SUCCESS STORY

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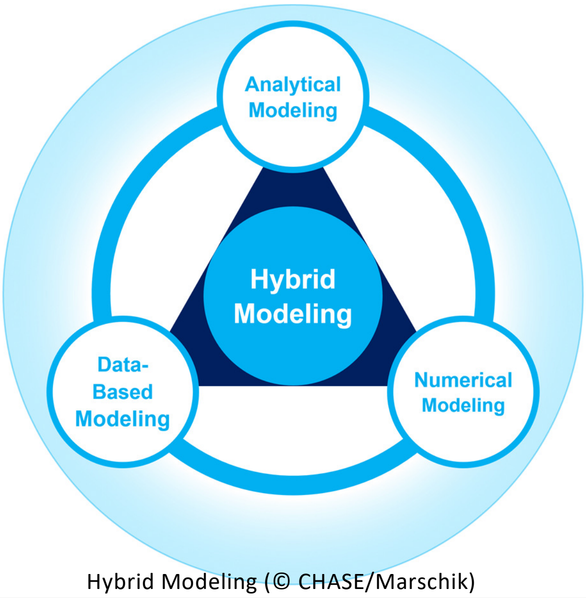

Hybrid Modeling (© CHASE/Marschik)

MODELING THE PUMPING CAPABILITY OF SINGLE-SCREW EXTRUDERS

A HYBRID MODELING APPROACH TO SIMULTANEOUSLY INCREASING PREDICTION ACCURACY UND REDUCING CALCULATION TIME

Single-screw extruders are one of the most important processing machines in the polymer industry. They are widely used to convert solid polymeric materials, typically in the form of granules or powder, to homogeneous melts in order to form plastic products such as pipes, profiles, films, cables, sheets or fibers. The most important machine component is a rotating screw fixed in a heated barrel, which transports and melts the solid feed and pumps the polymer melt through a die at the discharge end of the processing machine.

Taking economic boundary conditions into account, the primary objective of machine manufacturers is to increase output rate and improve polymer product quality. To meet the ever-increasing demands on the machinery, the process requires further optimization and hence a deeper understanding of the transport mechanisms governing physical operation is very important.

A critical process parameter in the analysis of single-screw extruders is the pumping capability of the extruder screw. To force the molten material through the die at the end of the processing machine, the screw must generate sufficient pressure. The pumping capability relates the output rate to the discharge pressure and depends on screw geometry, material behavior, and processing conditions. Numerous pumping models have been presented in literature to predict the flow of polymer melts in single-screw extruders. Due to the complex flow behavior of polymer melts, however, most of these are either based on various modeling assumptions and simplifications (e.g., constant viscosity) or require use of time-consuming and computationally expensive simulations. Even for the most simplified mathematical model – a fully-developed isothermal drag-pressure flow of a power-law fluid between two parallel plates, no exact analytical solution is known.

To increase prediction accuracy and simultaneously reduce calculation time, we applied a hybrid modeling approach to predicting the pumping capability of single-screw extruders. Our method incorporates analytical, numerical, and data-based modeling techniques into one approach and provides fast and robust solutions (even for complex physical processes), which can be employed in time-critical applications such as digital twins, assistance systems, or soft sensors.

Using the theory of similarity, we transformed the governing flow equations describing extruder operation into a dimensionless form to identify the physically-independent input parameters of the system. These were then varied in a broad industrially-relevant range to create a large number of independent modeling setups, which were solved numerically. The target variables of our parametric study were the throughput of the processing machine and the dissipation in the screw channel. In the final step, we approximated the numerical solutions of the parametric study analytically as a function of the input parameters via symbolic regression based on genetic programming.

Our hybrid modeling approach yielded a set of analytical regression models for predicting the throughput and dissipation of single-screw extruders. The new models, which couple the shear-thinning flow behavior of the polymer melt with the multi-dimensional flow field in the screw channel, were validated both numerically and experimentally. For a variety of screw designs, material, and processing conditions the regressions were shown to outperform numerical simulations by showing almost equal prediction accuracy at significantly reduced calculation time. Comparison to experimental data additionally confirmed the high accuracy of the pumping models. The new regression models extend the tools needed in analysis, design and optimization of extruder screws.

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