**Chapter 2: Non-Newtonian Fluids**

1. Introduction
   1. Newtonian fluids follow Newton’s law of viscosity
      1. Shear stress is proportional to shear rate
   2. Most food systems are not Newtonian
      1. Shear stress vs. shear rate is not linear through origin
      2. Examples: concentrated solutions of macromolecules, colloidal materials
      3. Viscosity and shearing are dependent on continuous and dispersed phase, particle-particle interaction, particle-solvent interaction, concentration of particles, shape, size, chemical composition.
         1. Examples: milk, cream, mayo, tomato paste.
      4. Harder to classify.
      5. Use apparent viscosity: shear stress/shear rate.
   3. Categories: Time-Independent and Time-Dependent
      1. Time-Independent
         1. Apparent viscosity is independent of previous shearing history
      2. Time-Dependent
         1. Apparent viscosity is dependent upon previous sharing history
         2. More difficult to classify experimentally.
2. Time-Independent Fluids
   1. Dilatant and Pseudoplastic
      1. Apparent viscosity is ratio of shear stress to shear rate (same as Newtonian)
      2. Apparent viscosity is slope at a point on the line to the origin.
      3. Pseudoplastic behavior is shear thinning behavior, becomes less viscous
      4. Dilatant behavior increases in viscosity increases as shear rate increases.
         1. More rare than pseudoplastic
3. Plastic Fluids
   1. Have a yield stress and a plastic viscosity.
   2. At low shear stress no deformation (like solids) until a critical shear stress is reached.
      1. Beyond the shear stress, the fluid flows
   3. Bingham plastic has a constant viscosity after yield stress
   4. Casson Body has parabolic shape: straight line when square root of shear stress is plotted against square root of shear rate
4. Time-Dependent Fluids
   1. Shear rate increases and decreases means it’s a time dependent fluid
   2. At any shear rate, there’s two possible apparent viscosities, depending on history of shear rate
   3. Constant shear applied, apparent viscosity increases, but then if the shear is removed, the viscosity changes.
   4. Thixotropic: breakdown in structure with application of shear
   5. Rheopectic: buildup in structure with application of shear
5. Power Law Equation
   1. Straight line relationship of shear stress vs. shear rate in log-log coordinates
   2. Equation relating shear stress and shear rate is Power Law Equation
      1. Equation 1: τ = k(dv/dy)n
         1. τ is shear stress
         2. k is consistency index
         3. dv/dy is shear rate
         4. N is power law index, flow behavior index
      2. Equation 2: log(τ) = log(k) + nlog(dv/dy)
      3. Power law index is slope of log-log plot
      4. N and k can characterize the fluid over the experimental range of values
      5. Apparent viscosity:
         1. Equation 3: μa = τ/(dv/dy)
      6. Combine equations 1 and 2:
         1. Equation 4: μa = k(dv/dy)n-1
            1. Only use absolute value of shear rate
            2. Newtonian: n = 1
            3. Pseudoplastic: n < 1
            4. Dilatant: n > 1
            5. Further n is from 1, greater deviation from Newtonian behavior
      7. Fluids with some plastic behavior:
         1. Equation 5: τ = k(dv/dy)n + τ0
            1. τ0 is yield stress
            2. Herschel-Bulkley equation
   3. Casson body
      1. Equation 6: τ1/2 = τ01/2 = μa(dv/dy)1/2