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Integrated computer model for intermeshing counter-rotating twin-screw extrusion

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Metering, melting, and solid conveying are considered in an experimentally verified simulation approach for the calculation of melting, pressure, temperature, and fill factor profiles.

Extrusion is the process in which molten plastic is pushed—by a rotating screw—through a shaping die as a continuous, formed shape. This process is used to manufacture objects such as pipes, sheets, and films. There are, however, a number of different types of machines used for extrusion, e.g., single-screw and twin-screw (either co-rotating or counter-rotating) extruders. Indeed, intermeshing counter-rotating twin-screw extruders are recognized as fundamentally different from single-screw, and from co-rotating twin-screw, machines. Although computer modeling is commonly used in the polymer extrusion industry for process design, there is little available literature on process modeling for counter-rotating twin-screw extruders.[1–4] Such computer models are used to predict process parameters (e.g., pressure, temperature, polymer melting, power consumption) and are based on process input data, including material data, the geometry of the screw and die, and the operating conditions.

The first composite model of metering, melting, and solid conveying for counter-rotating twin-screw extruders was developed in 2007.[6] This model was based on descriptions of polymer melt flow[7,8] and of polymer melting.[2,3] The mechanism of polymer flow in counter-rotating twin-screw extruders is a result of the screws acting as a positive displacement pump and forming closed chambers (C-chambers) that transport the material. Since the screw channels are closed, the material cannot flow from one screw to another, except via leakage flows that reduce the degree of positive conveying (see Figure 1). In contrast, for single-screw extruders and co-rotating twin-screw extruders, the screw channels are open along their length and there is drag-type material transport.

We have recently conducted an extensive study of polymer flow within an intermeshing counter-rotating twin-screw extruder.[5,10] In our integrated approach we consider the die flow. We also combine new

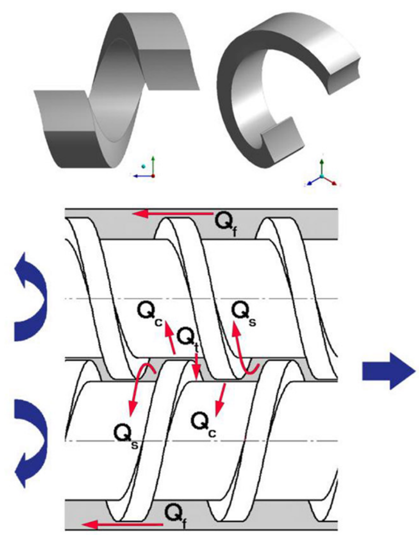

Figure 1. *Configuration of a counter-rotating twin-screw extruder, illustrating the closed chambers and leakage flows.* Q_c*,* Q_t*,* Q_f*, and* Q_s *denote the calendaring, pressure (tetrahedron), flight, and side leakage flows, respectively.*[5]

melt conveying models with models of melting and conveying solids to produce a global model of the extruder. We are thus able to predict the pressure and temperature profiles, as well as the melting progress and filling of the screws.

For our work, we performed the first fully 3D non-Newtonian finite-element-method (FEM) computations to design the screw pumping characteristics for an intermeshing counter-rotating twin-screw extruder. We then used the results to develop a global model of the extrusion process. We performed the analysis for the flow in the C-chambers, and we identified the leakage flows over the calendar, tetrahedron, flight, and side gaps (see Figure 2). We calculated and modeled the screw pumping characteristics for different screw elements, at

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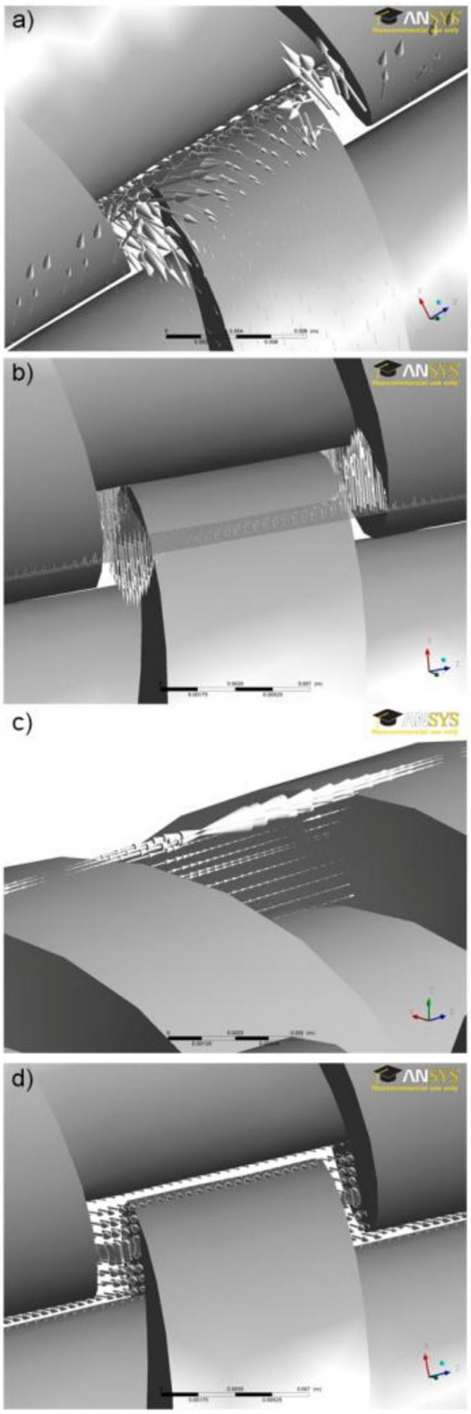

