

Anaerobic Digestion

Mass Balance and Modeling

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Overview (choose a few topics from the paper)

- Part 1: Analytical Methods
- Part 2: Calculations
- Part 3: Evaluation Protocol

Overview

- Part 1: Analytical Methods
- Part 2: Calculations
- Part 3: Evaluation Protocol

How do we know that something works better than ...

What we already have?

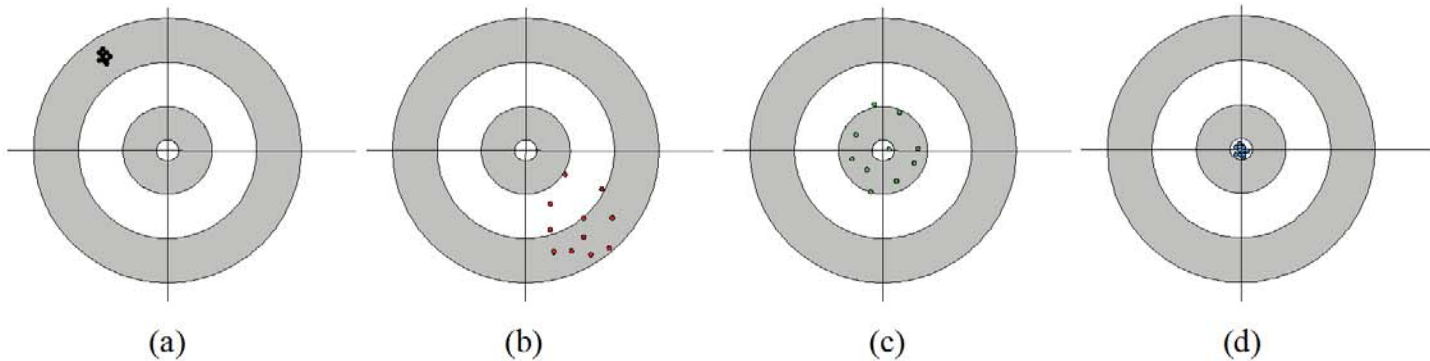
What we could buy from someone else?

Part 1: Measurement



Topic 1: Are our measurements accurate or precise?

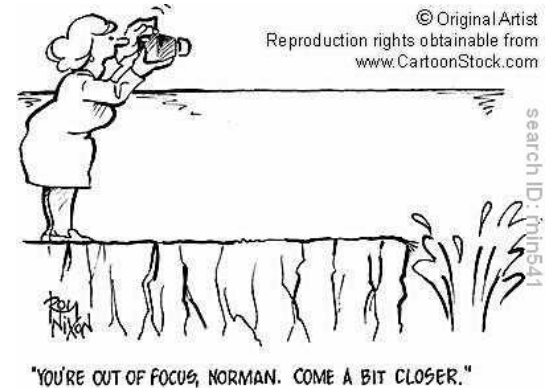
Illustration of Accuracy and Precision: (a) inaccurate but precise; (b) inaccurate and imprecise; (c) accurate but imprecise; and (d) precise and accurate.





Topic 1: Solids test results are imprecise

- Total solids test ($\pm 5\%$)
 - Weigh empty dish
 - Dry at 103 to 105 °C
 - Weigh dish until weight is constant
- Fixed solids test ($\pm 5\%$)
 - Ash at 550°C
 - Weigh dish until weight is constant
- Volatile solids = Total solids – Fixed solids
 - $\pm 8\%$ to 10%
 - e.g. 3% dried solids $\pm 0.3\%$





Topic 2: Solids test results may also be inaccurate

- No “standard solids” so measure duplicate samples
 - Loss of water of crystallization
 - Loss of volatile matter prior to ashing
 - Incomplete oxidation of some complex organics
 - Decomposition of minerals salts
- Different from Fuel Value (725°C, absence of oxygen)
- Not a direct measure of “organic carbon in the sample”
- Principal source of error is failure to obtain a **representative** sample



