**Chapter 3: Instruments for Viscometry**

1. Introduction
   1. To calculate non-Newtonian systems, need to know rheological properties
   2. Special-purpose viscometers
2. Capillary Tube Rheometers
   1. Relationship between shear rate and shear stress is inferred indirectly from measurements of pressure gradient and volumetric flowrate.
   2. Components
      1. Fluid reservoir
      2. Capillary tube
      3. Means for applying a driving force on fluid
      4. System for measuring flowrate
      5. Thermostating device
   3. Oswald glass viscometer
      1. Simplest type
      2. Driving force: hydrostatic head of fluid
      3. Sample of specifid volume charged to lower bulb, viscometer immersed in thermostated bath. Sample drawn into upper bulb by suction and then released. Time for liquid to drop from upper to lower is measured. Gives kinematic viscosity
         1. Time between 100s and 500s allows for accuracy and relatively quick time.
      4. Small samples
      5. Cheap
      6. Cannot determine difference between Newtonian and non-Newtonian fluids
         1. Apply gas pressure to bulb and study non-Newtonian behavior
   4. Burrell-Severs extrusion rheometer
      1. Reservoir: thermostated stell cylinder containing free-floating follower plug.
      2. Nitrogen pressure forces fluid through capillary.
      3. Flowrate measured by weighing extrudate collected
      4. Driving force measured by pressure gage
      5. High temps and pressures
      6. Characterization of Newtonian fluids with viscosities up to 106 poise, shear stress up to 2 \* 106 dynes cm-2
   5. Melt Indexer
      1. Type of Burrell-Severs that uses dead weight as driving force
      2. Limited usefulness due to single deadweight and short capillary available
   6. Capillary Extrusion Rheometer
      1. Uses a tensile-testing machine to drive a piston at constant speed in a thermostated reservoir
      2. Forces the fluid through capillary
      3. Force measured by load cell and recorded
      4. Flow rate determined from crosshead speed
      5. Extrudate samples collected
      6. Pressure up to 40000psi
      7. Viscosity up to 5 \* 106 poise
      8. Shear rate range from 1 to 12,000 s-1
   7. Errors of measurement
      1. Kinetic energy may represent fraction of pressure energy applied to fluid
      2. Energy losses at ends of capillaries
      3. Viscoelastic fluid acceleration produces elastic stresses and energy absorption
      4. Corrections
         1. Run tests with different capillary lengths and extrapolate data to zero pressure drop
         2. Conduct experiments with very long and very short capillaries and difference corresponds to a capillary length equal to difference between the two.
      5. High viscosity, low thermal conductivity = temperature gradients
         1. Too low viscosity
         2. Use small diameter for high shear rate studies
      6. Steady laminar flow of fluid, shear stress vs shear rate is unique and independent of tube dimensions in a time-independent fluid.
         1. Determine thixotropy or rheopexy behavior with different length/radius ratios.
         2. Thixotropic: shear stress decreases for longer tubes and smaller diameter tubes
3. Rotational Rheometer
   1. Subject entire sample to uniform shear rate and measures shear stress to determine viscosity
      1. Coaxial cylinder
      2. Cone-and-plate type
   2. Continuous measurements over extended time
      1. Quantitative analysis of time-dependent behavior
      2. Test different conditions on same sample
   3. Coaxial cylinder
      1. Sample between stationary cup and inner rotating cylinder.
      2. Inner cylinder spins
      3. Shear stress measured by deflection of spring with potentiometer on spring.
      4. Permit measurement of fluids of viscosity from 5 \* 10-3 to 107 poise with shear rates of 10-2 to 104 s-1
   4. Brookfield Synchro-letric viscometer
      1. Spindle through calibrated spring
      2. Deflection of spring observed visually
      3. Spindle immersed in “infinite” liquid
   5. Error
      1. End-effect: contribution to the torque influid between end of bob and bottom of cup
      2. Fix similar to fix for end-effect in capillary tube rheometers
         1. Extrapolate to zero torque
         2. Intercept is depth-correction term to add to actual immersion depth in equations
4. Cone and Plate Rheometers
   1. At a given angular velocity, tangential velocity of driven component increases linearly with radius, as does gap between cone and plate.
      1. For small angles, shear rate and shear stress are uniform in fluid.
      2. No correction calculations required
      3. Apparent viscosity:
         1. Equation 1: τ = 3T/2πRc3
         2. Equation 2: γ = Ω/β
         3. Equation 3: μa = 3βΤ/2πΩRc3
            1. τ: shear stress
            2. T: torque
            3. Rc: radius of cone
            4. γ: shear rate
            5. Ω: rotational speed
            6. β: angle between cone and plane in radians
            7. μa: apparent viscosity
   2. Weissenberg Rheogoniometer
      1. Most versatile
      2. Measure viscosity in simple shear
      3. Determine dynamic properties of viscoelastic materials
      4. Plate driven into sinosodial motion
      5. Measure normal stress of viscoelastics
      6. Fluids with viscosities from 10-3 to 1010 poise, shear rates from 10-4 to 103 s-1
   3. Limitations
      1. High viscosity matierals, sample balls up leaving gap between cone and plate at sehear rate ranges normally encountered in processing
      2. Biconal rotor avoids this problem- two cone and plate instruments back to back