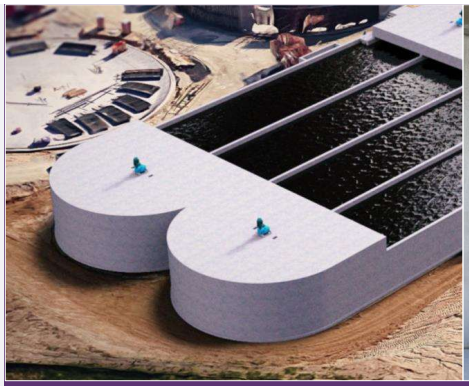
The Value of Thickened Aerobic Digestion In BNR Plants



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By: Elena Bailey, M.S., P.E.

The Evolution of Thickened Aerobic Digestion To Achieve Low TN and Low TP

Does Effluent Only Depend on the Main Biological Treatment Process?

Did you know…
We can improve the efficiency of BOTH the main treatment and dewatering processes without doing anything to either one of them?

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Does Effluent Only Depend on the Main Biological Treatment Process?

- Sidestreams from solids handling processes can impact the main treatment system
- For example, sidestreams from anaerobic digestion can add 10%-30% TN and TP load on the main plant

What Happens in Traditional Aerobic Digester Systems?
Do they negatively impact the Biological Process Treatment as well?

Aerobic Digestion/Aerated SHT – Decant

Facility	Total P (mg/L)	Ammonia (mg/L)	TN (mg/L)
North Branch, MN	104	23.30	41.10
Lyon, CO	64.4	26.00	48.50

- ✖ This load is highly concentrated. Decanting is typically done once a day at a high flow rate over a short time.
- ✖ HIGH O2 DEMAND: 4.6 lb O2 to oxidize 1 lb of NH3-N
- ✖ Is the main treatment system designed to handle this additional loading biologically? Typically it's not!
- ✖ Would chemicals need to be added to meet effluent limits?
- ✖ **Why pay twice to treat it?**

High TN and TP From solids handling is like the QB getting sacked

How to Improve Efficiency of Main Treatment Process?

How do we stop that? A successful quarterback needs a good offensive line to protect him!

A BNR Process, such as a Carrousel, needs optimizing the solids handling process to protect it and reduce both TN and TP impact to the liquid stream.

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BNR-1 and BNR-2

Main Process

BNR 1

+

Optimized Aerobic Digestion

BNR 2

=

Touch Down!

Aerobic Digestion Fundamentals - Chemistry
Necessary to Understand How To Optimize the Process

Aerobic Digestion is a biological process similar to Activated Sludge with the exception that…

Activated Sludge (Growth)

Aerobic Digestion (Decay)

Aerobic Digestion Fundamentals - Chemistry

1. Digestion:

$C_5H_7NO_2 + 5O_2 = 4CO_2 + H_2O + (NH_4HCO_3)$

Biomass — Ammonium Carbonate

2. Nitrification:

$NH_4^+ + 2O_2 = H_2O + 2H^+ + NO_3^-$

Ammonia — Acid — Nitrate

3. Digestion with Nitrification:

$C_5H_7NO_2 + 7O_2 = 5CO_2 + 3H_2O + HNO_3$

Biomass — Nitric Acid

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Aerobic Digestion Fundamentals - Chemistry

4. Digestion with Nitrification:

$C_5H_7NO_2 + 7O_2 = 5CO_2 + 3H_2O + HNO_3$

Biomass — Nitric Acid

5. Denitrification:

$C_5H_7NO_2 + 4NO_3^- + H_2O = NH_4^+ + 5HCO_3^- + 2N_2$

Biomass — Nitrate — Ammonia — Alkalinity — N Gas

6. Complete Nitrification / Denitrification:

$C_5H_7NO_2 + 5.75O_2 = 5CO_2 + 3.5H_2O + 0.5N_2$

Biomass — N Gas

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Aerobic Digestion Fundamentals - Chemistry

3. Digestion with Nitrification:

$C_5H_7NO_2 + 7O_2 = 5CO_2 + 3H_2O + HNO_3$

Vs.

6. Complete Nitrification / Denitrification:

$C_5H_7NO_2 + 5.75O_2 = 5CO_2 + 3.5H_2O + 0.5N_2$

18% Oxygen Savings

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Aerobic Digestion Process System
THE HOW

1. Series or Batch Operation
2. Thickening
3. Aerobic & Anoxic Operation
4. Temperature Control
5. Operational Flexibility