Topic 3: Chemical Oxygen Demand difficult to execute on sludge

- Precision of 200 mg/L Potassium Pthalate Solution
 - 6.5% for open reflux to 9.6% for closed colorimetric
- **Homogenize** sample
- Dilute sample
 - 6% dried solids feed requires 150 to 200 x **dilution**
- Sample **volume** to test
 - 50 mL for open reflux (graduated cylinder)
 - 2.5 mL for 10 mL closed reflux tube (pipette)

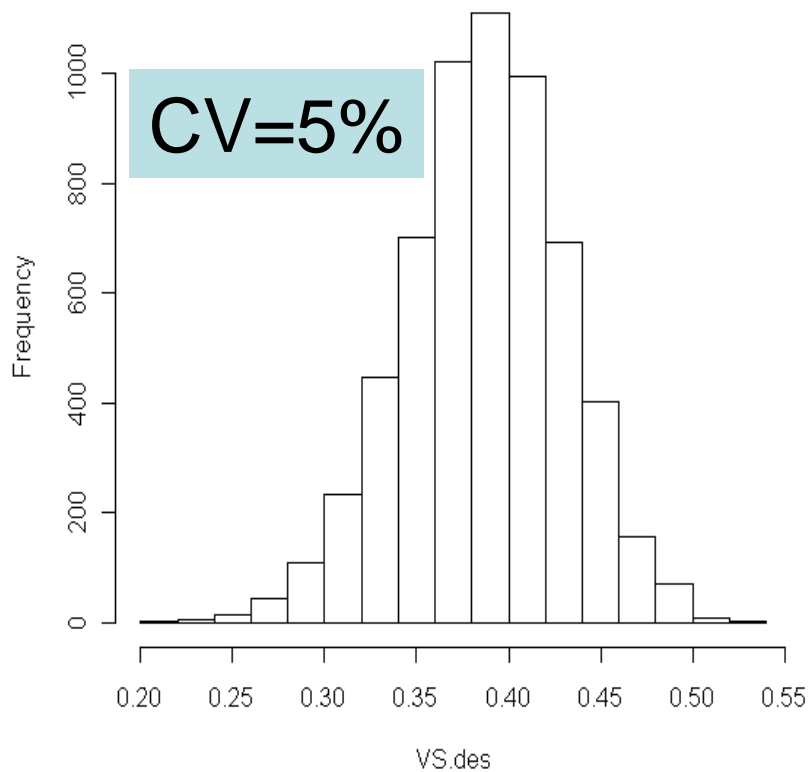
Example: Volatile Solids Destruction Across the Digester

$$\%VS_{des} = (1 - cVS_{out}/cVS_{in}) * 100\%$$

Coefficient of Variation (CV) is the ratio of standard deviation to the mean

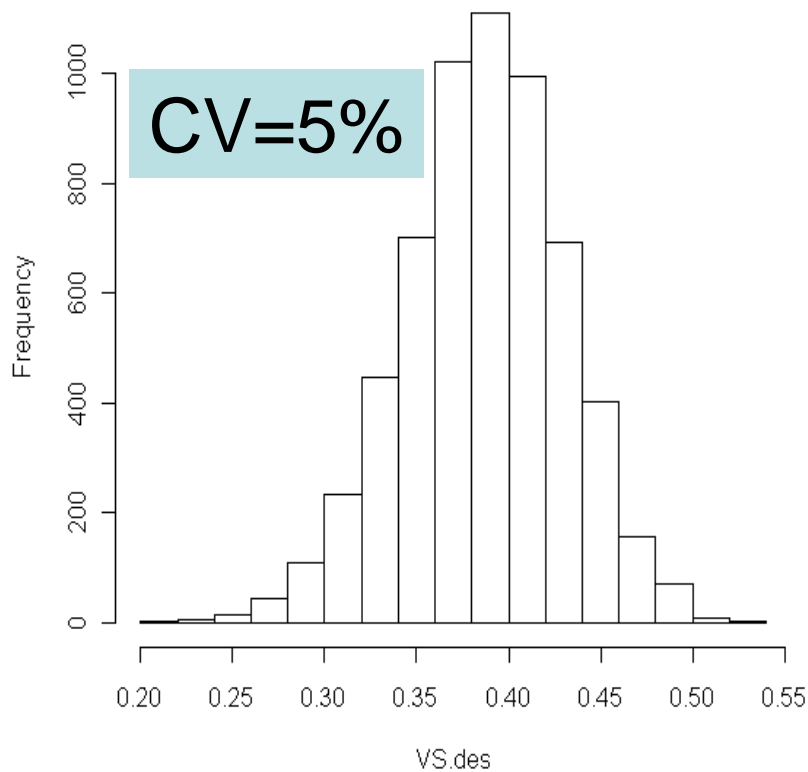
Example: Volatile Solids Destruction Across the Digester

