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Background on Viscosity and Importance in Biological Engineering Applications

      Viscosity is defined as a fluid's resistance to flow. Knowing the viscosity of a fluid enables one to predict how a fluid will behave within a bioengineering process, such as within a piping system, a mixing vessel, or a reactor (Doran, 1995). Viscosity changes with the temperature of a system. One can calculate the viscosity of a Newtonian fluid by dividing the shear stress placed on the fluid by the shear rate or finding the slope of a graph of shear stress vs. shear rate (Equation 1) (Doran, 1995). For a non-Newtonian fluid, the viscosity also depends on the shear rate as well as other intermolecular properties of the fluid. Most biomaterials are pseudoplastic fluids, specifically shear thinning fluids, and have their viscosity described by a power-law model. The flow consistency index, k, and the flow index, n, are used in the power law model (Equation 2) (Doran, 1995). For a shear thinning fluid, the flow index number is less than one.

$$\tau \; = \; \mu\gamma \qquad\qquad\qquad [1]$$

$$\tau \; = \; k\gamma^{n} \qquad\qquad\qquad [2]$$

Operating Principles for Brookfield Viscometer

      The Brookfield viscometer operates in a similar manner to a kitchen hand mixer. A spindle or bob is attached to the device, inserted into the sample, and rotated. The machine measures the stress placed on the fluid over time as the torque created by the viscometer is increased and decreased. A torque range must be defined for the sample so that values returned by the viscometer are accurate and usable for data analysis ("3 Easy Steps", n.d.). The machine outputs the torque % reading as well as the viscosity reading. With torque and viscosity, it can be determined whether the sample is shear thinning, shear thickening, or time dependent.

Cells Influence on Viscosity of Fermentation Broth

      It has been found that the presence of cells in a fermentation broth increases the viscosity of the broth and that as the cell density in the broth increases, the viscosity also increases (Newton, et. al., 2016). This indicates that the presence of cells causes the fermentation broth to resist flow due to an increase in weight and density.

Time-Dependent Fluid Recognition from Graph

When graphing the shear rate versus the shear stress of a time-dependent fluid, the fluid will behave in one manner as the shear stress increases (e.g. show a concave down curve, suggesting shear thinning behavior) and another while the shear stress decreases (e.g. show a concave up curve, suggesting shear thickening behavior); otherwise, the behavior will be approximately the same whether the shear stress is increasing or decreasing (Doran, 1995).

References

Doran, P.M. (1995). *Bioprocess Engineering Principles*. London, UK. Academic Press Limited.

Newton, J.M., Schofield, D., Vlahopoulou, J., Zhou, Y. (2016). Detecting cell lysis using viscosity monitoring in *E. coli* fermentation to prevent product loss. *Biotechnology Progress*.

3 Easy Steps to Successful Viscosity Measurement. (n.d.). Brookfield Ametek. Instrumentation & Specialty Controls Division.