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Isothermal and Non-isothermal Analytical Solutions for Deep-Channel, Single-Screw Extruders

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Analytical solutions for the isothermal and non-isothermal flow of polymer melts in the metering section of single screw extruders are developed. The true helical path of the channel and curvature effects are taken into account by using a helical coordinate system and the method is applicable to deep as well as shallow channel extrusion. Using the calculus of variation, velocity and temperature functionals have been developed in integral form, which are equivalent to the momentum, continuity, and energy equations governing the extrusion problem. An integral form of the continuity constraint is incorporated into the velocity functional through a Lagrangian multiplier which assumes constant values in the present formulation. The functionals have the feature of being minimum at the steady state and yield the desired velocity and temperature fields upon minimization. Another important feature of the functionals is that they involve linearized-type of variables which are fixed during the numerical solution and can assume their values from the previous iteration until convergence is reached. Such feature allows inertia and convective

terms to be handled with relative ease. Curvature effects were taken into account by using a non-orthogonal helical coordinate system consisting of radial, helical, and axial coordinates which represent the true helical path in the extruder channel. The necessary transformations to the helical coordinate system were performed and the resulting system of equations was solved for radial, helical and axial components of velocity as well as temperature. The finite element method of solution was used with triangular elements and linear interpolating polynomials for each velocity component and for temperature. The isothermal two-dimensional steady flow of Newtonian and non-Newtonian polymer melts was analyzed. Results were presented in terms of dimensionless velocities, flow rates and pressure groups and compared with available solutions for shallow channels and with experimental data for a deep channel of a depth-to-diameter ratio of 0.25. Good agreement was obtained for all cases considered.