5 Key Techniques
Necessary for Optimum Results

Aerobic Digestion Process System
THE HOW

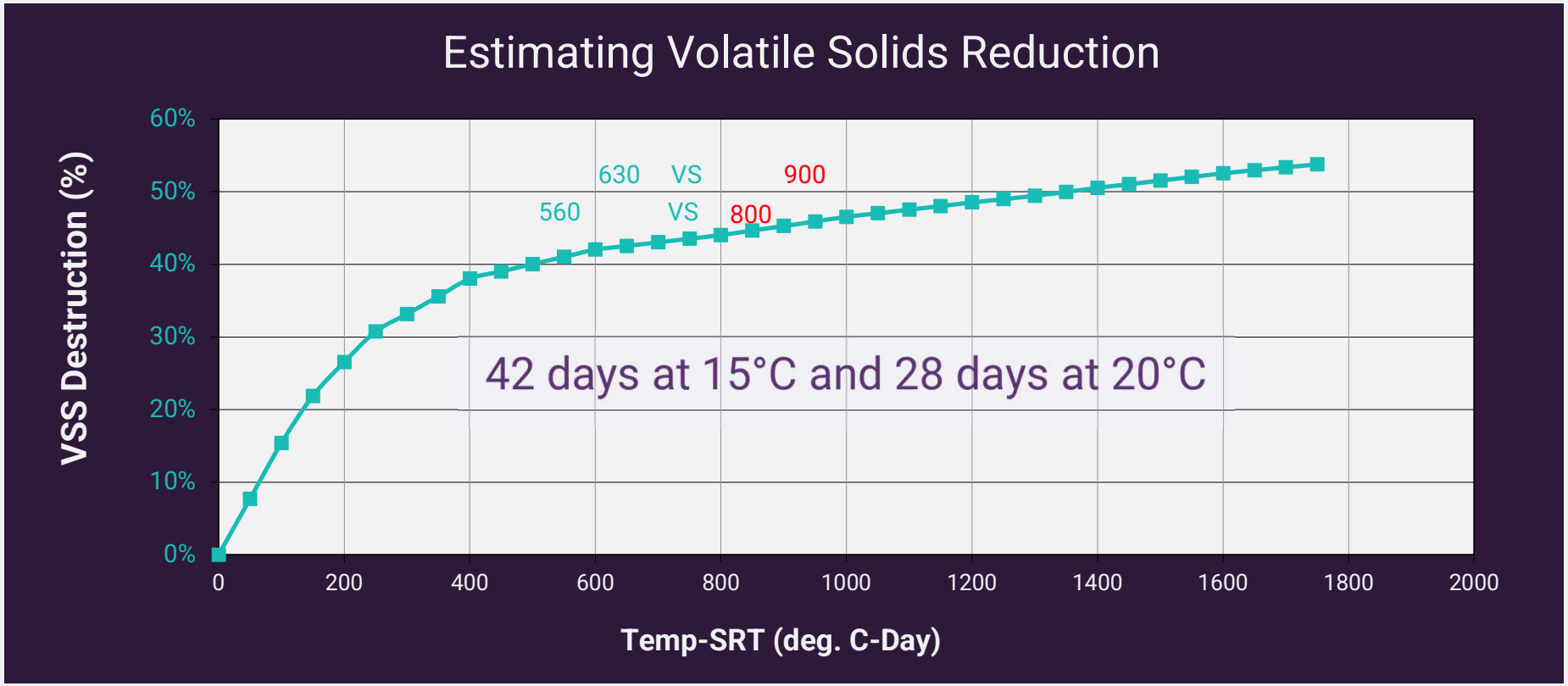
1. Series or Batch Operation

- Reduces short circuiting of partially digested sludge
- Improved kinetic reactions provide approximately 50% less volume to achieve same volatile solids reduction
- Provides a Time Temp credit of 30%. As a result, in Series Operations can meet the pathogen reduction requirements for Class B with only

  42 days at 15°C (630 days°C)

  28 days at 20°C (560 days°C)

