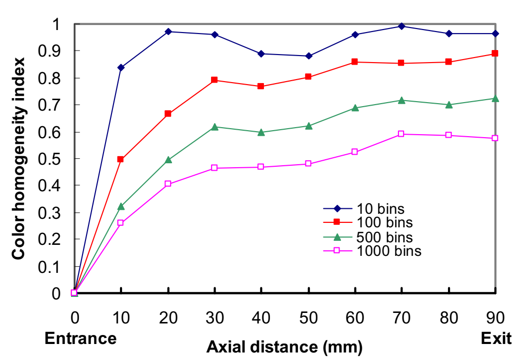


Fig. 4: Evolution of color homogeneity index along the twin-screw extruder axis.