95% of the values between
31% and 46%

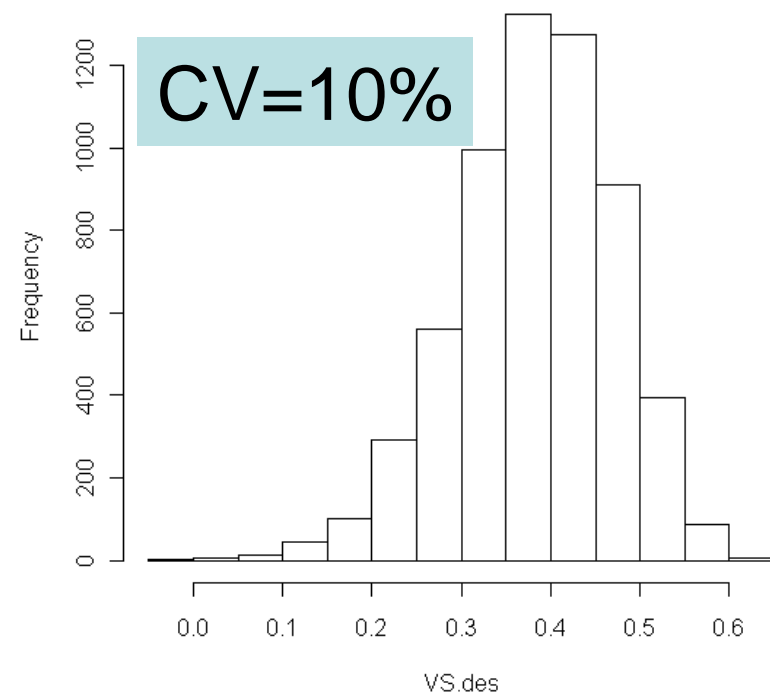


Example: Volatile Solids Destruction Across the Digester

95% of the values between
31% and 46%



95% of the values between
23% and 52%



Example: Volatile Solids Destruction Across the Digester

Histogram of VS.des

Histogram of VS.des

Frequency

When comparing two systems...
The greater the uncertainty,

The more significant must be the
difference between them

0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55

VS.des

0.0 0.1 0.2 0.3 0.4 0.5 0.6

VS.des

Storytime – we forget the level of uncertainty in our numbers



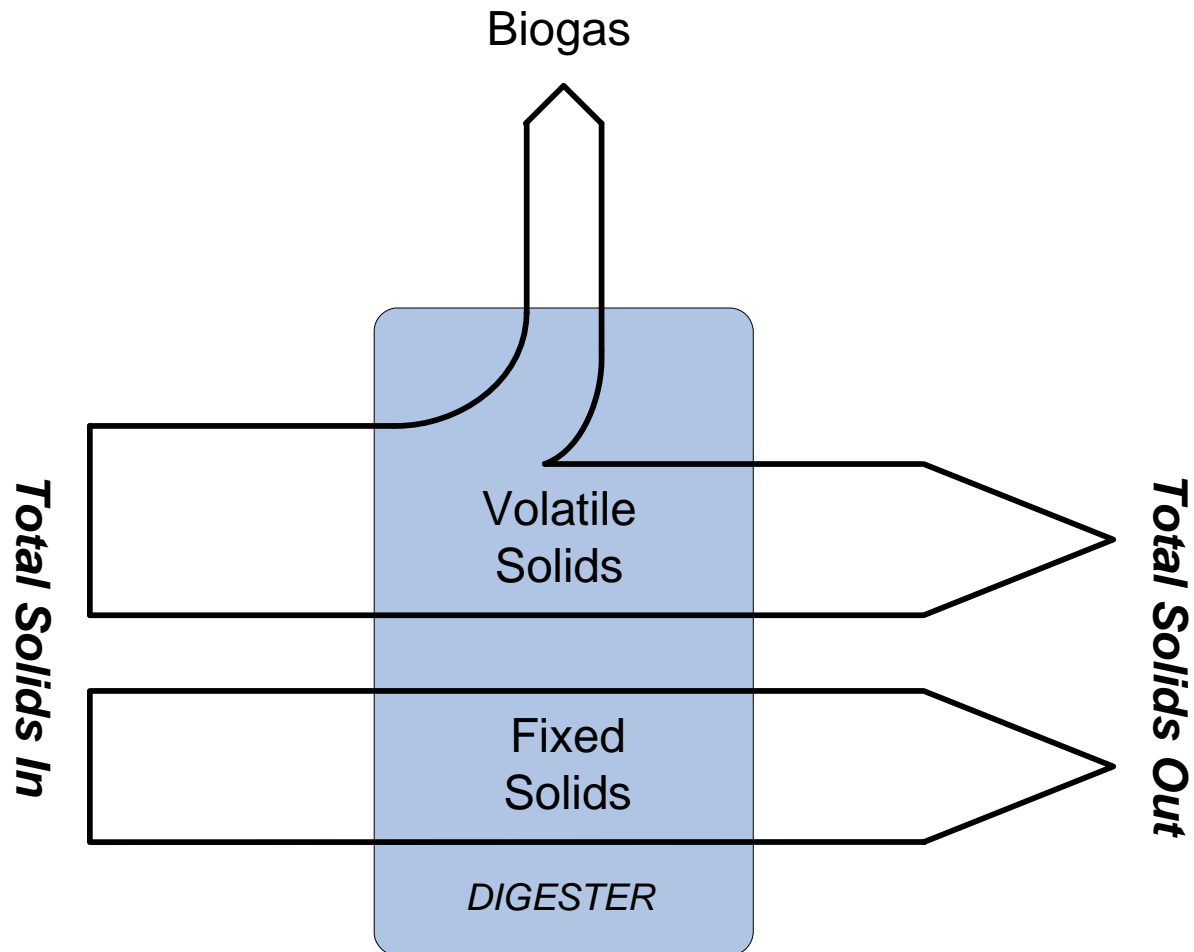
Part 2: Calculations



Topic 1: Link between Plant and Model CODp to Volatile Solids

- Models estimate solids from the COD:VSS ratio
- Raw Sludge
 - WERF 1.83 ± 0.27
 - Varies from site to site based on protein, fiber, fat, carbohydrates and ash in the sewage
- Secondary Sludge
 - WERF 1.45 to 1.55, $\pm 15\%$
- Ratio changes through digestion
- Conduct a parallel solids and COD balance
- *All models are wrong but some are useful. Bruce Beck*

Topic 2: Ideal Mass Balance



Topic 2: Mass balance uncertainty

- Analytical (Solids, COD)
- Instrument (Flow)
- Process
 - Accumulation of inert solids in digester
 - **Converting solids (Topic 2a)**
 - **Creating solids (Topic 2b)**

Topic 2a: Blue Plain WWTP – Biogas Yield

- Yield expressed as
 - m^3 of biogas per kg volatile solids destroyed
- Yield from CAMBI digester 20% higher
- Why?

