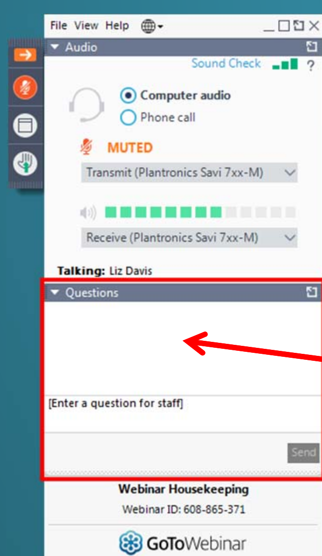
Operation of Anaerobic Digestion

Jeanette Brown, Manhattan College
Paul Dombrowski, Woodard & Curran, Inc.
Spencer Snowling, Hydromantis, Inc.

1

How to Participate Today



- **Audio Modes**
  - Listen using Mic & Speakers
  - Or, select "Use Telephone" and dial the conference (please remember long distance phone charges apply).
- **Submit your questions using the Questions pane.**
- **A recording will be available for replay shortly after this webcast.**

2

Jeanette Brown, PE, BCEE, D.WRE, Dist.M.ASCE, F.WEF

Research Assistant Professor
Manhattan College

1853
MANHATTAN COLLEGE

Water Environment Federation
the water quality people

3

Paul Dombrowski, PE, BCEE, F.WEF, Grade 6 Operator (MA)

Chief Technologist
Woodard & Curran, Inc.

WOODARD &CURRAN

Water Environment Federation
the water quality people

4

Spencer Snowling, Ph.D, P.Eng

V.P., Product Development

Hydromantis Environmental Software Solutions, Inc.

Hydromantis Environmental Software Solutions, Inc.

Water Environment Federation the water quality people

5

Webinar Agenda

- Introductions
- Fundamental Concepts of Anaerobic Digestion Process Theory
- Simulator Overview
- Types of Anaerobic Digestion Processes
- Anaerobic Digestion Process Control
- Simulator Case Study
- Questions

Water Environment Federation the water quality people

6

Anaerobic Digestion Process Theory

Jeanette Brown, Manhattan College

Water Environment Federation the water quality people

7

Anaerobic digestion

- Anaerobic Digestion is a
  - complex biochemical process which converts organic compounds to methane and carbon dioxide (biogas).
  - Reduces odor, pathogens, and volatile solids
  - Can produce Class A or B biosolid as per 40CFR503
    - Recover nutrients in the form of fertilizer
  - Recovers energy in the form of biogas
    - Heat
    - Electricity

Water Environment Federation the water quality people

8

Advantages/Disadvantages of Anaerobic Digestion

- Advantages
  - Can accept high strength wastes
  - Useful end product-CH_4
  - Lower cell yield-less residual sludge
    - BOD removal about 0.45 lbs of biomass per lb of BOD
    - AD about 0.08 lb/lb
  - Lower N/P requirements
- Disadvantages
  - Optimum temperature requires heat input
  - Presence of oxidizing agents is toxic (oxygen)
  - Low growth rate-start-up and recovery from adverse conditions is slow
  - Digester supernatant high in nitrogen and phosphorus

Water Environment Federation
the water quality people

9

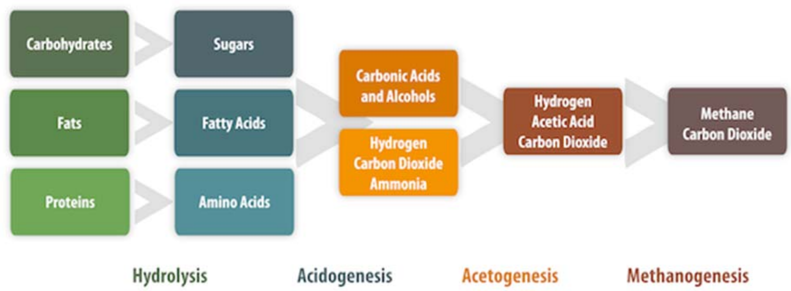
Terms

- Anaerobic processes
  - Biological processes occur in the absence of free dissolved oxygen and oxidized compounds
- Digestate
  - Solid material remaining after digestion
- Supernatant/centrate/filtrate
  - Liquid from separated from digestate

Water Environment Federation
the water quality people

10

Overview of Anaerobic Digestion Process



Hydrolysis Stage

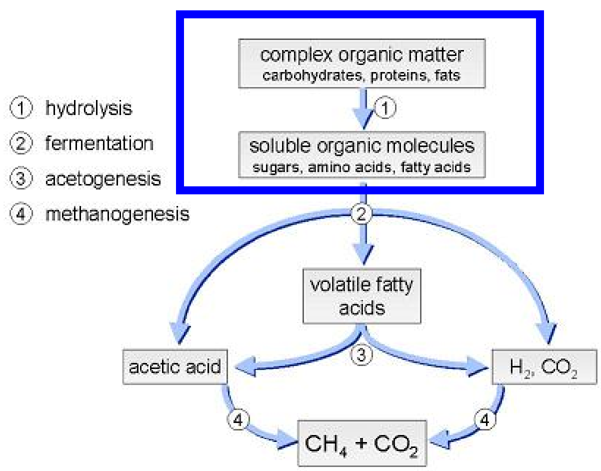
Volatile Solids Reduction (VSR)

Methanation Stage

Volatile Solids → Soluble Organics, Gases

11

Step 1 - Hydrolysis



12

Hydrolysis

- The chemical breakdown of compounds due to reaction with water
- Particulates made soluble
- Large molecules (polymers) broken down into smaller molecules (monomers)
  - Allow passage through bacterial cell wall
- Rate limiting step
  - Driving new pretreatment technologies such as thermal hydrolysis

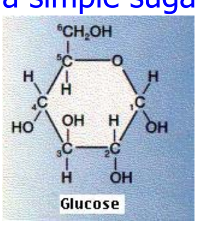
Water Environment Federation the water quality people

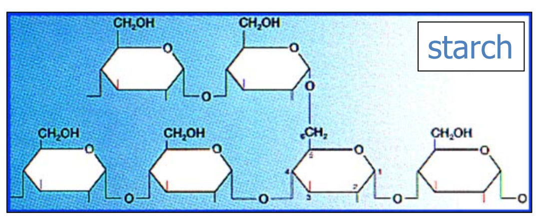
13

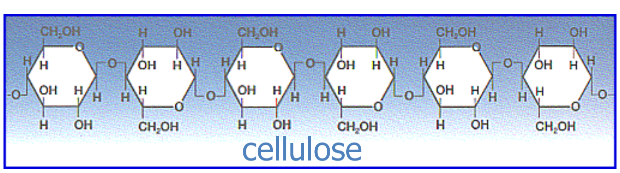
Carbohydrates

- A macromolecule (polymer)

a simple sugar







common carbohydrates

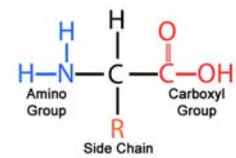
Water Environment Federation the water quality people

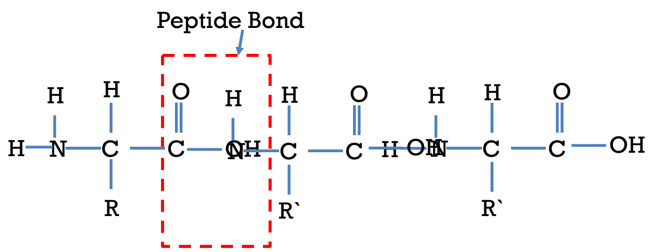
14

Protein

- A macromolecule (polymer)

Amino Acid





15

Fats (Lipids)

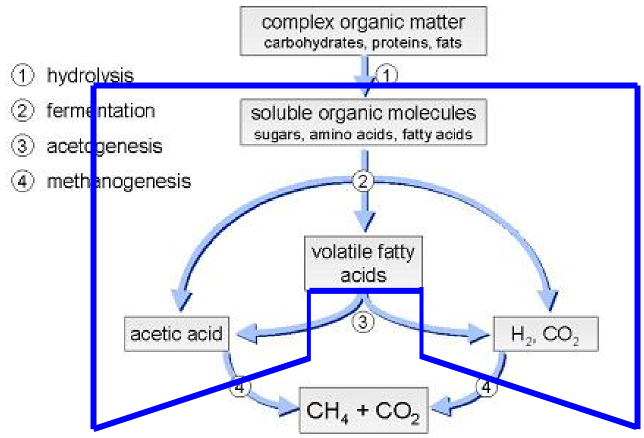
- Molecule composed of fatty acids

Fatty Acids: Long-chain hydrocarbon (~C5 to C24) molecule capped by a carboxyl group (COOH)

C2:0	**Acetic acid**	$C_2H_4O_2$	CH_3COOH
C3:0	**Propionic acid**	$C_3H_6O_2$	CH_3CH_2COOH
C4:0	**Butyric acid**	$C_4H_8O_2$	$CH_3(CH_2)_2COOH$
C4:0	**Isobutyric acid**	$C_4H_8O_2$	$(CH_3)_2CHCOOH$
C5:0	**Valeric acid**	$C_5H_{10}O_2$	$CH_3(CH_2)_3COOH$
C5:0	**Isovaleric acid**	$C_5H_{10}O_2$	$(CH_3)_2CHCH_2COOH$
C6:0	**Caproic acid**	$C_6H_{12}O_2$	$CH_3(CH_2)_4COOH$
C8:0	**Caprylic acid**	$C_8H_{16}O_2$	$CH_3(CH_2)_6COOH$
C10:0	**Capric acid**	$C_{10}H_{20}O_2$	$CH_3(CH_2)_8COOH$
C12:0	**Lauric acid**	$C_{12}H_{24}O_2$	$CH_3(CH_2)_{10}COOH$

16

Step 2 – Acidogenesis (Fermentation)



Step 2 – Acidogenesis (Fermentation)

