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Predictions for the Anisotropy in Thermal Conductivity in Polymers Subjected to Model Flows by Combination of the eXtended Pom-Pom Model and the Stress-Thermal Rule

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Abstract : The viscoelastic behavior of polymeric flows under isothermal conditions has been extensively researched. However, most of the processing of polymeric materials occurs under non-isothermal conditions and understanding the linkage between the thermo-physical properties and the process state variables remains a challenge. Furthermore, the cost and energy required to manufacture, recycle and dispose polymers is strongly affected by the thermo-physical properties and their dependence on state variables such as temperature and stress. Experiments show that thermal conductivity in flowing polymers is anisotropic (i.e. direction dependent). This phenomenon has been previously omitted in the study and simulation of industrially relevant flows. Our work combines experimental evidence of a universal relationship between thermal conductivity and stress tensors (i.e. the stress-thermal rule) with differential constitutive equations for the viscoelastic behavior of polymers to provide predictions for the anisotropy in thermal conductivity in uniaxial, planar, equibiaxial and shear flow in commercial polymers. A particular focus is placed on the eXtended Pom-Pom model which is able to capture the non-linear behavior in both shear and elongation flows. The predictions provided by this approach are amenable to implementation in finite elements packages, since viscoelastic and thermal behavior can be described by a single equation. Our results include predictions for flow-induced anisotropy in thermal conductivity for low and high density polyethylene as well as confirmation of our method through comparison with a number of thermoplastic systems for which measurements of anisotropy in thermal conductivity are available. Remarkably, this approach allows for universal predictions of anisotropy in thermal conductivity that can be used in simulations of complex flows in which only the most fundamental rheological behavior of the material has been previously characterized (i.e. there is no need for additional adjusting parameters other than those in the constitutive model). Accounting for polymers anisotropy in thermal conductivity in industrially relevant flows benefits the optimization of manufacturing processes as well as the mechanical and thermal performance of finalized plastic products during use.

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