Topic 2a: Blue Plain WWTP – Biogas Yield

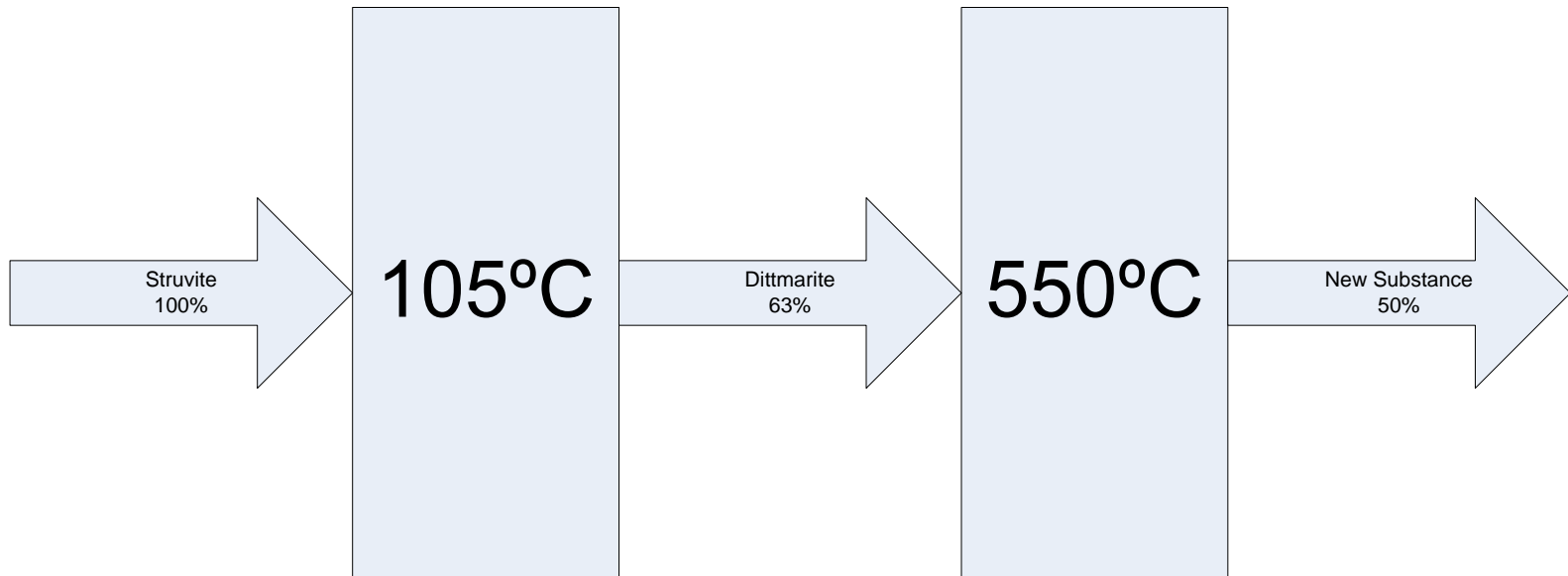
- Yield expressed as
 - m³ of biogas per kg volatile solids destroyed
- Yield from CAMBI digester 20% higher
- Why?