- Sugars, amino acids, and long-chain fatty acids converted to short-chain volatile fatty acids (76%), H_2 (4%), and some acetic acid (20%)
- Optimum growth rate occurs near pH 6
- Volatile fatty acids generally not significant consumer of alkalinity
- CO_2 significant consumer of alkalinity
- NH_3 produced from amino acids

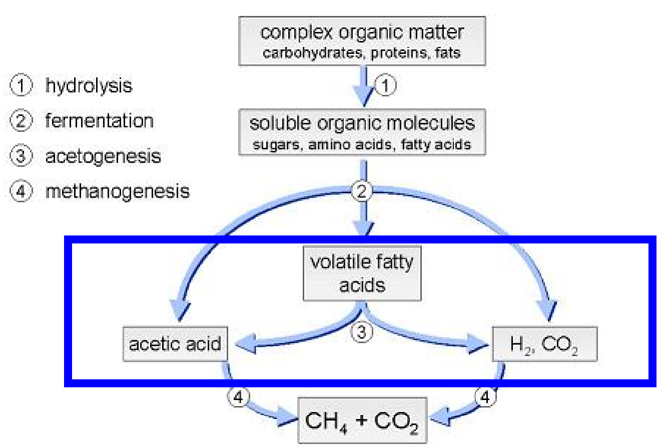
Step 2 – Acidogenesis (Fermentation

- Principal fermentation products are
  - Propionic and Butyric Acid (plus some Acetic Acid)
  - CO_2 , and
  - H_2

C2:0	**Acetic acid**	$C_2H_4O_2$	CH_3COOH
C3:0	**Propionic acid**	$C_3H_6O_2$	CH_3CH_2COOH
C4:0	**Butyric acid**	$C_4H_8O_2$	$CH_3(CH_2)_2COOH$
C4:0	**Isobutyric acid**	$C_4H_8O_2$	$(CH_3)_2CHCOOH$
C5:0	**Valeric acid**	$C_5H_{10}O_2$	$CH_3(CH_2)_3COOH$
C5:0	**Isovaleric acid**	$C_5H_{10}O_2$	$(CH_3)_2CHCH_2COOH$
C6:0	**Caproic acid**	$C_6H_{12}O_2$	$CH_3(CH_2)_4COOH$
C8:0	**Caprylic acid**	$C_8H_{16}O_2$	$CH_3(CH_2)_6COOH$
C10:0	**Capric acid**	$C_{10}H_{20}O_2$	$CH_3(CH_2)_8COOH$
C12:0	**Lauric acid**	$C_{12}H_{24}O_2$	$CH_3(CH_2)_{10}COOH$

19

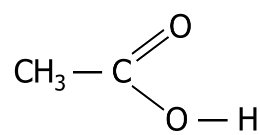
Acetogenesis



20

Step 3 - Acetogenesis

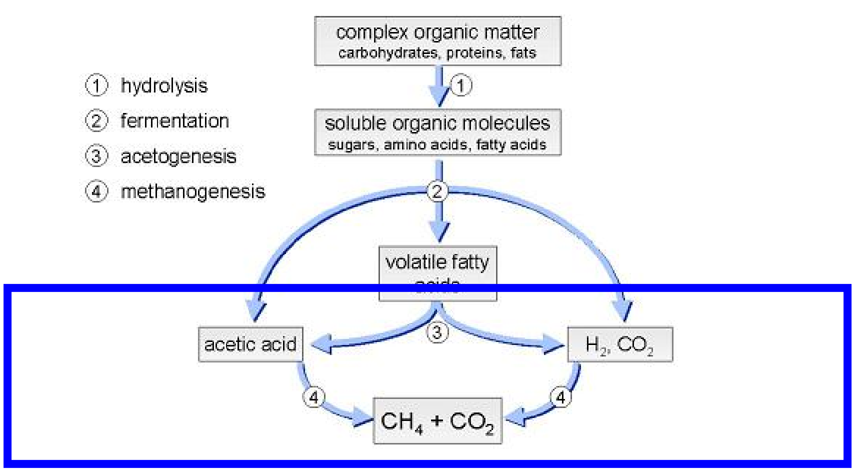
- Propionic and butyric acids are converted to acetic acid H_2, and CO_2
  - Sensitive to H_2 concentration
  - Syntrophic (mutually beneficial) relationship with the methanogens
- Final products (acetic acid, hydrogen, and CO_2 ,
  - precursors of methane formation.



ethanoic acid (acetic acid / vinegar)

21

Step 4 - Methanogenesis



22

Methanogenesis

- Methanogens
  - Obligate anaerobes
  - Tend to have slower growth rates
  - H_2 utilizing methanogens use H_2 to produce methane
  - Acetic acid utilizing methanogens us acetic acid to produce methane
  - Limited pH range 6.7 to 7.4
    - importance of alkalinity in system
  - Sensitive to temperature change
  - Produce methane

Water Environment Federation the water quality people

23

Routes to Formation of Methane

Hydrogenotrophic methanogens

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O$$

Acetotrophic methanogens

$$4\,CH_3COOH + 2\,H_2 \rightarrow 4\,CH_4 + 4\,CO_2 + 2\,H_2$$

Water Environment Federation the water quality people

24

Products of Digestion

- Beneficial
  - Biogas
  - Digestate
- Nuisance
  - Scum
  - Sidestream

25

Biogas

- Biogas
  - Methane-CH_4 (Typically 60 to 65 %)
  - Carbon Dioxide-CO_2 (Typically 30 to 35%)
- Energy Content
  - CH_4 -1000 BTU/ft^3
  - @60% methane-biogas is ~600 BTU/ft^3
- Gas production rate
  - 12 to 18 ft^3 per pound of VS destroyed

Water Environment Federation the water quality people

26

Biogas

- Used to
  - Heat the digester and incoming sludge
  - Heat building
  - Generate electricity
- Requires clean-up
  - Remove moisture
  - Remove H_2S
  - Remove soloxanes

Water Environment Federation
the water quality people

27

Digestate

- Digestate are stabilized biosolids
  - Reduced volatile solids and pathogens
  - Meets Class A or B standards-typically Class B
- Digestate
  - Used as a fertilizer in land application to recover
    - nutrients,
    - carbon, and
    - water

Water Environment Federation
the water quality people

28

Scum

- Scum
  - Lighter solids which float to the top of the digester
  - Foam
- Problems
  - material is not digested because it is floating
  - reduces digester capacity
  - plugs piping
  - plugs vents and flame traps

Water Environment Federation the water quality people

29

Sidestreams

- Supernatant if using two-stage digestion
- Filtrate or Centrate produced by dewatering
- Characteristics
  - High solids concentration
  - High BOD concentration
  - High nutrient concentration
    - Especially ammonia-nitrogen
    - Phosphorus

Water Environment Federation the water quality people

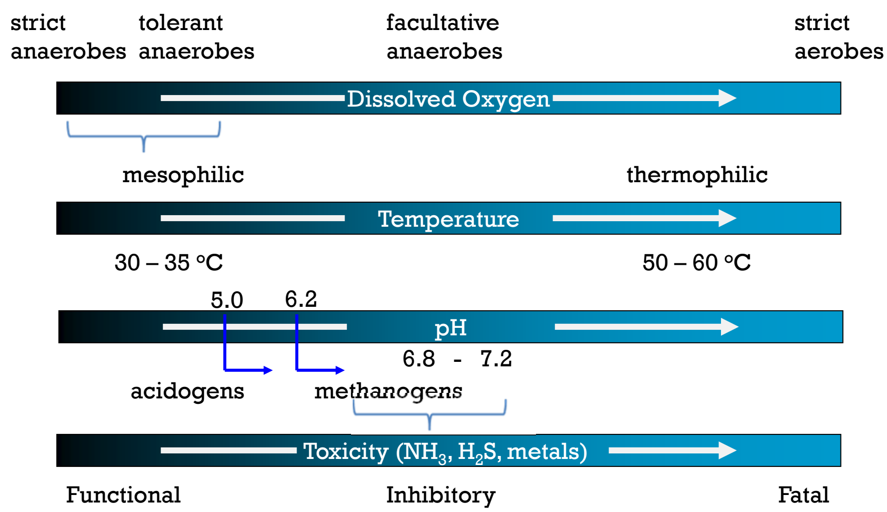
30

Anaerobic Digestion Processes

- Defined by temperature range
  - Mesophilic Range 30-38°C (85 to 100°F) ; typical 35°C (95°F)
  - Thermophilic Range 50-57°C (122 to 135°F); typical; 55°C (131°F)
- pH
  - Optimum 7.0 to 7.1
  - General Limits 6.7 to 7.4
- Gas Production
  - 12 to 18 ft^3 of gas per pound of volatile solids destroyed

31

Bacteria: Environmental Conditions



32

Process Simulators

Paul Dombrowski, Woodard & Curran, Inc.

