COMSOL Multiphysics® Software Simulation Application for Thermoplastics Viscosity Measurement

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Abstract

Present study discusses the application of numerical simulation with COMSOL Multiphysics® software for viscosity measurements of polymer melts. The main emphasis is placed on investigating effects of entrance and exit geometry of a custom-designed capillary rheometer on the measurement of viscosity by combining experimental and COMSOL simulation results for a low density polyethylene (LDPE) grade having MFI equals 0.33 g/10min - a stable power-law polymer melt. Simulation results clearly reveal shear thinning behavior of polymer melt i.e. viscosity dependence on shear rate, and are in good agreement with the experimental results. The study will provide a new method that could precisely measure the viscosity of thermoplastics for online rheometers attached on an extrusion line.

3D geometry of custom-designed capillary rheometer was created in Autodesk Inventor®, and imported to COMSOL software for simulation. The cap-face feature of the COMSOL software helped to create domains for holes and cavities including the cavity of capillary die, which is 5mm in diameter and 150 mm long. The physics added to the simulation model include: 1) conjugate heat transfer to incorporate heat transfer both in solids and liquids, 2) non-isothermal laminar flow to investigate the flowfield through cavity and see the viscous heating effects on flowfield and the viscosity and 3) events interface to control the setting temperature of heaters.

Integration operators were employed in the COMSOL model at thermocouple control points to control setting temperature of heaters. Under the study node a stationary study step was introduced to obtain consistent initial conditions followed by a time-dependent study. The solver uses finite element method to solve equation of continuity, momentum and energy along with power law viscosity model. A finer mesh with free tetrahedral elements was employed to domains of capillary cavity and solid geometry ensuring accuracy of results.

Temperature profiles of thermocouple controllers for stage 1(L/D=10), stage 2(L/D=20) and stage 3(L/D=30) are presented in Figure 1, which clearly indicates the temperature perfectly controlled to a setting temperature of 200 °C by the integration operators. Presented below in Figure 2 and Figure 3 are Bagley Plots representing simulation and experiment results respectively. It is evident from simulation Bagley plot [1,2,3] that the entrance correction factor (e) for various shear rates is found same i.e. -0.79 on the L/D

axis and is lower than experimental value. In other words, entrance pressure drop reported by simulation is lower compared with experiment. Which is why the viscosity curve obtained from simulation is 10 ~ 13% higher than that of experiment as shown in Figure 4 that presents a perfect shear thinning behavior of LDPE. However difference in viscosity can be associated with temperature variation caused by viscous heating during experiment as reflected in Figure 5.

Reference

1. C. D. Han, Rheology and processing of polymeric materials: volume I - polymer rheology, Oxford University Press, Inc., New York, 2007.

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Figures used in the abstract

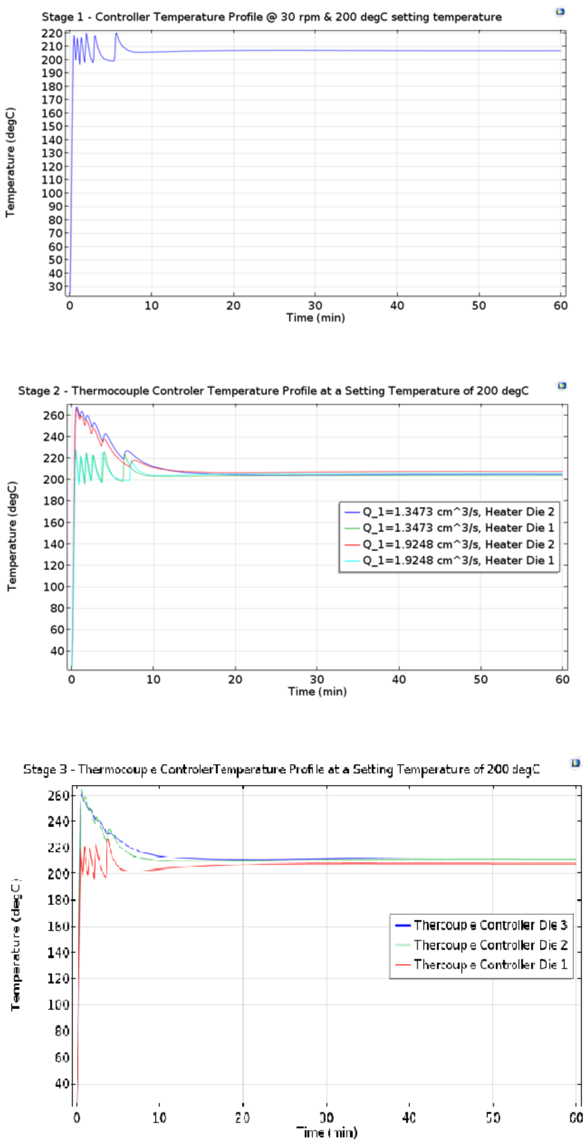

Figure 1: Temperature profile of the thermocouple controller for a) Stage 1, b) Stage 2, and c) Stage 3.

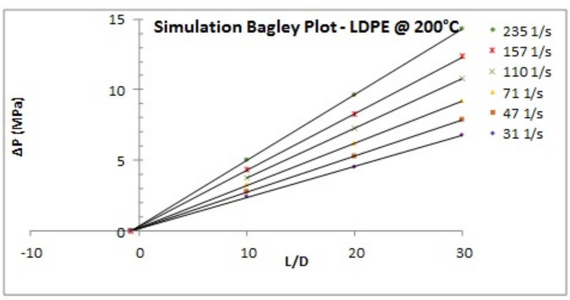

Figure 2: Simulation results showing the Bagley end correction "e."

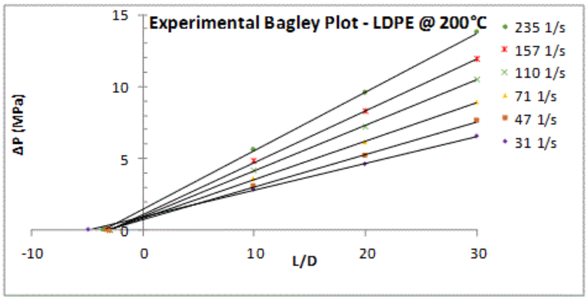

Figure 3: Experimental results showing the Bagley end correction, “e."

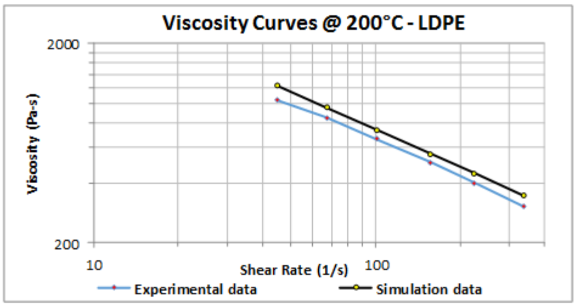

Figure 4: Comparison of viscosity curves for simulation vs experimental results.