- ✓ Volatile solid test done on hydrolysed sludge
- ✓ Hydrolysis converted particulate matter to soluble matter
- ✓ Soluble matter is evaporated during the test
- ✓ Volatile solids underestimated increasing yield

Topic 2b: Kapuciska, Poland

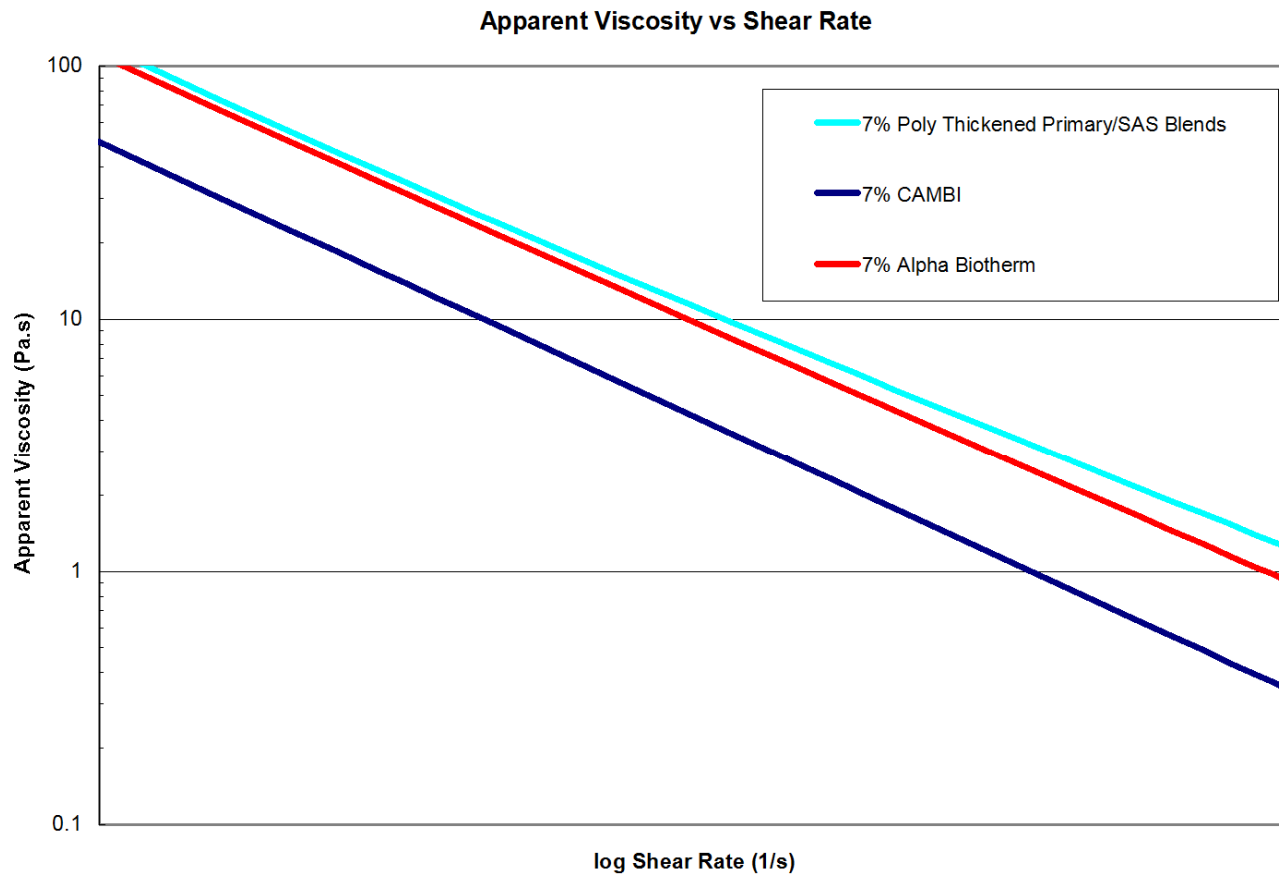
Struvite formed in digester increased total solids (0.5% higher)