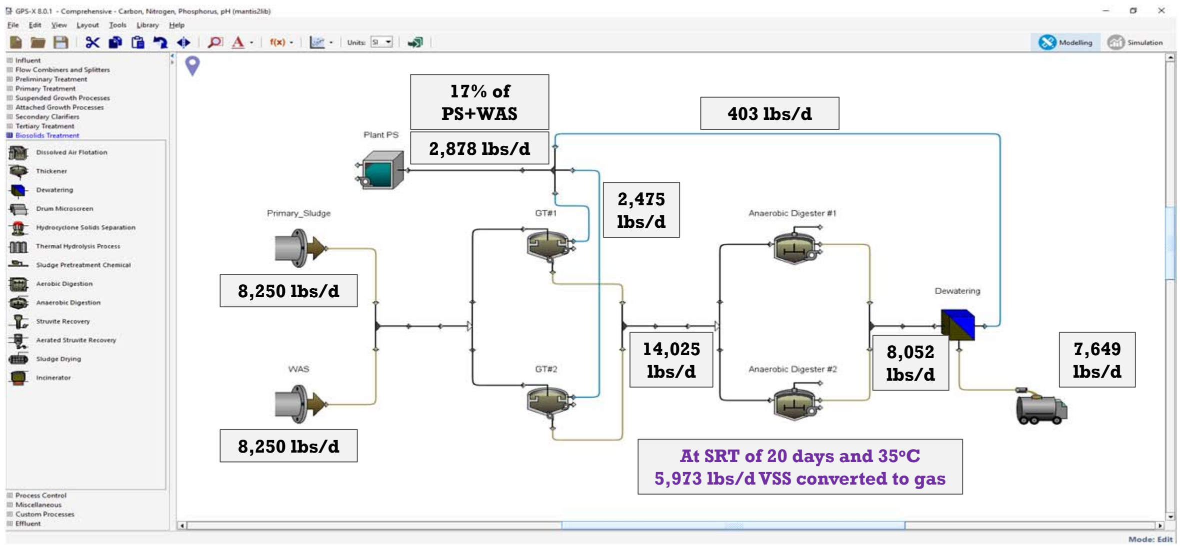
33

Simulator Overview

- Model = Series of equations that defines a process or plant
  - Model based on mass balances and biological conversions of organics (COD), nitrogen, phosphorus and solids
- Simulator = Program that uses a process model to experiment with a plant configuration
- OpTool SimuWorks Overlay = Plant-specific layout that provides graphical interface for plant operational testing and training

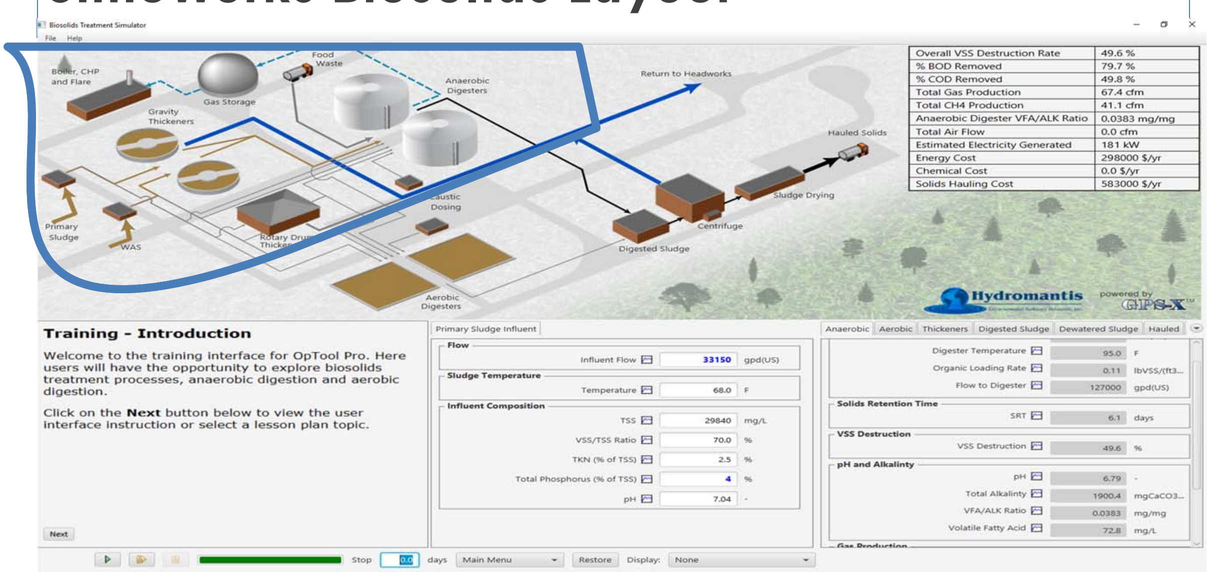
34

GPS-X Biosolids Model Layout



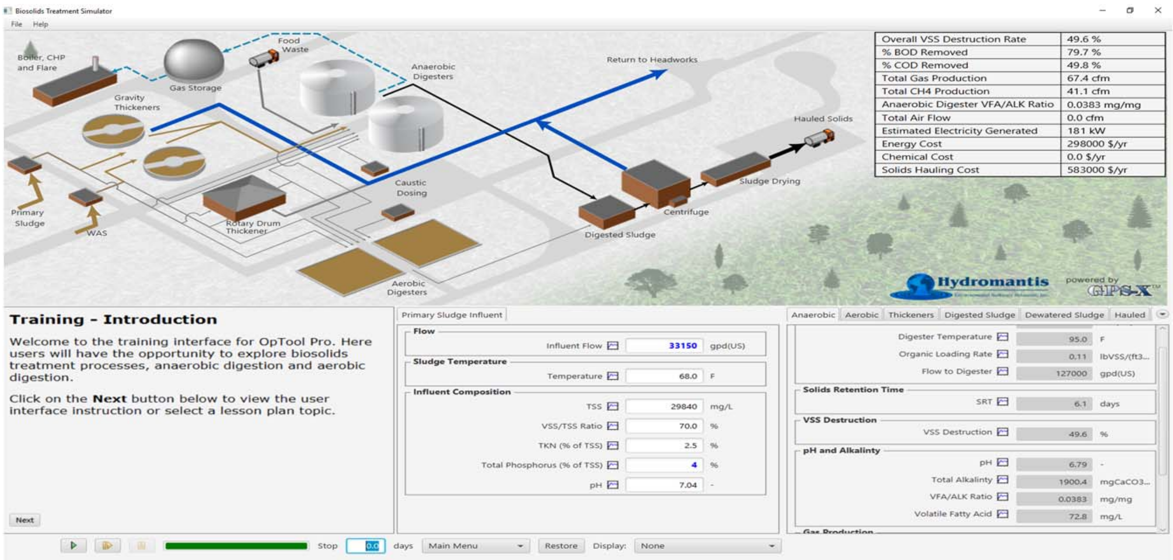
35

SimuWorks Biosolids Layout



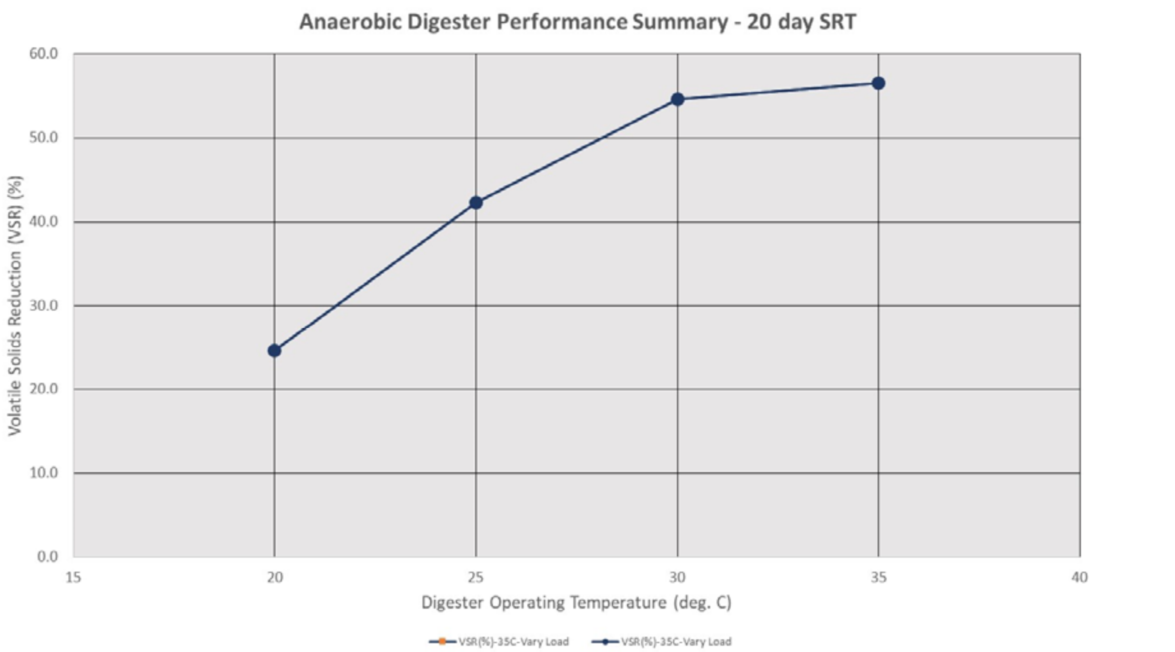
36

Digester Performance vs. Changing Temperature



Water Environment Federation
the water quality people

37



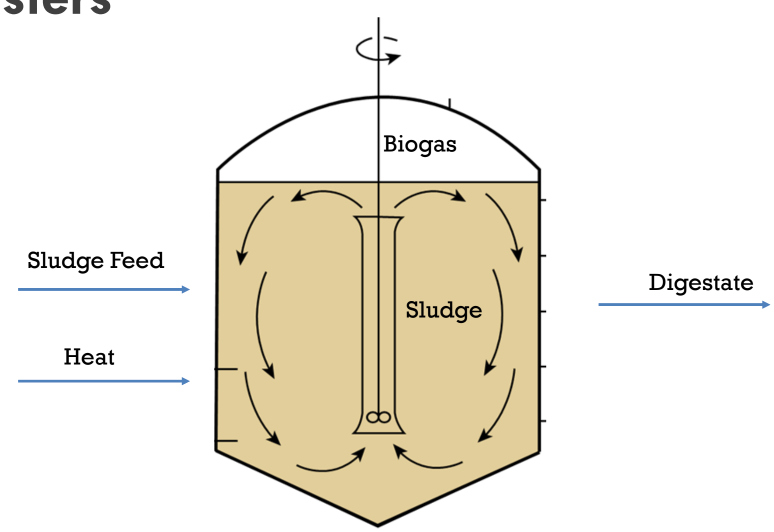
Water Environment Federation
the water quality people

