Extensional Rheology Experiment Developed to Investigate the Rheology of Dilute Polymer Solutions in Microgravity

A fundamental characteristic of fluid is viscosity; that is, the fluid resists forces that cause it to flow. This characteristic, or parameter, is used by manufacturers and end-users to describe the physical properties of a specific material so that they know what to expect when a material, such as a polymer, is processed through an extruder, a film blower, or a fiber-spinning apparatus. Normally, researchers will report a shear viscosity that depends on the rate of an imposed shearing flow. Although this type of characterization is sufficient for some processes, simple shearing experiments do not provide a complete picture of what a processor may expect for all materials.

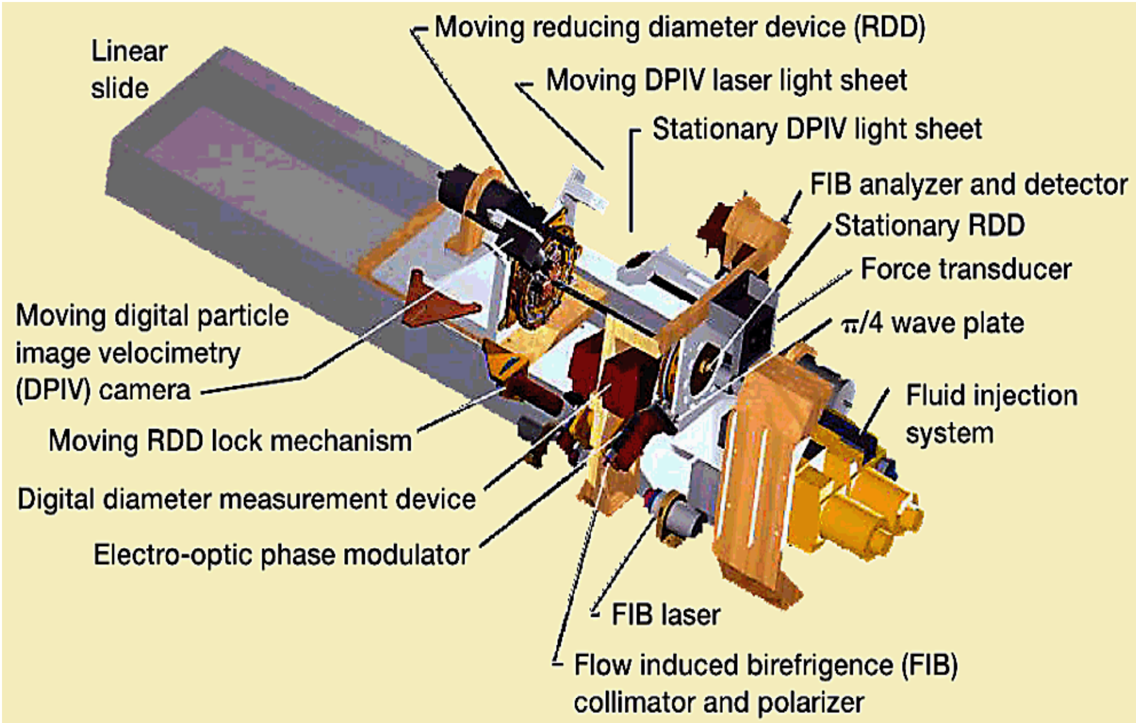
Extensional stretching flows are common in many polymer-processing operations such as extrusion, blow molding, and fiber spinning. Therefore, knowledge of the complete rheological (ability to flow and be deformed) properties of the polymeric fluid being processed is required to accurately predict and account for the flow behavior. In addition, if numerical simulations are ever able to serve as a priori design tools for optimizing polymer processing operations such as those described above, an accurate knowledge of the extensional viscosity of a polymer system and its variation with temperature, concentration, molecular weight, and strain rate is critical.