1. Series or Batch Operation – Process Optimization
THE HOW



Ref: WEF MOP No. 8, Vol II, 1992

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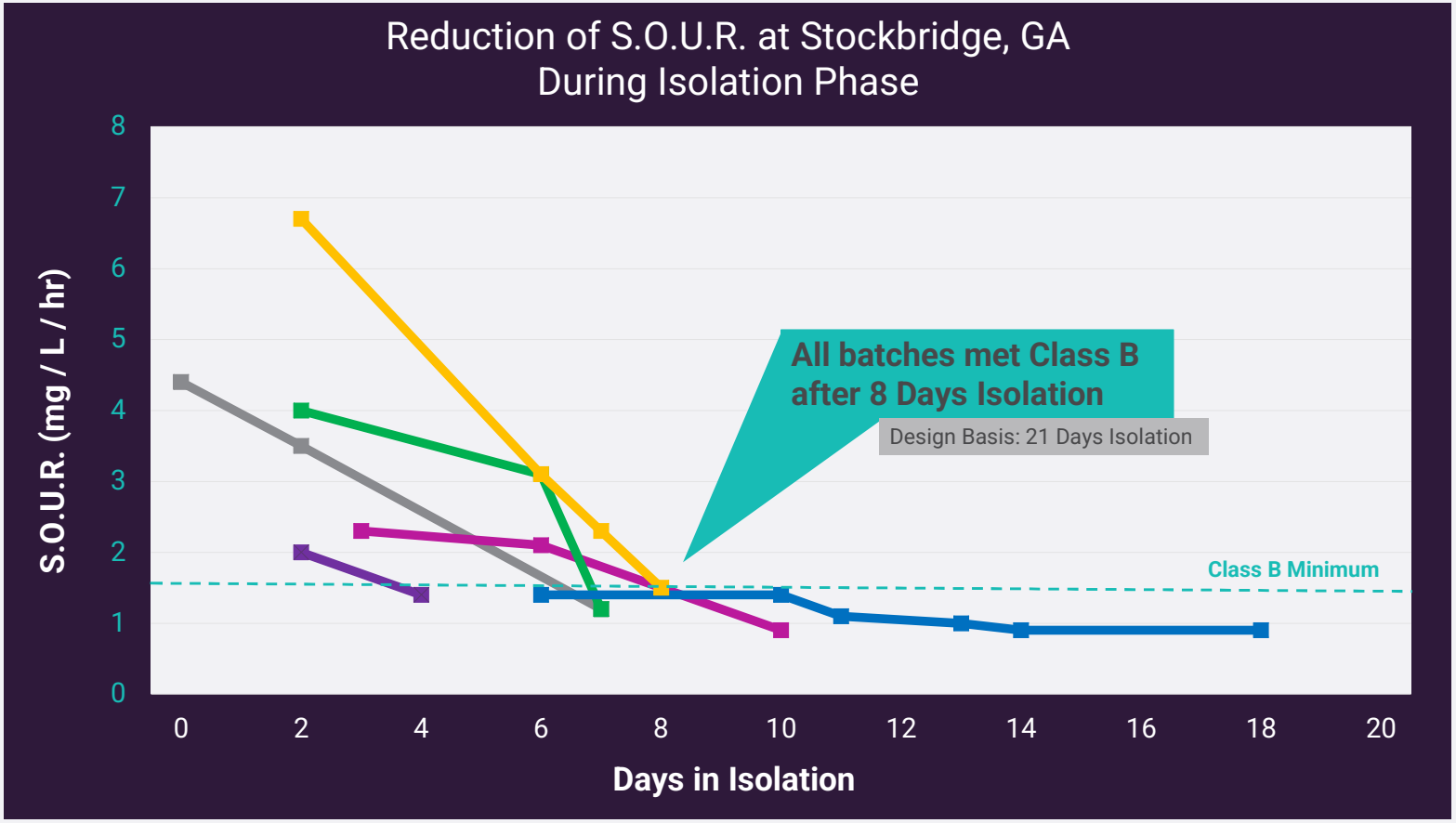
1. Series or Batch Operation – Process Optimization

Stockbridge, GA WWTP



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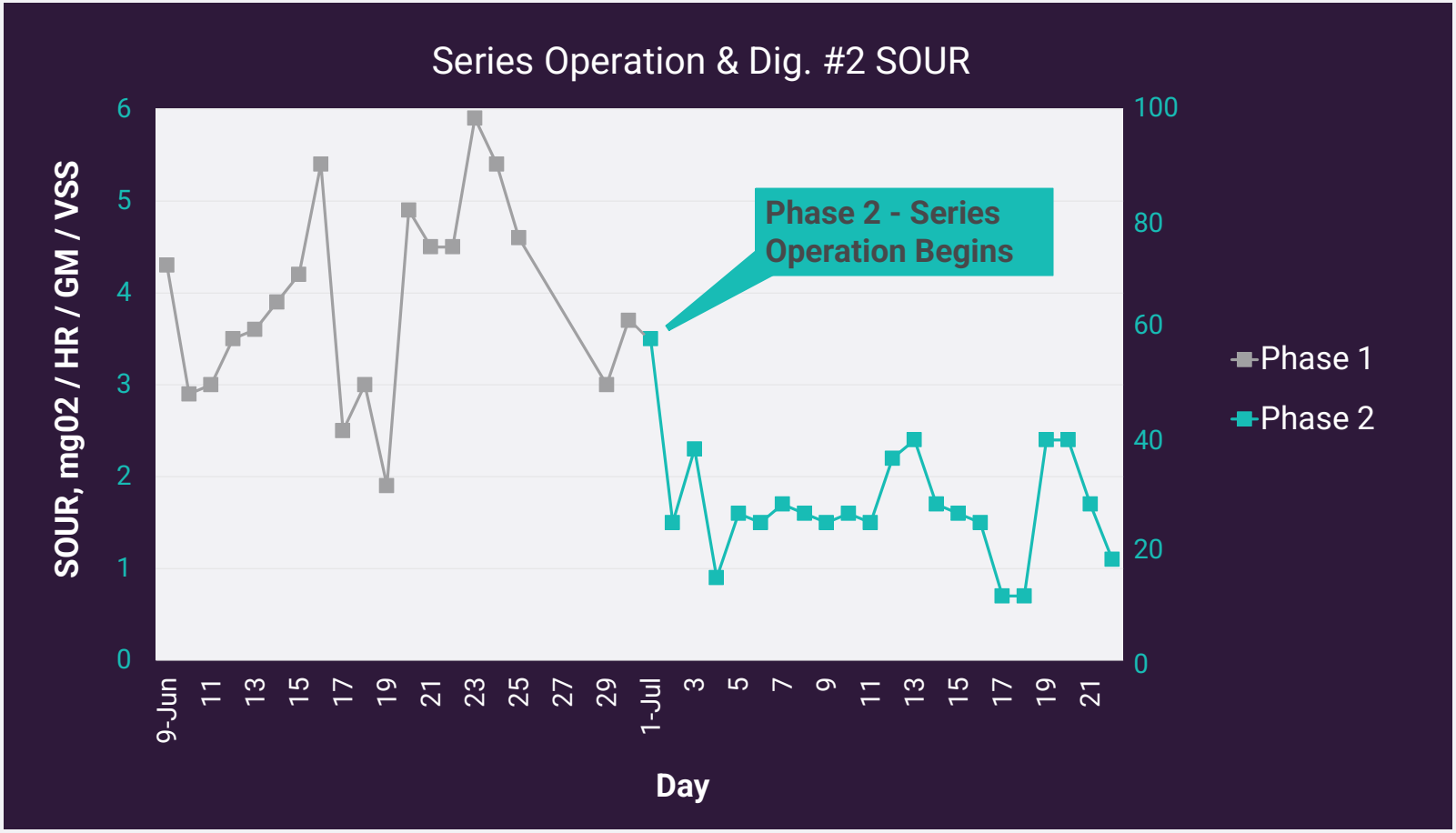
1. Series or Batch Operation – Process Optimization