38

Anaerobic Digestion Processes and Process Control

39

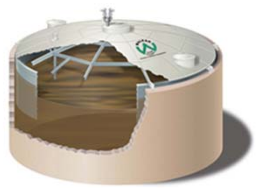
Digesters



40

Digester Geometry-Cylindrical

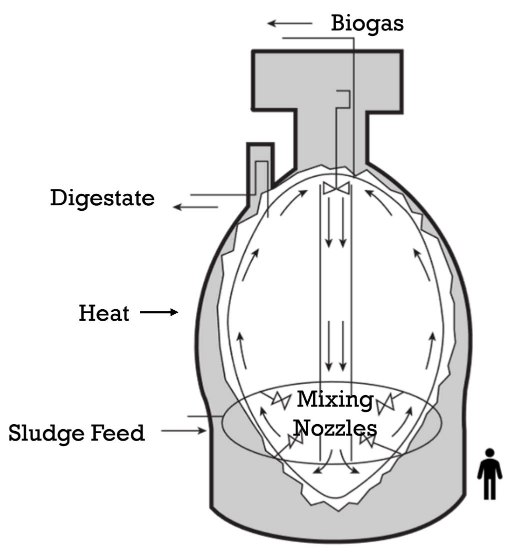
Cylindrical Digester

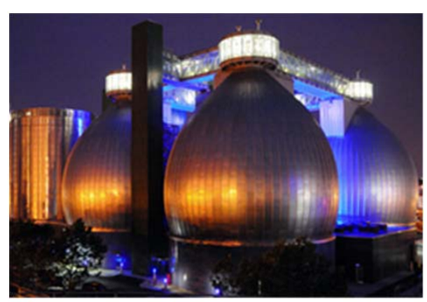


Fixed Cover

Floating Cover

Digester Geometry-Egg-Shaped





Egg-shaped Digester

43

Advantages and Disadvantages of Shape

Cylindrical
- shape results in large volume for gas storage
- can be equipped with gas holder covers
- Low profile
- Conventional construction techniques can be applied; construction costs can be competitive

Egg Shaped
- Minimum grit accumulation
- Reduced scum formation • Higher mixing efficiency
- More homogeneous biomass is obtained
- Lower operating and maintenance costs; cleaning frequency significantly reduced
- Smaller footprint; less land area is required
- Foaming is minimized

Cylindrical
- Shape results in inefficient mixing and dead spaces
- Poor mixing results in grit accumulation
- Large surface area provides space for scum accumulation and foam formation
- Cleaning is required for removal of grit and scum accumulation; digester may be required to be taken out of service

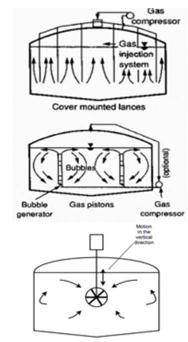
Egg Shaped
- Very little gas storage volume; external gas storage is required if as is recovered
- High profile structures; may be aesthetically objectionable
- Difficult access to top-mounted equipment; installation requires a high stair tower or an elevator
- Greater foundation requirements and seismic considerations
- Higher construction costs
- Construction limited to specialty contractors

44

Mixing and Heating

- Digesters must be
  - Heated
    - Incoming sludge is cold
    - Requires heat exchanger
  - Mixed
    - Organisms must contact substrate
    - Releases gas from sludge

Source: HRS Heat Exchangers, 2018



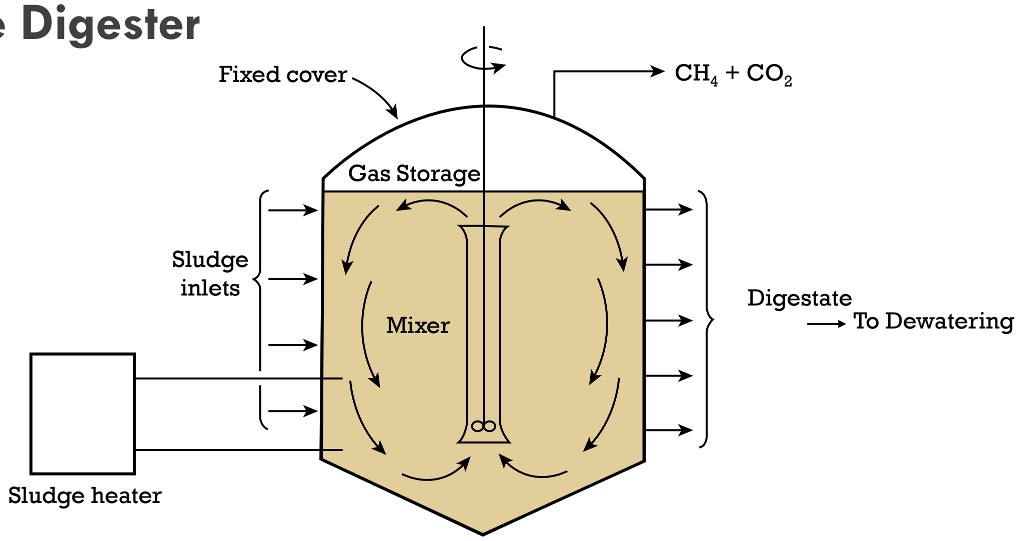
45

Types of Digestion Processes

- Single-Stage High Rate Digestion
- Two-Stage Digestion
- Temperature-Phased Digestion
- Acid/Gas Phased Digestion

46

High Rate, Continuous-Flow, Stirred Tank Single Stage Digester



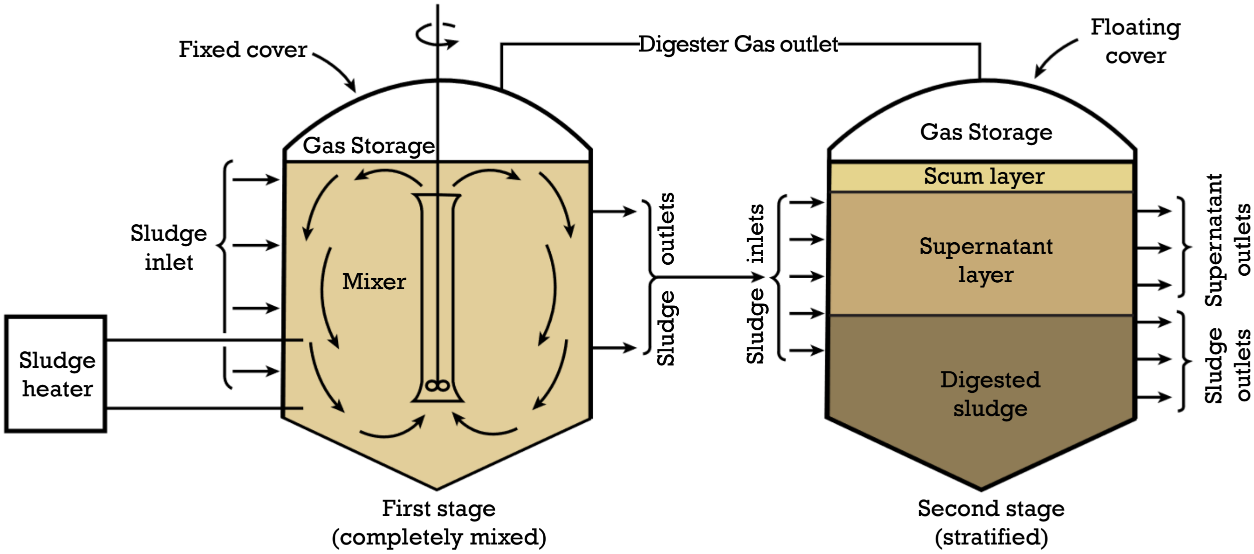
47

High-Rate Digestion

- Contents are heated and mixed completely
  - Mesophilic
- Detention time typically 15 to 20 days
- Uniform feeding required for optimum performance
- No supernatant separation
- Either egg or cylindrical with fixed or floating covers

48

Two-Stage Anaerobic Digester



49

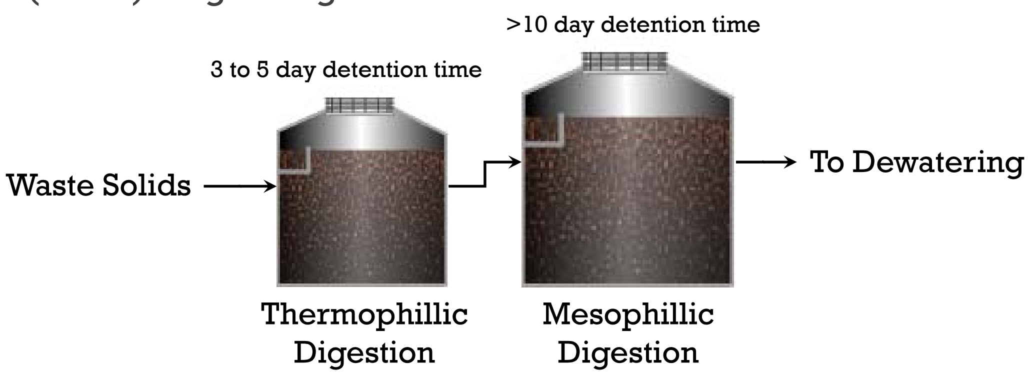
Characteristics of Two-Stage Digestion

- High-rate digester coupled in series with a second digestion tank
- First stage used for digestion
  - heated and mixed
- Second stage used to separate the digested solids from the supernatant
  - not heated or mixed
  - some additional digestion and gas production may occur.