Portion mistaken for volatile solids

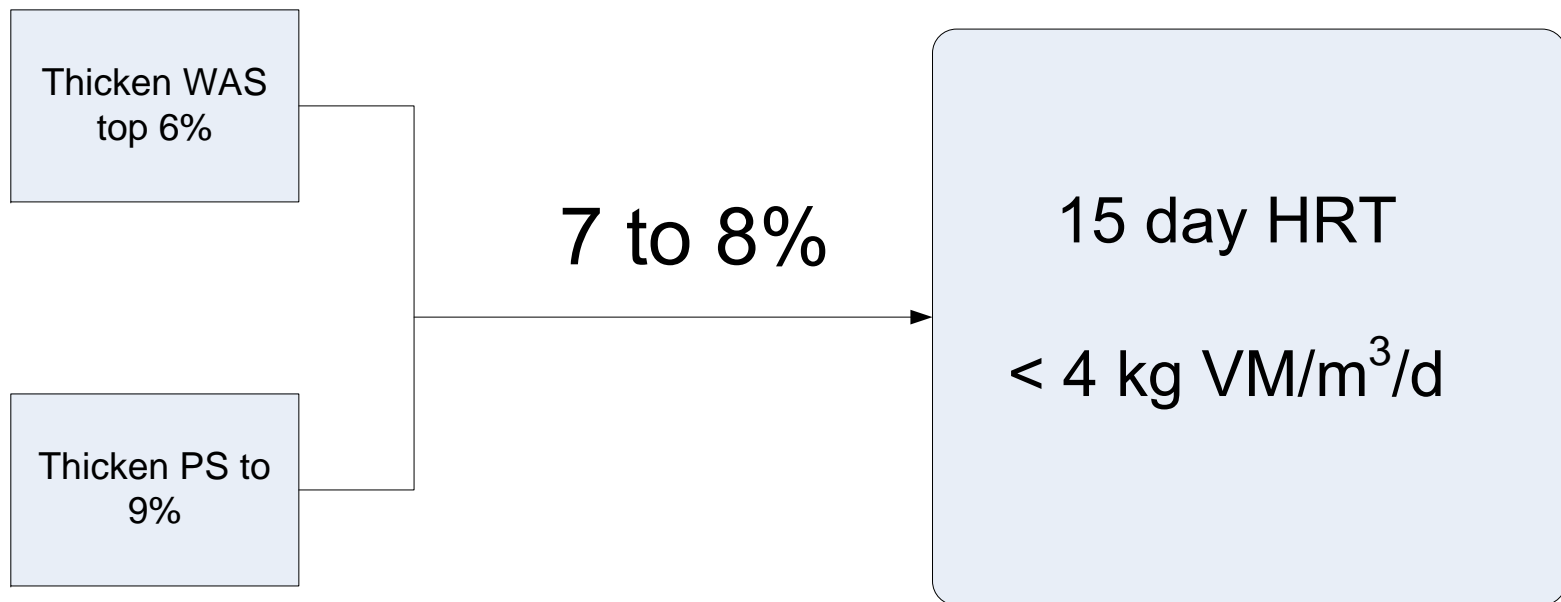


Topic 3: Nominal & Activae Hydraulic Retention Time

Processing sludge can change rheology



Topic 4: What feed concentration we can achieve comfortably with existing thickening technology



To go higher, dewater and dilute

Topic 5: Chemical Oxygen Demand

- COD is a measure of organic loading
- Biogas yield is typically
 - between 0.8 and 1.0 m³/kg VM destroyed
 - Measure volatile solids prior to pre-processing
- Yield is better tracked using COD
 - 0.25 kg methane per kg COD destroyed
 - 3.5 kWh per kg COD destroyed

Part 3: Evaluation Protocol



Why use advanced digestion technology

- Destroy pathogens
- Increase biogas production
- Reduce mass of digested solids to be processed
- Improve digested sludge dewatering
- Increase digester capacity

Evaluation Protocol (short list)

- Conduct solids, COD, N and P balance across system
- Reduce or eliminate uncertainty
- 10% to 25% of samples should be duplicates
- Design sampling to confirm objectives