Clyde, OH WWTP



Aerobic Digestion Process System
THE HOW

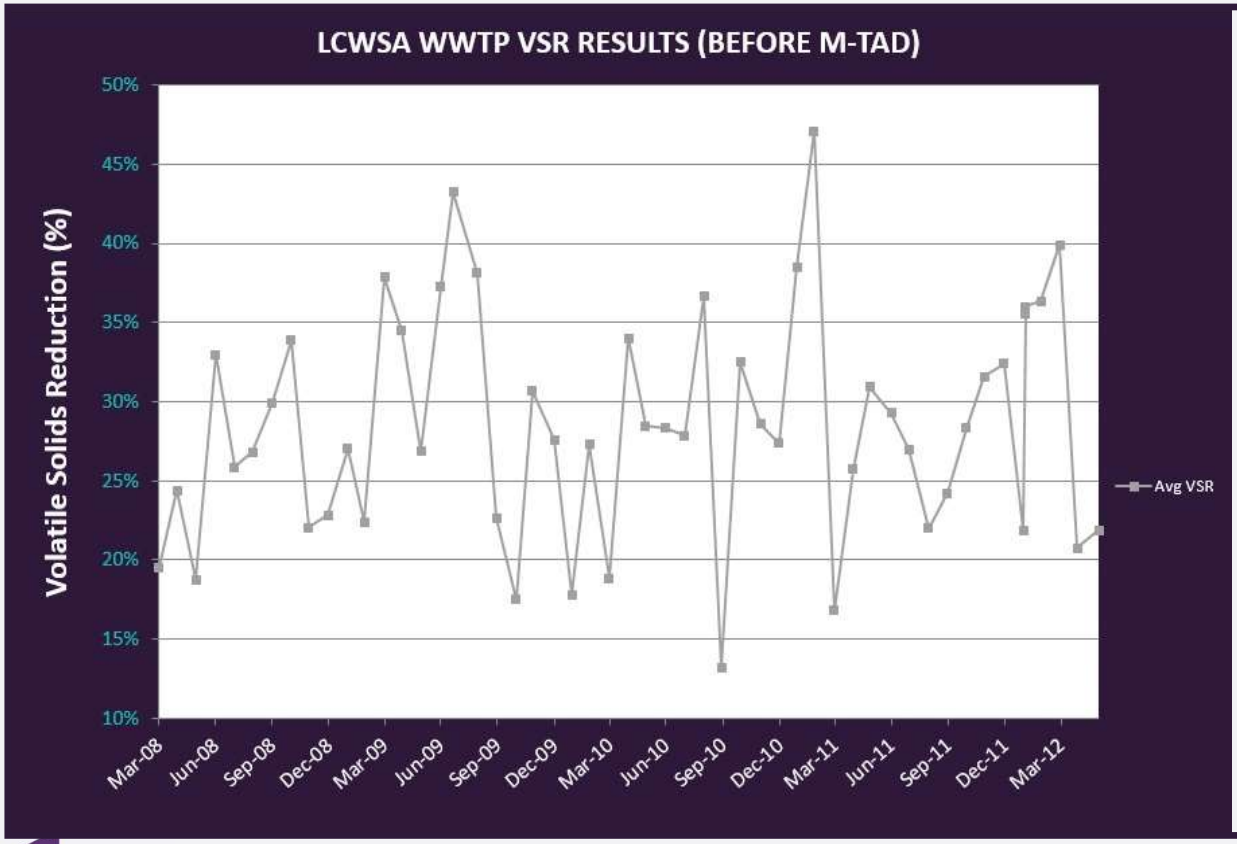
2. Thickening:

Volatile solids destruction is an exothermic reaction.
Thickening solids retains the heat from VS destruction more effectively