50

Temperature Phased Digestion

- Temperature Phased
  - Various combinations of mesophilic (35° C) and thermophilic (55° C) staged digesters



51

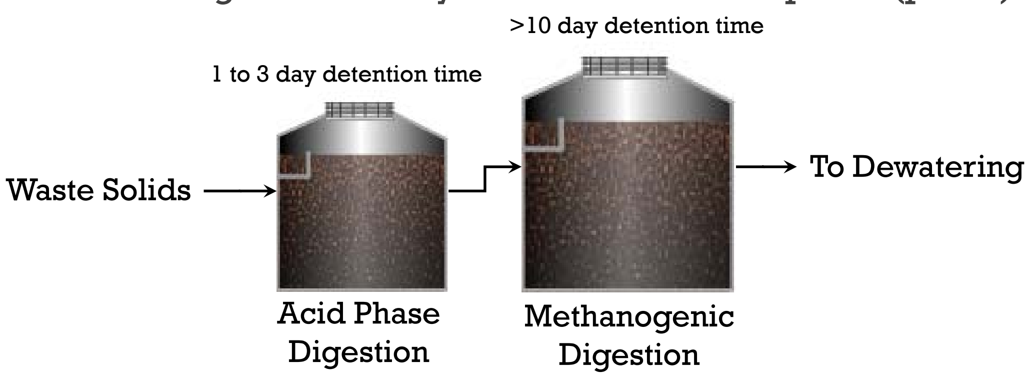
Temperature Phased Digestion

- Advantage
  - Thermophilic-greater hydrolysis and biological activity
    - greater VS destruction and gas production
  - Mesophilic-additional VS destruction
    - destruction of odorous compounds (mostly fatty acids)
    - improved stability of the digestion operation.

52

Acid / Gas Phased Digestion

- Acid/Gas Digestion
  - First Stage is low pH (5 to 6) fermentation step
  - Second Stage is normally conventional Mesophilic (pH=7)



Water Environment Federation the water quality people

53

Acid / Gas Phased Digestion

- Acid phase digester
  - Hydrolysis and acidogenesis
  - pH of 6 or less and at a short SRT
  - produces high concentrations of volatile acids (> 6000 mg/L)
- Gas phase digester
  - neutral pH and a longer SRT
  - maximize gas production

Water Environment Federation the water quality people

54

Important Process Variables

- Volatile solids reduction/destruction
- HRT/SRT
- Temperature

55

Volatile Solids Reduction and Destruction

- % VS Reduction

$$VSR = \frac{VS_{in} - VS_{out}}{VS_{in} - (VS_{in} x VS_{out})} x100$$

- VS Destruction (lbs/d VS destroyed per ft^3)

$$VSD = \frac{VS_{added}\ (VSR)}{Vol_{digester}}$$

Water Environment Federation the water quality people

56

Hydraulic and Solids Retention Time

- Digester sizing based on
  - Sufficient residence time for significant reduction of VS
- HRT-average time liquid is held in the process
  - Digester volume/volume of sludge removed per day
- SRT-average time solids are in digestion process
  - mass in reactor/mass per day removed
- For most AD processes HRT=SRT

Water Environment Federation the water quality people

57

Solids Retention Time

- Hydrolysis, Fermentation, and methanogenesis directly related to SRT
- An increase or decrease in SRT results in an increase of decrease in the extent of each reaction.
  - If SRT is less than the minimum SRT for each reaction, bacteria will not grown rapidly enough and the process will fail.

SRT, d	% VSD
30	50-65
20	50-60
10	45-60

Water Environment Federation the water quality people

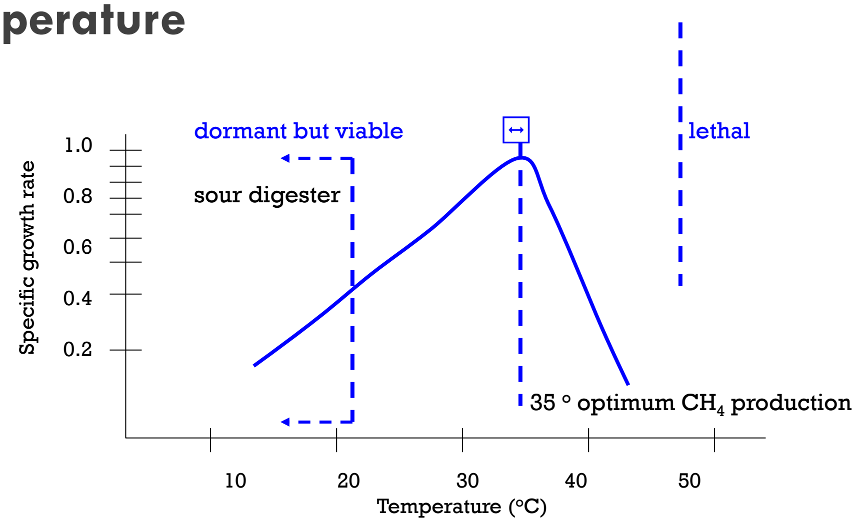
58

Temperature

- Influences
  - Metabolic activity
  - Gas transfer
  - Settling characteristics
  - Digestion rate
  - Minimum SRT for VS destruction

