Using Sludge Rheology in Solids Systems Design, Planning, and Operation

Tracy Chouinard, PhD, PE

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Overview

- Rheology basics
- Measuring rheology
- Factors that affect rheology
- When to measure rheology
- Implementing rheological data
Have you ever...

- video of overflowing digester
Rheology Fundamentals

• video of different fluids’ viscosities

The Sci Guys: https://www.youtube.com/watch?v=f6spBkVeQ4w

Rheology is going to matter in our new processes and efficient designs.
How to measure rheology?
Effects of temperature

- As temperature increases viscosity decreases
Factors that influence sludge rheology

- Temperature
- Solids content
Viscosity vs Shear Rate at Varying Total Solids

RN: TS = 9.88% (50°F)
RN: TS = 9.88% (68°F)
TS = 3.12% (75°F)
TS = 3.25% (75°F)
When to do Rheology Testing?

- Pumping design
  - Especially for really thick or unusual sludge characteristics where data isn’t available.
- Mixing designs
  - Confirm how much energy is needed and if the sludge will mix
What does that look like on system curve?

- High viscosity / friction at low flow causes steep slope in H-Q curve.
- Shear thinning, decreasing viscosity actually causes curve to dip as flow/velocity increase.
- Once fully turbulent (viscosity becomes constant), H-Q curve shape resembles water curve.
- Yield Stress, which must be overcome before the sludge will flow.
Digester Sludge Rheology and RVE
- No Mixing
Rapid Volume Expansion (RVE) Definition

- A rapid change in liquid volume driven by a sudden change in conditions of gas holdup, the volume of gas retained within a volume of liquid

- Rapid rise or fall of tank level can occur
The Principle of Gas Holdup

NO GAS

WITH GAS
Biogas bubbles overcoming yield stress
Gas holdup and RVE are most severe when mixing stops
In the absence of mixing, digester sludge exhibits a yield stress (force)
Therefore,
  • Biogas bubbles must generate a buoyant force to overcome the yield force (function of yield stress)
Otherwise:
  • Biogas bubbles will remain in suspension
  • Biogas bubbles will continue to grow and remain in suspension
  • Digester contents will expand
Until
  • Biogas bubbles grow to a sufficient size to escape suspension
  • Or, mixing is restored
What does volume expansion look like in real life

- video of overflowing digester
Viscosity and max extent of RVE trend

Main observations:

- Viscosity and maximum extent of RVE follow a similar trend
- Small increases in mixing result in significant decreases in sludge viscosity
- Small decreases in sludge viscosity result in significant increase in bubble rise velocity
- Increases in bubble rise velocity result in less gas holdup and RVE
Feed dispersion modeling

• Using shear stress data from viscosity testing, demonstrates that mixing is not “complete mix” (i.e. instantaneous Incorporation)

• Comparison
  • Design Criteria= 1 hour turn over
  • Modelled Result= 2.92 hours
Things to think about . . .

- Common sludges like raw, or digested, less than 5-6% TS – “textbook” or simplified approaches likely OK.
- If data exists for a “similar” sludge use it with caution.
  - KNOW your sludge
- Hydraulic modeling software come with sludge correction/rheology models – apply with engineering judgement (do some homework on limitations/applicability).
Summary

• Sludge is shear thinning, non-Newtonian
• In digesters with low or no mixing, rapid volume expansion can occur
  • Mixing decreases viscosity, reduces trapped gas bubbles
• Increased viscosity = decreased heat transfer
• Yield stress can influence pump size, which influences pipe selection
Thank you! Any Questions?

Tracy Chouinard,
tchouinard@brwnclald.com
Rheology basics

- Rheology is the study of the flow of matter, particularly liquid or semi-solids materials.
- Viscosity is how quickly material moves or resistance to flow
  - High viscosity – slow moving
  - Low viscosity – fast moving
- Newtonian – viscosity constant, independent of shear rate
  - water, milk, oil
Rheology basics (Cont’d)

- Non-Newtonian - viscosity not constant with change in shear rate
  - Ketchup, sludge, yogurt, toothpaste
- Shear rate is the resulting velocity gradient when shear force is applied
- Shear-thinning: viscosity decreases as shear-rate increases.
- Shear-thickening: viscosity increases as shear-rate increases.
- Yield Stress: minimum amount of force (shear) applied to initiate flow.
Simplified biogas balance

To prevent gas holdup and RVE:

Rate of bubble nucleation and growth

Rate of bubble rise and evolution into headspace

IF

Rate of bubble nucleation and growth

Rate of bubble rise and evolution into headspace

Gas Holdup and RVE!