Figure 2. 3D non-Newtonian finite-element-method simulation of polymer flow within an intermeshing counter-rotating twin-screw extruder. Models are shown for (a) Q_c, (b) Q_t, (c) Q_f, and (d) Q_s leakage flows.[9]

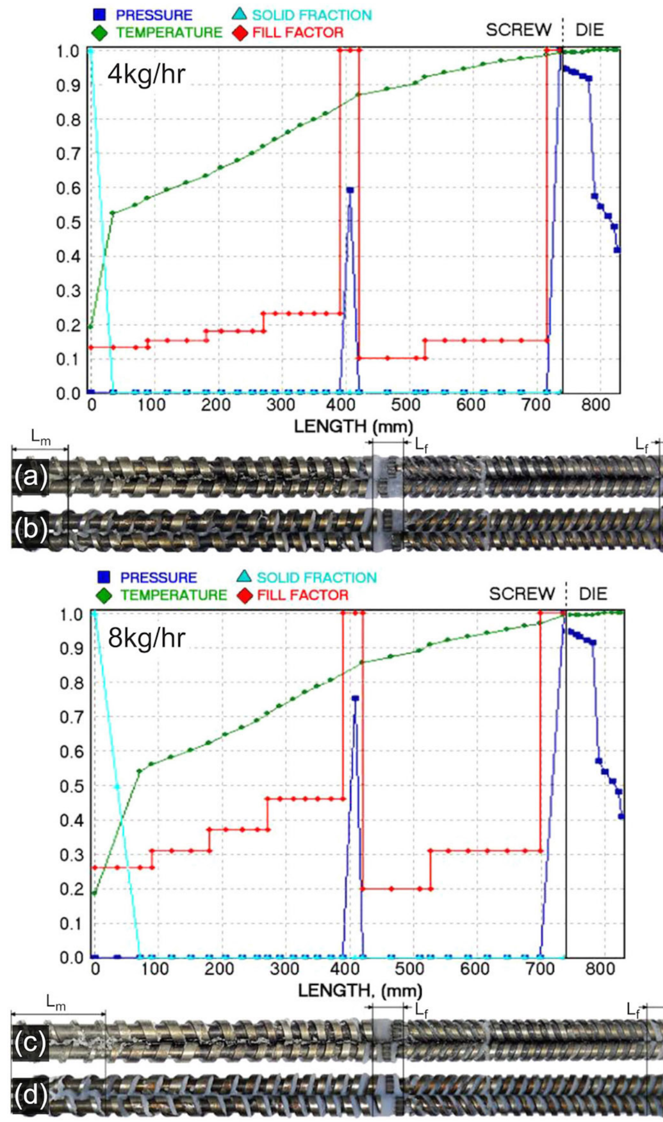

Figure 3. Results from the computer simulation of low-density polyethylene extrusion for a screw speed of 80rpm and a metered feed rate of (top) 4kg/h and (bottom) 8kg/h. Photographs of the screws from above (a) and (c), and from below (b) and (d) are also shown so that the models can be evaluated. The vertical axis indicates the relative values of pressure, temperature, solid fraction, and fill factor (where 1 is the maximum value and 0 is the minimum). L_m: Melting length. L_f: Fully filled region.[9]

various power law indices that describe the non-Newtonian behavior of polymers.

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We have also conducted experiments to validate our model.[9,10] We thus performed the simulations and experiments for two Leistritz intermeshing counter-rotating twin-screw extruders. One machine (LSM 30.34) was equipped with 34mm-diameter screws, and the other (ZSE 27HP) was equipped with 27mm-diameter screws. We arranged various screw elements on the shafts to produce specific configurations. We also used two different polymers—a polypropylene and a low-density polyethylene (LDPE)—in our study, and a 'screw pulling-out' technique to investigate the extrusion process. In this technique, after the machine has reached a steady state, the screws are stopped and the barrel is cooled to room temperature. The barrel temperature is then increased slightly (to the polymer melting point), and the screws are withdrawn from the barrel. At this point, we measured the solid conveying, melting positions, as well as the extent of the starved region and fully filled regions. We then ran our computer model to simulate the process and to calculate the pressure temperature, solid fraction, and fill factor profiles along the screws.

The results of our simulations and experiments for the extrusion of LDPE are shown in Figure 3. The top and bottom views of the screws (as removed from the barrel) are also shown so that the computations can be evaluated. In general, we observe that when the feed rate increases, the C-chambers are more filled and the screw length (required for complete melting) is longer. Conversely, when the screw speed increases, the C-chambers are less filled and the screw length (required for complete melting) is shorter. We also find that the filled length increases with a higher flow rate (at fixed screw speed), but decreases when the screw speed is increased (at fixed flow rate). Our results also indicate that when the flow rate increases (i.e., from 4 to 8kg/h), the melting length and the fully filled length also increase. For the screw configuration that we have studied, the full filling occurs within two regions, i.e., close to the die and in the shearing element area. In the rest of the barrel the screws are mostly empty.

In summary, we have developed a global computation program with which we can iteratively calculate the melting, pressure, temperature, and fill factor profiles for an intermeshing counter-rotating twin-screw extruder. In our model, we include a consideration of the die flow. We have used our model to calculate the axial fill factor, pressure, temperature, and melting during extrusion of two polymers at different feed rates, and have compared the data with experimentally obtained results. We find that our simulation can accurately predict (both qualitatively and quantitatively) our experimental measurements. At present, we are working to extend our experimental and theoretical studies to the extrusion of more advanced materials, polyblends, and wood plastic composites.

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