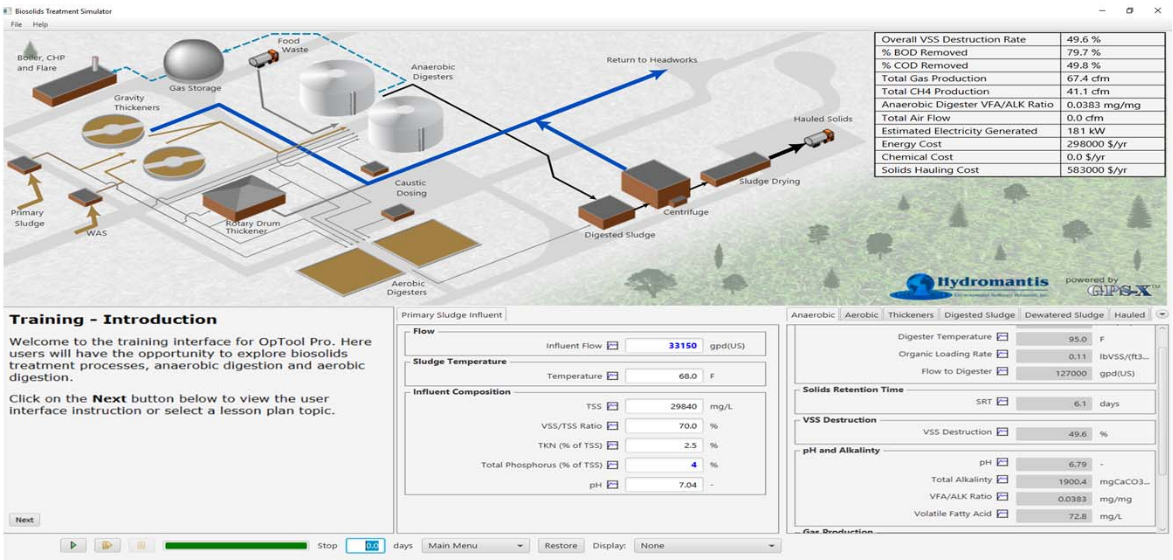
59

Response of Mesophilic Bacterial Growth to Temperature

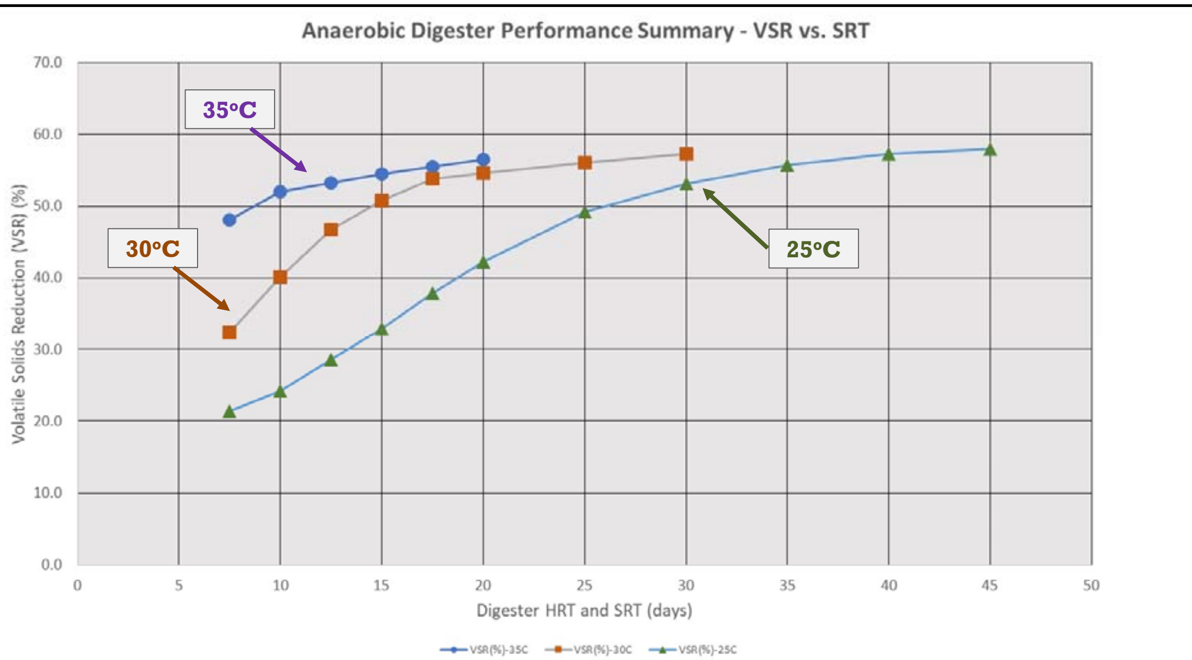


60

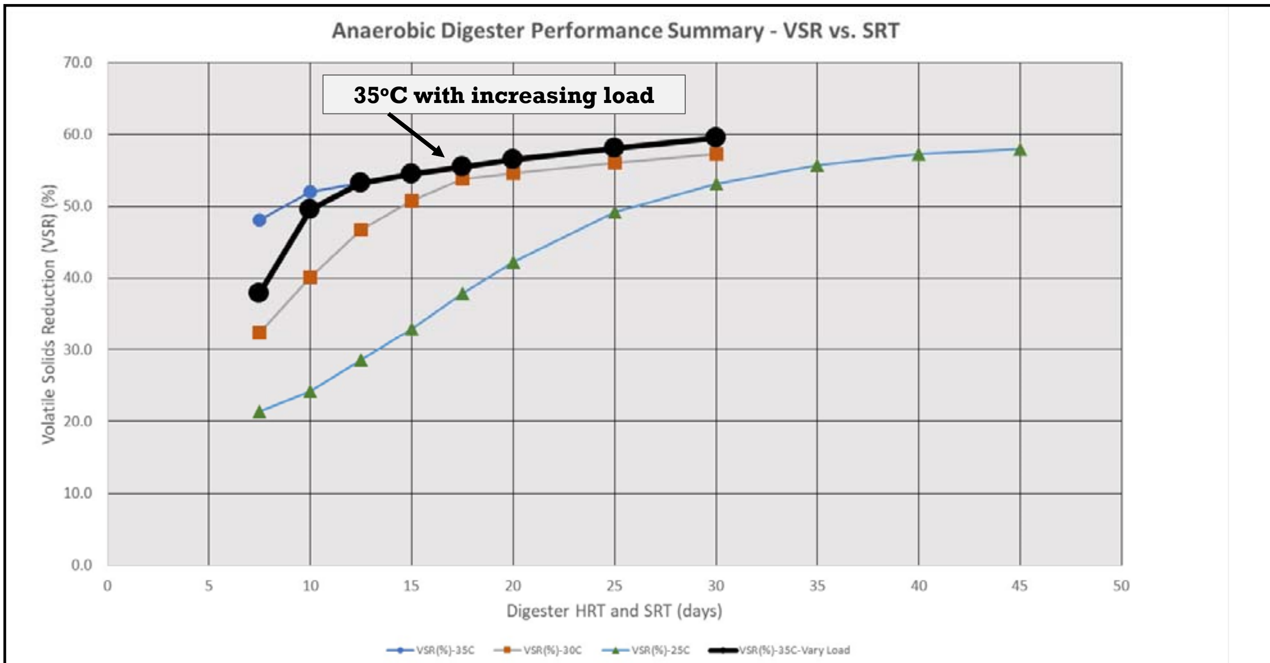
Digester SRT vs. Volatile Solids Reduction



61



62



63

Process Monitoring and Control-sampling

- Process control and monitoring require sampling and testing of the
  - digester feed,
  - biogas, and
  - digested solids

64

Process Monitoring and Control

Solids (feed and digestate)
- COD
- pH
- Alkalinity
- Volatile Acids
- TS/VS
- Nitrogen/Phosphorus

Temperature

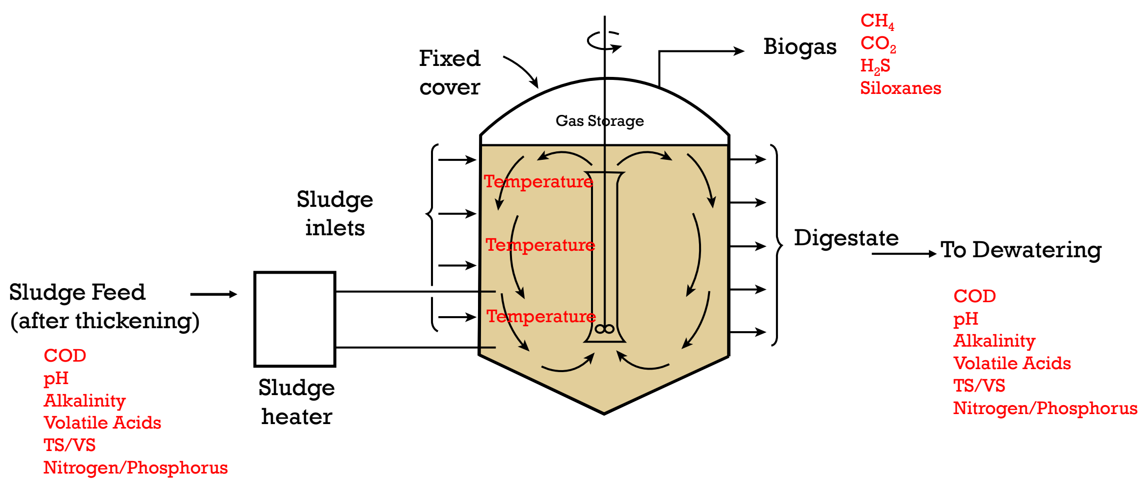
Gas
- Methane
- CO2
- H2S
- Siloxanes (if electrical generation is used)

Supernatant/Centrate/Filtrate
- NH4-N/TKN
- Ortho and total P
- TS/VS
- COD/BOD

Water Environment Federation the water quality people

65

Sampling and Monitoring Locations

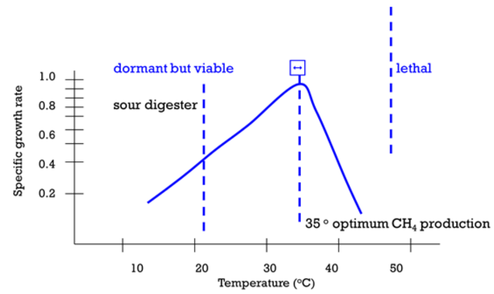


Water Environment Federation the water quality people

66

Process Monitoring and Control-temperature

- Each group methanogens has an optimum temperature for growth
  - If temperature fluctuates, methane formers cannot develop a large, stable population
- Temperature should not vary more that ±1° F for optimum performance
- Temperature should be continually monitored



67

Process Monitoring and Control-COD

- By measuring COD coming in and COD going out
  - Calculate a COD balance
  - Accounts for changes in COD in the reactor
  - COD loss in anaerobic reactor is accounted for by methane production
  - CH_4 equivalent of COD equals 0.35 L CH_4/g COD

68

Process Monitoring and Control-pH

- Best pH operating range: 6.8 to 7.2
  - below 6.0-unionized volatile acids become toxic to methane-forming microorganisms
  - Above 8.0-unionized dissolved ammonia becomes toxic to methane-forming microorganisms.
- pH of the digester contents is controlled by the ratio of volatile acids to alkalinity

Water Environment Federation the water quality people

69

Process Monitoring and Control-Alkalinity

- Digesters typically have sufficient alkalinity
  - breakdown of protein and amino acids to produces NH_3, which combines with CO_2 and H_2O to form alkalinity as $NH_4(HCO_3)$, $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ also present
- A well operated digester
  - total alkalinity of 2000 to 5000 mg/L
- The higher the alkalinity, the more stable the digester (supplemental alkalinity can be supplied by sodium bicarbonate, lime, or sodium carbonate)

Water Environment Federation the water quality people

70

Process Monitoring and Control-Alkalinity

- Volatile acids are intermediate digestion byproducts
  - Typically C2 to C4 (acetic, propionic, butyric)
- Typical total volatile acid concentrations range from 50 to 300 mg/L
- Unstable digester operation can develop where VA production rate exceeds methanogenic VA utilization rate
  - VA concentration increases
  - Causes pH to drop, depending on the amount of alkalinity available to buffer the organic acid concentration increase

Water Environment Federation the water quality people

71

Process Control-Volatile Acid to Alkalinity Ratio

- VA:ALK ratio
  - indicates progress of digestion and
  - balance between the acid fermentation and methane utilization microorganisms
  - need for balance between volatile acids and alkalinity
  - VA:ALK ratio is an excellent indicator of digester health
- Careful monitoring of the rate of change in this ratio can indicate a problem before a pH change occurs.

Water Environment Federation the water quality people

72

Process Control-Volatile Acid to Alkalinity Ratio

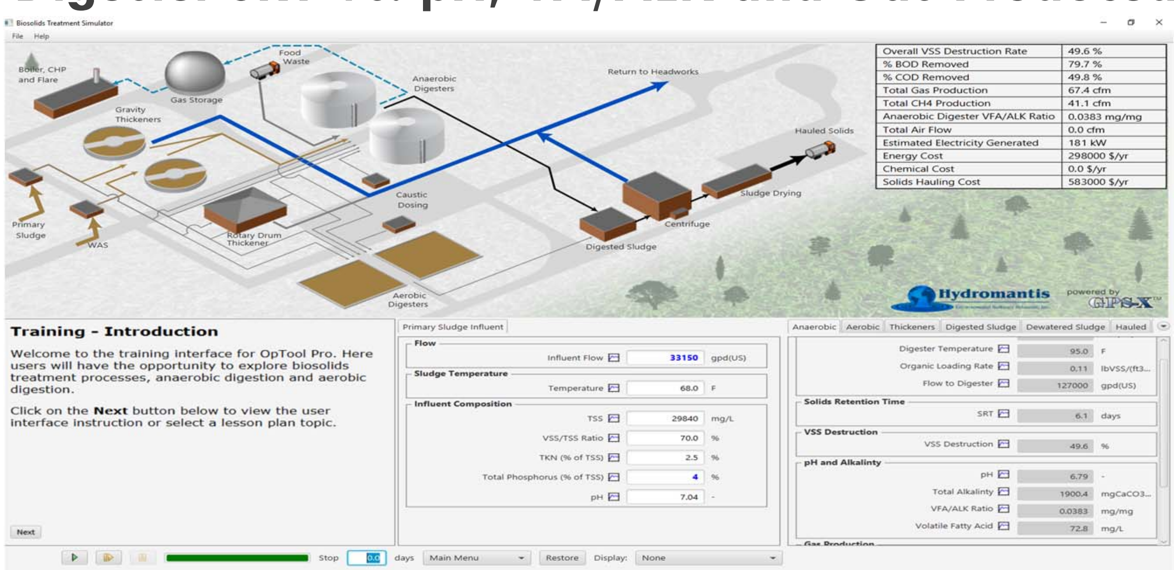
- VA:ALK ratio should be approximately 0.05 to 0.25.
  - Digester pH depression and inhibition of methane production occur if the ratio exceeds 0.8;
  - Ratios higher than 0.3 to 0.4 indicate upset conditions and the need for corrective action.
    - Add alkalinity
    - Check temperature measurements
    - Check heat exchanger