- Smaller sludge volume
- Smaller digesters
- Higher sludge temperatures

2. Thickening – Process Optimization

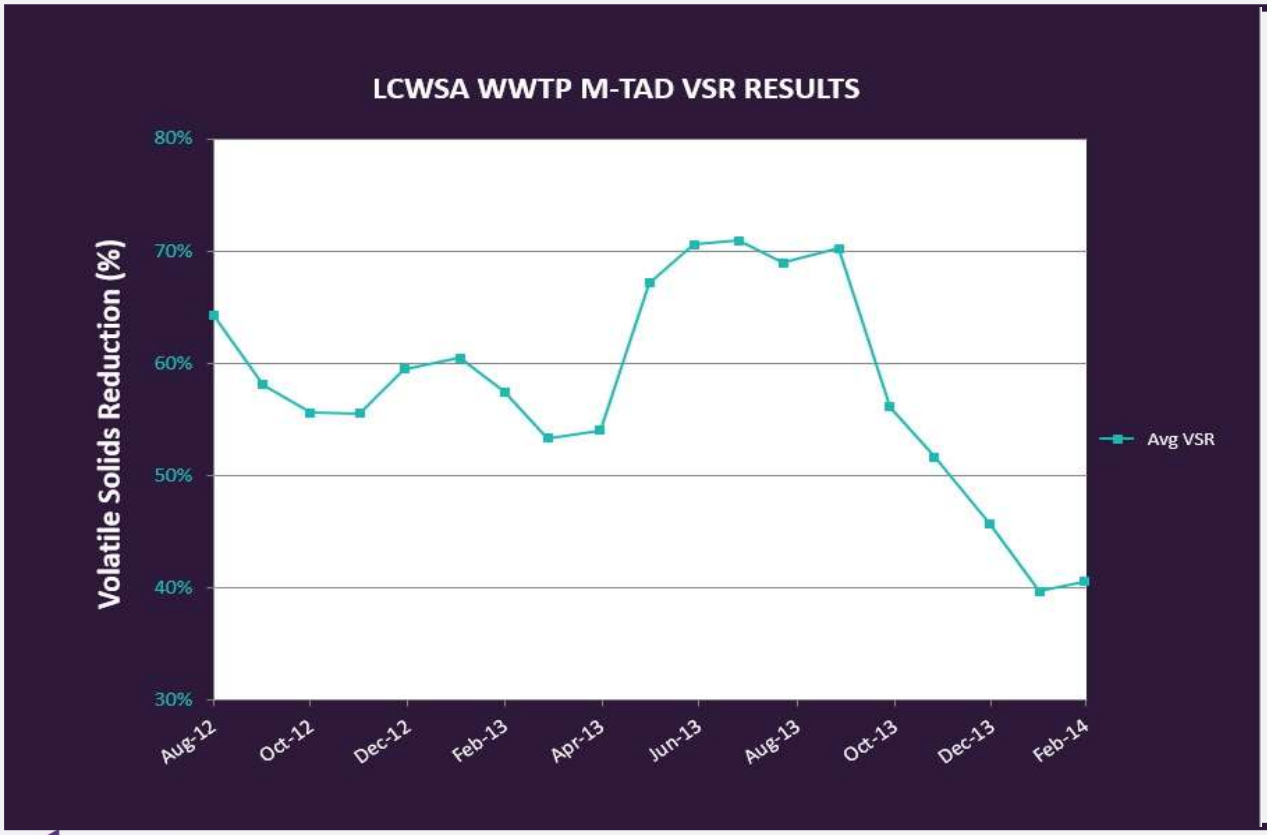
Lycoming County, PA WWTP – Results WITHOUT Thickening



- Un-thickened Aerobic Digestion System
- Floor Mounted Fine Bubble Diffuser Aeration System
- Average VSR of 29%
- Solids in Digesters were between 0.5% and 1.5%

2. Thickening – Process Optimization

Lycoming County, PA WWTP – Results With Thickening



- ✓ WAS thickened with GBT typically between 4% to 5%
- ✓ Single drops/shear Tubes
- ✓ VSR ranged between 40% and 71%
- ✓ More than 50% reduction of dry solids = $37,000 annual savings on disposal

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2. Thickening – Process Optimization

Cherokee WWTP, Iowa since 2006 - Results

- ✓ WAS thickened with Drum Thicker typically between 4% to 5%
- ✓ VSR ranged between 60-70%
- ✓ NH3-N in the range of 7-9 with average of 8.75

Aerobic Digestion Process System
THE HOW

3. Aerobic and Anoxic Operation

- Reduced total nitrogen
- Preserve alkalinity
- Control odors
- Provides an 18% savings in oxygen requirements
- Plants can meet/exceed the Class B requirements

3. Aerobic and Anoxic Operation – Process Optimization

Muncy, PA Facility

Muncy Aerobic Digester Operation Data
(January 2003 – April 2004)

Parameters	Warm Season	Cold Season
Monthly average SRT (days)	29 – 54	32 – 75
Temperature (°C)	22.5 – 30.5	15.5 – 22.5
Dissolved oxygen (mg/L)	0.3 – 2.1	0.5-3.4
VS reduction – Class B ≥ 38%	**69% – 84%**	**62% – 84%**
SOUR – Class B ≤ 1.5 mg/g/hr	**0.60**	**0.62**
F. Coliform – Class B ≤ 2 million/g TS		80,000
pH range	6.5 – 8.1	6.7 – 7.6
Average alkalinity (mg/L)	79 – 140	100 – 275
Average NH_3-N (mg/L)	**1.1 – 10**	**1.1 – 8.5**
Average NO_3/NO_2-N (mg/L)	**0 – 7**	**0 – 8.5**

