Abstract

Scaling model for macroscopic viscosity analysis of polymer solutions.

Processing of polymeric materials in different types of industries require precise control over the flow of polymer solutions/ melts. This kind of control is possible when the material flow is properly characterized and investigated for internal structure property relationships. Such relationships for complex liquids like polymer solutions contain internal length-scales (e.g., the radius of gyration or correlation length) influencing their rheological properties. Because of this internal structure, the viscosity of polymer solutions depends on the flow length-scale. Previous studies of nanoprobe diffusion in different polymer systems defined the effective viscosity experienced by those probes as a function of the probe size, the concentration of the system, the molecular weight of the polymers and the temperature of the surroundings. However, it was observed that when the probes had sizes extremely larger than the coil radius of the polymer, the flow was governed by the macroscopic viscosity instead of the nanoviscosity. The effective viscosity defined through the studies on various complex liquids such as: colloidal solutions, protein solutions, micellar solutions, cytoplasm of HeLa cells and E.coli, was still relevant to the study of macroviscosity. In this work, our goal was to use the effective viscosity to derive the macroscopic viscosity for different polymer systems that are commonly used: polydimethylsiloxane (PDMS) in ethyl acetate, hydroxypropyl cellulose (HPC) in water, polymethylmethacrylate (PMMA) in toluene, and polyacrylonitrile (PAN) in dimethyl sulfoxide (DMSO). Our experiments involved measurements of viscosity by rheometer for a wide range of polymer concentrations at different temperatures, hydrodynamic radii by dynamic light scattering (DLS), and molecular weight distributions and polydispersity index by gel permeation chromatography (GPC). We have extended the scaling model to cover concentrations from dilute to concentrated in solution; obtained relations between the coil dimensions as a function of concentrations; explained its applicability for commercial or standard polymers with diverse molecular weight distributions; clarified the reasons and means for the validity of this model regardless of the polydispersity of the polymer samples; and provided a final consolidated information about all the different parameters in our models. Rheology of polymer solutions suffers from the lack of a viscosity model applicable across wide range of variable parameters. Our characterization method provides the possibility to use a length-scale based polymer investigation technique based primarily on easily affordable viscosity measurements. Crucially, this technique will be effective for a wide variety of applications, both at the nanoscale and the macroscale.