$$\frac{VA}{ALK} = \frac{VA, mg/L}{ALK, mg/L}$$

Water Environment Federation the water quality people

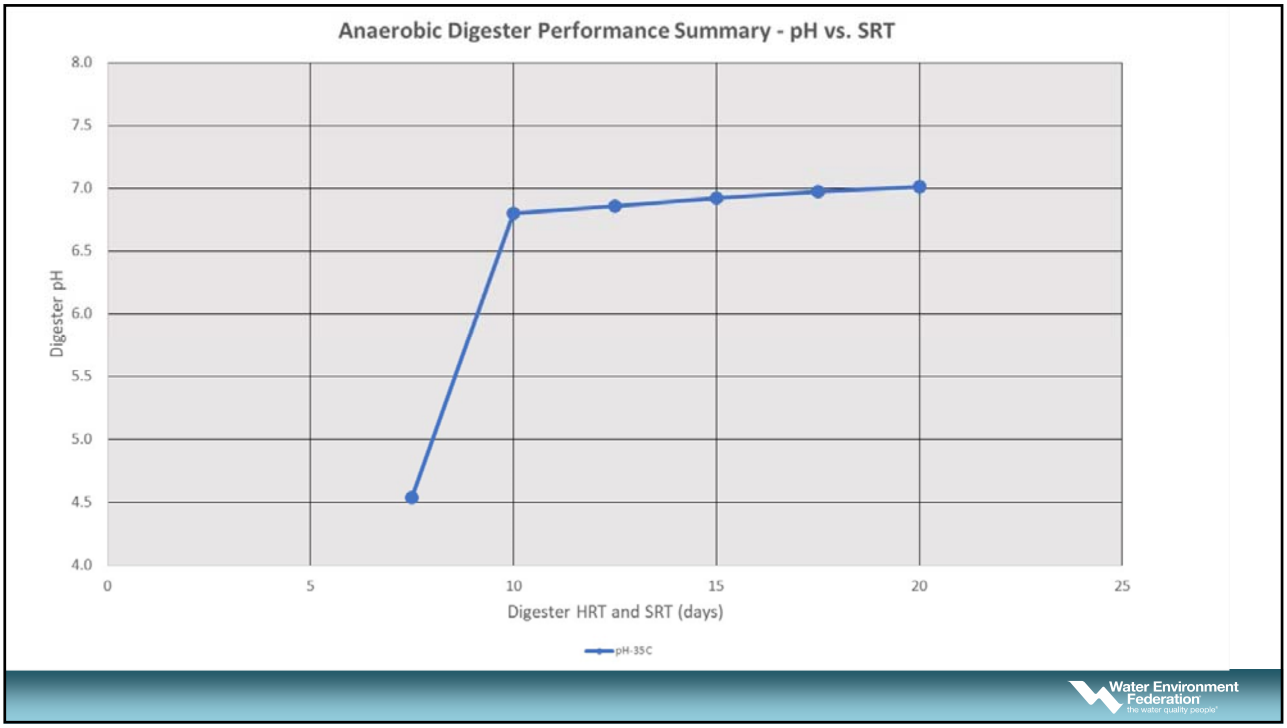
73

Digester SRT vs. pH, VA/ALK and Gas Produced

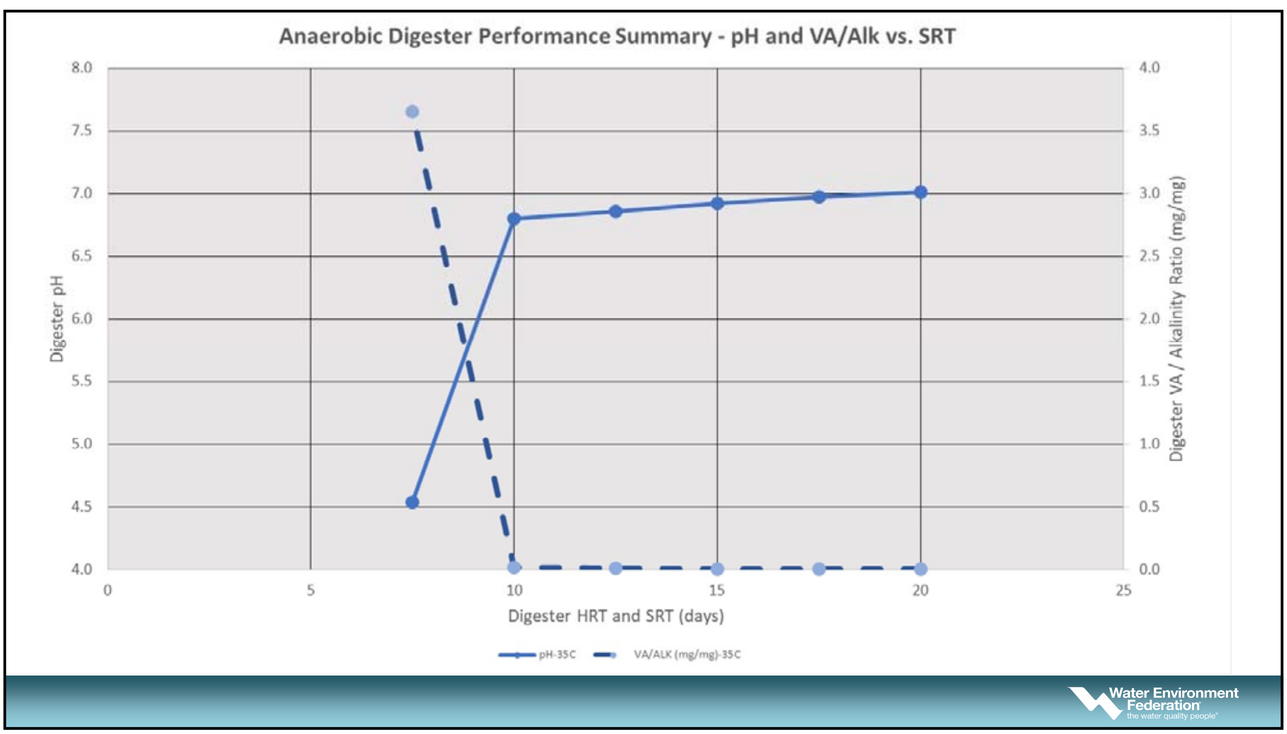


Water Environment Federation the water quality people

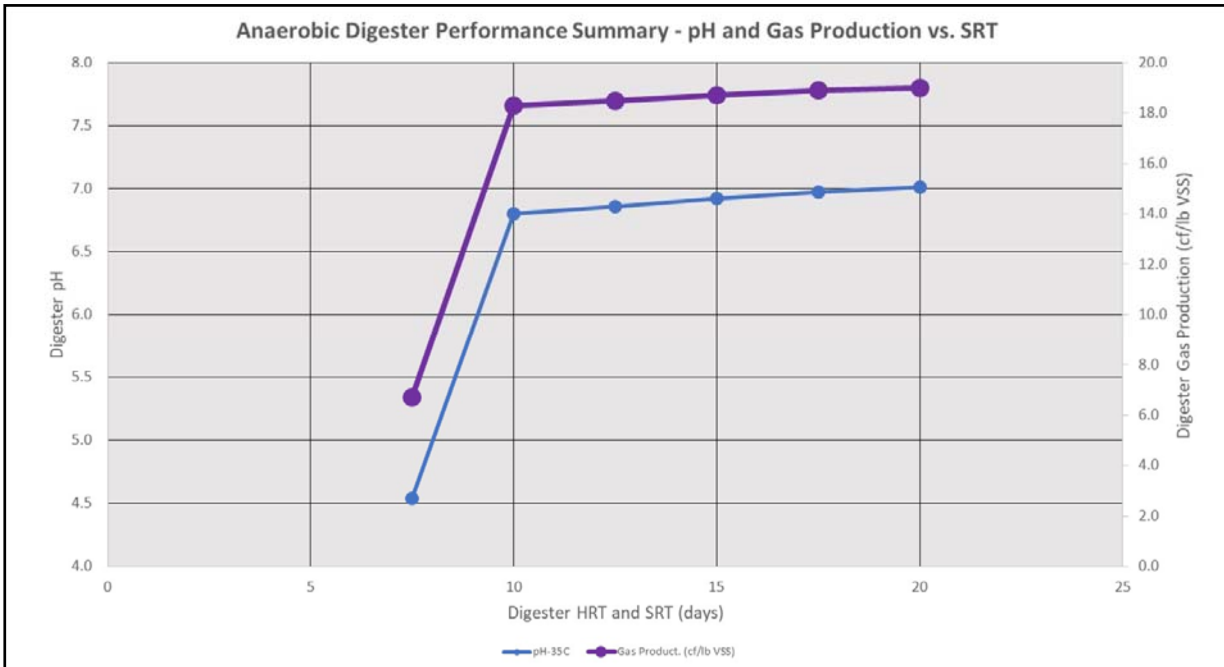
74


Anaerobic Digester Performance Summary - pH vs. SRT
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
Digester pH
0
5
10
15
20
25
Digester HRT and SRT (days)
pH-35C
Water Environment Federation
the water quality people

75


Anaerobic Digester Performance Summary - pH and VA/Alk vs. SRT
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
Digester pH
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Digester VA / Alkalinity Ratio (mg/mg)
0
5
10
15
20
25
Digester HRT and SRT (days)
pH-35C
VA/ALK (mg/mg)-35C
Water Environment Federation
the water quality people

76



77

Biosolids Handling Case Study

Spencer Snowling, Hydromantis, Inc.