- **Customized Aerobic and Anoxic Cycling**
- **Very low NH3-N and NO2-N observed**

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Aerobic Digestion – Process Optimization
THE HOW

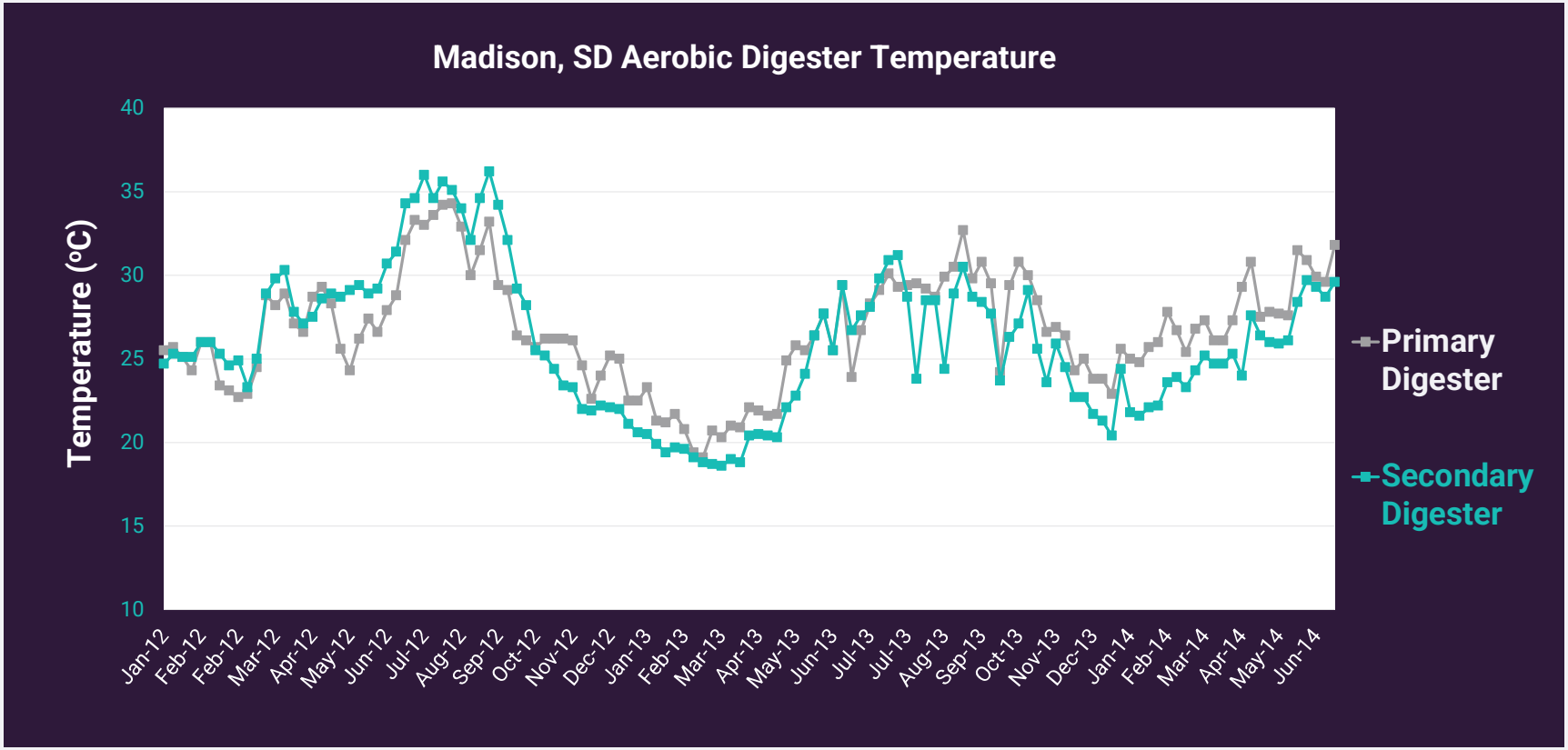
4. Temperature Control:

Mesophilic bacteria is very sensitive to temperature conditions.
Less then 15^{o}C nitrification and biological activity is hindered.
Temperature greater than 37^{o}C thermophilic bacteria begin to propagate.

- Increased digestion rate
- Consistent operation and performance year round
- Maintain healthy biomass