The Extensional Rheology Experiment (ERE) deals with the flow of polymers when they are subjected to stress and with their behavior after they have been deformed. The two primary objectives of the experiment are

1. To determine the extensional viscosity in a uniaxial stretching flow for dilute polymer solutions and their subsequent relaxation behavior after extensional deformation

2. To measure the transient birefringence during deformation and relaxation. (Birefringence is the difference in the index of refraction of a material between polarization states. When light passes through birefringent materials, like certain crystals and polymers, it is refracted in two different directions, depending on the polarization state of the light. Researchers can tell what the light is doing inside the material by measuring the birefringence. This gives them scientific information about how the material's molecules are behaving without having to disturb them.)

ERE was developed at the NASA Glenn Research Center under contract with Zin Technologies Inc. ERE is designed to fly on a Terrier Black Brant sounding rocket. Suborbital sounding rockets provide several minutes of useful microgravity time for conducting experiments without the effects of gravity. In the case of ERE, fluid sagging due to gravity prevents making these rheological measurements, particularly at low deformation rates.



Computer model image of extensional rheology experiment test section identifying components and subsystems. Direction of stretch is to the left. The stretching fluid is illustrated in the center, between the reducing diameter devices (RDD's).

The ERE hardware consists of three sections:

1. The avionics package, which contains all electronics systems for power, control, and data acquisition
2. Experiment package A
3. Experiment package B

Each experiment package contains a test section. The experiment packages are operated independently, and each performs a single test matrix point per flight. The test sections consist of a computer-controlled linear slide mechanism to cause the fluid deformation, a set of moving and stationary reducing diameter devices (RDD's), a flow-induced birefringence (FIB) apparatus, a digital diameter measurement system, and a digital particle image velocimetry (DPIV) system (see the figure).

Each RDD causes a 4:1 reduction in the diameter of the fluid column during the stretch to minimize shear stresses in the fluid. The stationary RDD on each slide has a very sensitive force transducer to measure the force induced by the deformation. The fluid is deployed between the RDD's by a fluid injection system. The DPIV system is used to record fluid motion near the endplates (RDD's) by illuminating glass spheres that were mixed in the fluid. A laser light sheet illuminates an axial plane (along the direction of flow) of the filament, allowing a charge-coupled device (CCD) camera to capture the position of these spheres. From DPIV postprocessing of the captured images, axial and radial fluid velocities can be computed.

The extent that the polymer chain has been deformed during stretch and relaxation is measured with a single-point flow-induced birefringence system developed at Glenn. This phase-modulated system simultaneously measures the retardance (degree of orientation of the polymer chains) and extinction angle (chain orientation angle relative to the flow direction) of the polymer chains as a function of time. The laser-micrometer-based digital diameter measurement system provides the fluid filament diameter necessary for the flow-induced birefringence calculation.

Assembly and testing of the ERE payload was completed in fiscal year 2000. The first two experiments will investigate the extensional viscosity of a non-Newtonian fluid (0.025 wt % high-molecular-weight monodisperse polystyrene dissolved in oligomeric polystyrene oil) at extensional deformation rates of 0.2083 sec^{-1} (slow stretch rate) and 2.6042 sec^{-1} (fast stretch rate). The first sounding rocket launch was conducted at the White Sands Missile Range in New Mexico on July 6, 2000.

The data from this first flight did not provide the desired scientific results. Several anomalies occurred. The RDD mechanisms did not function properly, resulting in nonideal fluid deformation. This impacted the FIB measurements by deflecting the incident laser beam away from the optical detector due to increased curvature of the fluid column. The force measurement on one of the test sections was also compromised because of larger than expected friction in some cross-roller bearings. (The magnitude of expected forces is in the range of milligrams to several grams.) Finally, reflective particles in the fluid used for flow visualization and flow velocity measurements were not sufficiently distributed in the fluid, preventing postflight DPIV analysis. A post-flight failure investigation was conducted. Causes and corrective action for each of the anomalies have been identified.

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