78

Biosolids Handling Case Study

- **Little Patuxent Water Reclamation Plant,** Savage, MD
- ENR - BOD, Nitrogen and Phosphorus Removal
- Biosolids Handling Facility
  - WAS Gravity Thickener
  - Primary Sludge GBT
  - 3 Anaerobic Digesters

Water Environment Federation the water quality people

79

Biosolids Case Study

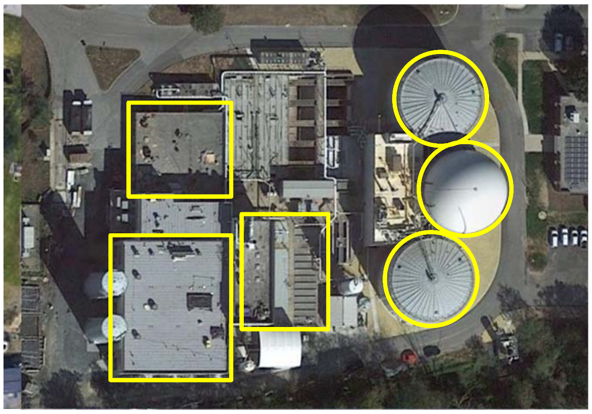
- **Little Patuxent Water Reclamation Plant, Savage, MD**

Water Environment Federation the water quality people

80

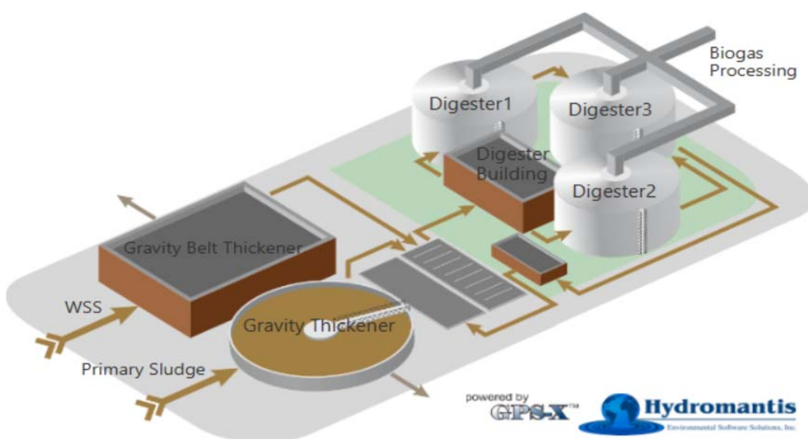
Biosolids Case Study

- **Little Patuxent Water Reclamation Plant, Savage, MD**



Biosolids Case Study

- **Little Patuxent Water Reclamation Plant, Savage, MD**



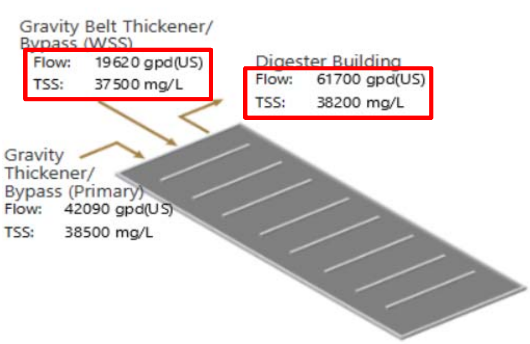
Biosolids Case Study

- **Standard Operation (WAS + Primary Sludge)**
- **2 Primary Digester and 1 Secondary Digester**

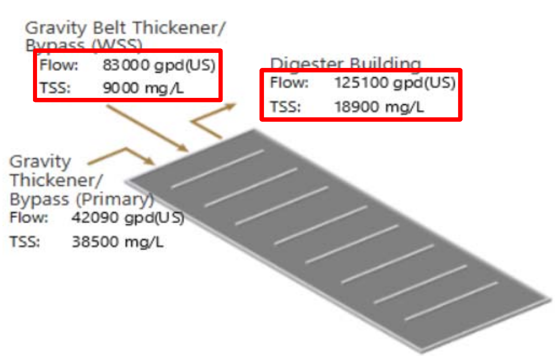
	Digester 1	Digester 2	Digester3
Flow Rate (gpd(US))	30900	30900	61700
Influent TSS (mg/L)	38200	38200	22800
Influent VSS (mg/L)	32700	32700	17200
VSS Loading Rate (lbVSS/(ft3.d))	0.040	0.040	0.042
VSS Removal Efficiency (%)	47.6	47.6	6.58
Gas Production per VSS Destroyed (ft3/lbVSS)	20.2	20.1	21.0
Gas Production Rate (ft3/d)	81200	80800	12200
Hydraulic Retention Time (d)	50.2	50.2	25.1
Digester pH	6.7	6.7	6.8

Biosolids Case Study #1

- **GBT Off-line (WAS unthickened)**



GBT On-line



GBT Off-line

Biosolids Case Study

- **GBT Off-line (WAS unthickened)**

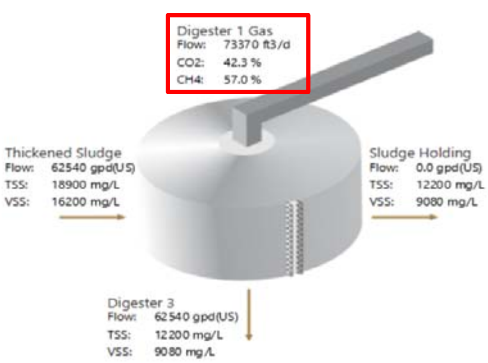
	Digester 1	%Change	Digester 2	%Change	Digester3	%Change
Flow Rate (gpd(US))	62500	103	62500	103	125000	103
Influent TSS (mg/L)	18900	-50.5	18900	-50.5	12200	-46.3
Influent VSS (mg/L)	16200	-50.4	16200	-50.4	9090	-46.9
VSS Loading Rate (lbVSS/(ft3.d))	0.040	0.0	0.040	0.0	0.045	0.000
VSS Removal Efficiency (%)	44.0	-7.54	44.0	-7.79	6.28	-4.68
Gas Production per VSS Destroyed (ft3/lbVSS)	19.7	-2.5	19.9	-1.1	20.5	-2.2
Gas Production Rate (ft3/d)	73400	-9.7	74100	-8.2	12200	0.0
Hydraulic Retention Time (d)	24.8	-50.7	24.8	-50.7	12.4	-50.7
Gas Methane Fraction (%)	57.0	2.5	57.0	2.5	49.5	5.4
Gas Carbon Dioxide Fraction (%)	42.3	-3.9	42.3	-3.8	50.4	-4.9
Effluent TSS (mg/L)	12200	-46.3	12200	-46.3	11700	-45.8
Effluent VSS (mg/L)	9080	-46.9	9090	-46.8	8520	-46.8
Digester Temperature (F)	95.0	0.0	95.0	0.0	95.0	0.0
Digester pH	6.4	-5.0	6.4	-5.0	6.4	-5.0
Alkalinity (mgCaCO3/L)	787	-58.3	787	-58.3	960	-58.2

Water Environment Federation
the water quality people

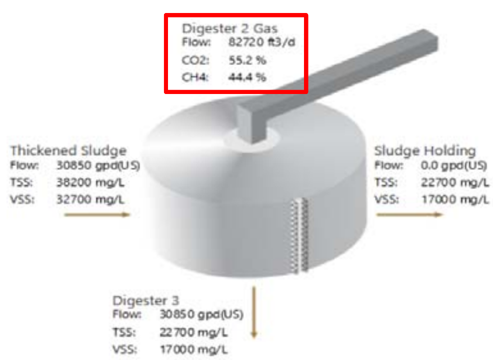
85

Biosolids Case Study #2

- **Increased Digester Temperature**



Base Temp (95°F)



3°F Increase (98°F)

Water Environment Federation
the water quality people

86

Biosolids Case Study

- **Increased Digester Temperature**

	Digester 1	%Change	Digester 2	%Change	Digester3	%Change
Flow Rate (gpd(US))	30900	0.0	30900	0.0	61700	0.0
Influent TSS (mg/L)	38200	0.0	38200	0.0	22700	-0.5
Influent VSS (mg/L)	32700	0.0	32700	0.0	17000	-0.6
VSS Loading Rate (lbVSS/(ft3.d))	0.040	0.0	0.040	0.0	0.042	-6.28e-05
VSS Removal Efficiency (%)	48.1	1.13	48.1	0.84	6.79	3.04
Gas Production per VSS Destroyed (ft3/lbVSS)	20.3	0.0	20.4	1.3	21.1	0.8
Gas Production Rate (ft3/d)	82600	1.6	82700	2.4	12600	3.0
Hydraulic Retention Time (d)	50.2	0.0	50.2	0.0	25.1	0.0
Gas Methane Fraction (%)	55.3	0.0	55.2	-0.6	46.1	-1.6
Gas Carbon Dioxide Fraction (%)	44.4	0.0	44.4	0.8	53.8	1.4
Effluent TSS (mg/L)	22700	0.0	22700	-0.5	21400	-0.7
Effluent VSS (mg/L)	17000	0.0	17000	-0.6	15800	-1.0
Digester Temperature (F)	98.0	3.1	98.0	3.1	98.0	3.1
Digester pH	6.8	0.0	6.8	0.0	6.8	0.0
Alkalinity (mgCaCO3/L)	1950	0.0	1950	0.0	2370	0.0

Case Study Summary

- Sludge thickening has a significant impact on digester performance
- Little Patuxent WRF has significant digester capacity, can absorb small changes in loading
- Increased temperature produces more gas, which can then be captured to supply heat to digesters

Questions?

Jeanette Brown
jeanette.brown@manhattan.edu
(203) 309-8768

Paul Dombrowski
pdombrowski@woodardcurran.com
(860) 253-2665

Spencer Snowling
snowling@hydromantis.com
(905) 522-0012 x223

Water Environment Federation
the water quality people

89