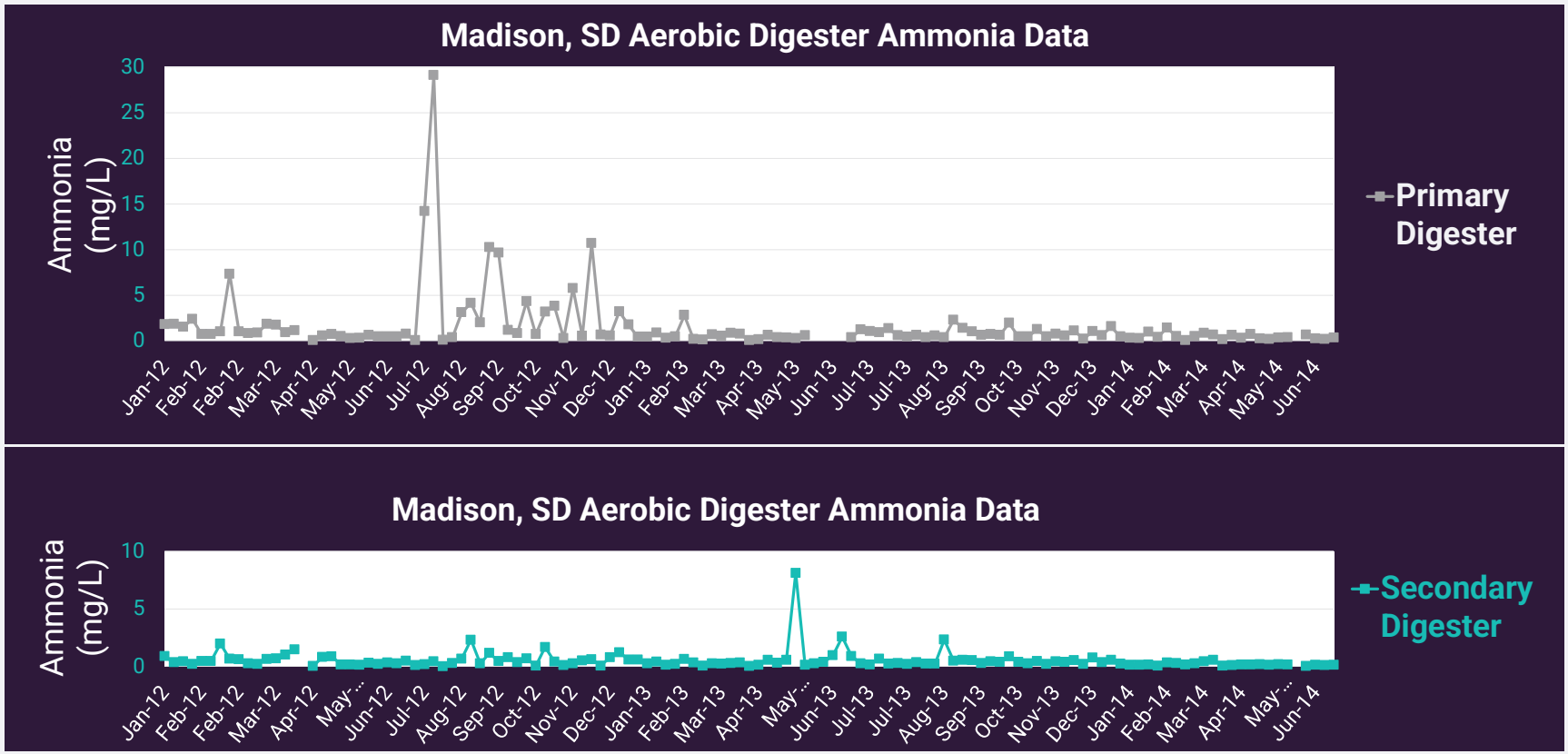
4. Temperature Control – Process Optimization

Madison, SD Facility



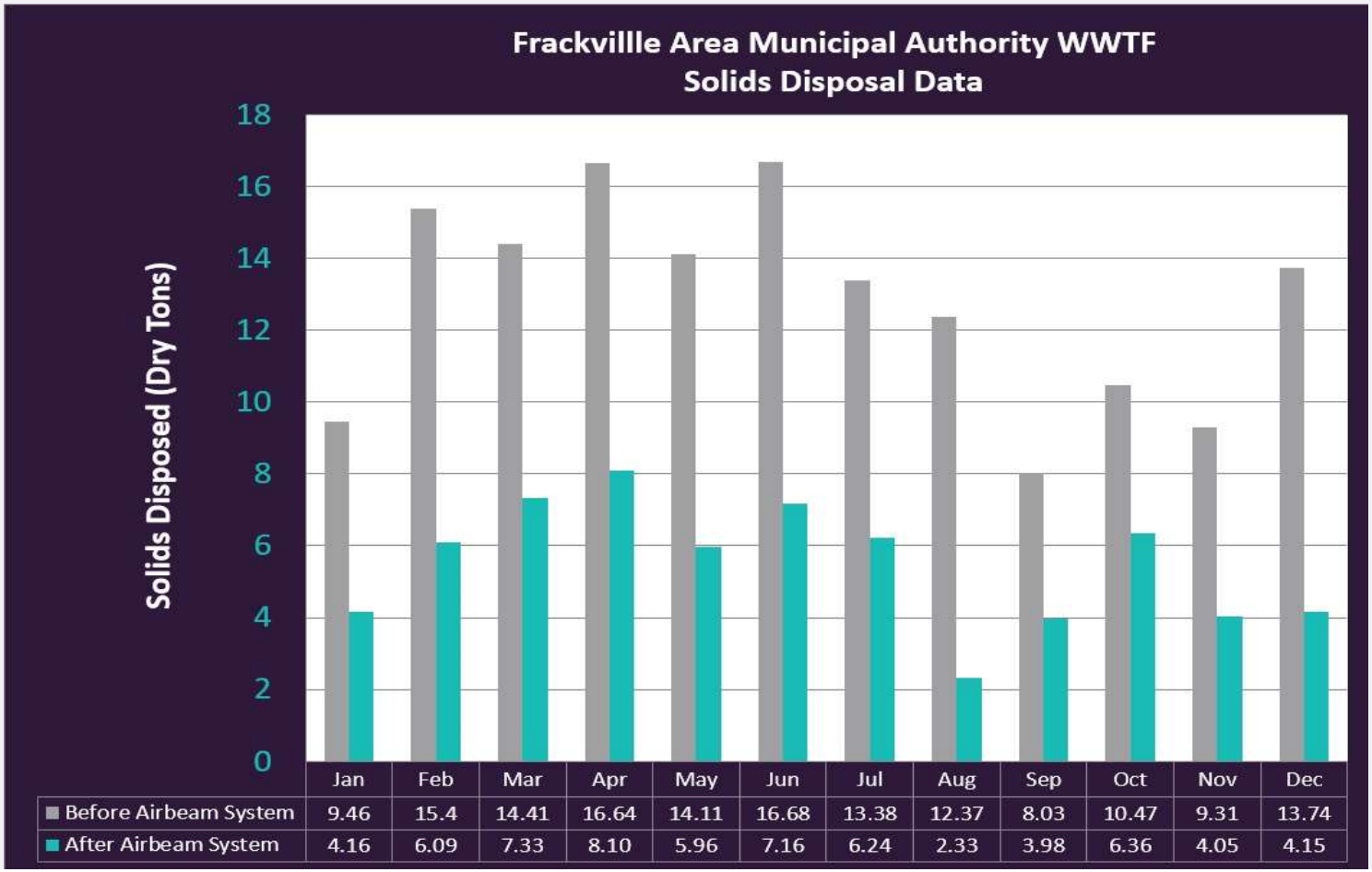
4. Temperature Control – Process Optimization

