Analysis of Shear-thinning Planar Flows

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In industry, it is common to handle complex fluids with shear-rate-dependent viscosity. Such non-Newtonian behavior may bring difficulty in controlling various types of flows that can be observed in many industrial processes. Therefore, it is crucial to understand the fluid flow's underlying key behaviors in response to various disturbances or situations. In this study, through two illustrative case studies, we present the use of flow modeling and simulation for a better understanding of the effects of shear-rate-dependent viscosities on the fluid flows.

In the first case, we explore the flow properties of pulsatile shear-thinning flows in a two-dimensional rectangular channel [1]. Various external disturbances such as oscillations from flow pumps are commonly encountered in industrial processes, and such disturbances may result in unexpected changes in the rheological properties of the complex fluids. Therefore, it is important to acquire an in-depth understanding of transient non-Newtonian flows.

The characteristic viscosity chosen based on the steady-state analysis was defined for the pulsatile shear-thinning flow. It was used to form a non-Newtonian Womersley number, which acts as a critical model parameter of the system of interest. Numerical analyses of Carreau fluids revealed the existence of master curves for the amplitudes and phase lags of the flows, indicating that our definition of non-Newtonian Womersley number concisely represented the transient dynamics of non-Newtonian flows. Interestingly, the shape of the master curve was determined by the degree of shear-thinning. We advanced further to demonstrate that the flow dynamics can be predicted using the pre-computed master curves with high accuracy, presenting a novel method of predicting shear-thinning pulsatile flow dynamics without explicit transient computations.

In the second case, we explore the effect of the shear-rate-viscosity on the operating conditions that lead to the formation of microvortices in the slot coating flows, which are known to have a detrimental effect on the stable process operation and production of defect-free film products [2]. We simplify the microvortices found in the downstream region of slot coating flow as flow reversal and present the effect of the shear-rate-dependent viscosity on the critical operating conditions at the onset of the flow reversal [3].

Two methods for computing the critical condition in slot coating flows of generalized Newtonian fluids (GNFs) are presented: a semi-analytical method based on the Weissenberg-Rabinowitsch equation and an approximate method based on the local power-law approximation. The two methods were applied to the flows of two illustrative GNFs, the Carreau-Yasuda, and Bingham-Carreau-Yasuda fluids. They were both found to be successful in computing the critical flow reversal conditions. It was also revealed that the critical conditions depended significantly on the local power-law index n, which quantifies the dependency of the viscosity on the magnitude of the shear rate.

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