Madison, SD Facility – Nitrification Year Round



4. Temperature Control – Process Optimization

Frackville, PA Facility – Reduced Solids Disposal



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Before Airbeam System	9.46	15.4	14.41	16.64	14.11	16.68	13.38	12.37	8.03	10.47	9.31	13.74
After Airbeam System	4.16	6.09	7.33	8.10	5.96	7.16	6.24	2.33	3.98	6.36	4.05	4.15

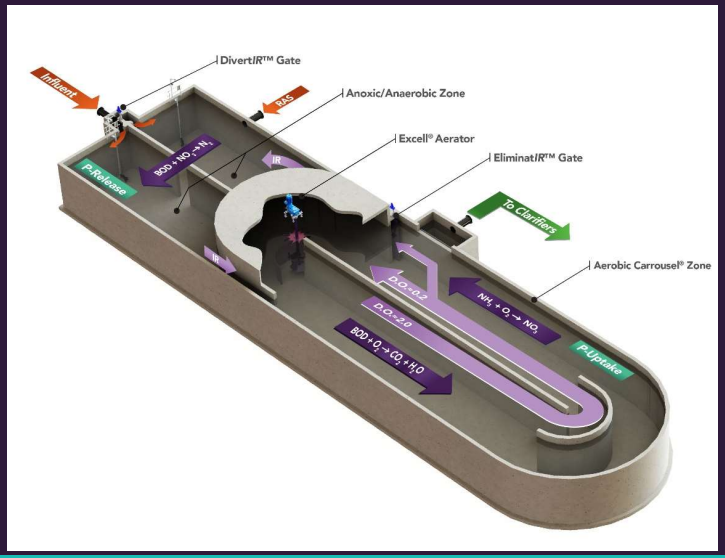
Aerobic Digestion – Process Optimization
THE HOW

5. Operational Flexibility

- Ability to monitor pH, T, and DO
- Ability to control sludge thickness
- Ability to control airflow to the digesters

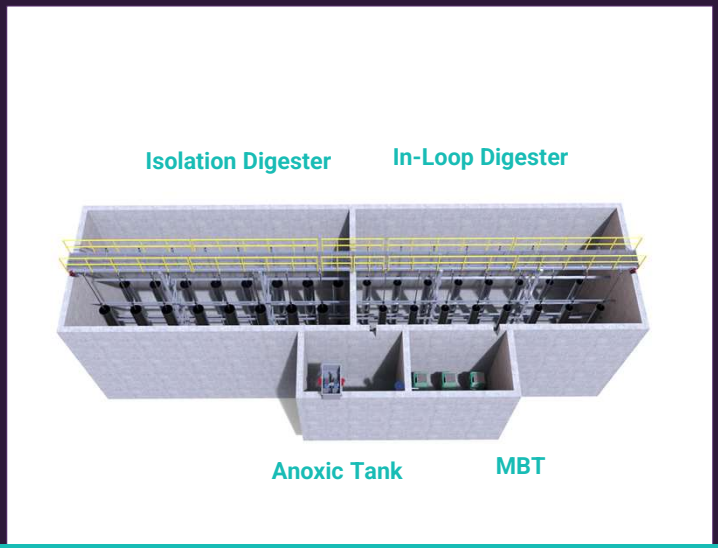
Membrane Thickened Aerobic Digestion for Low TN and Low TP

A biosolids process solution that integrates a controlled, well engineered, and optimized aerobic digestion process incorporating an SiC membrane thickening system



BNR 1

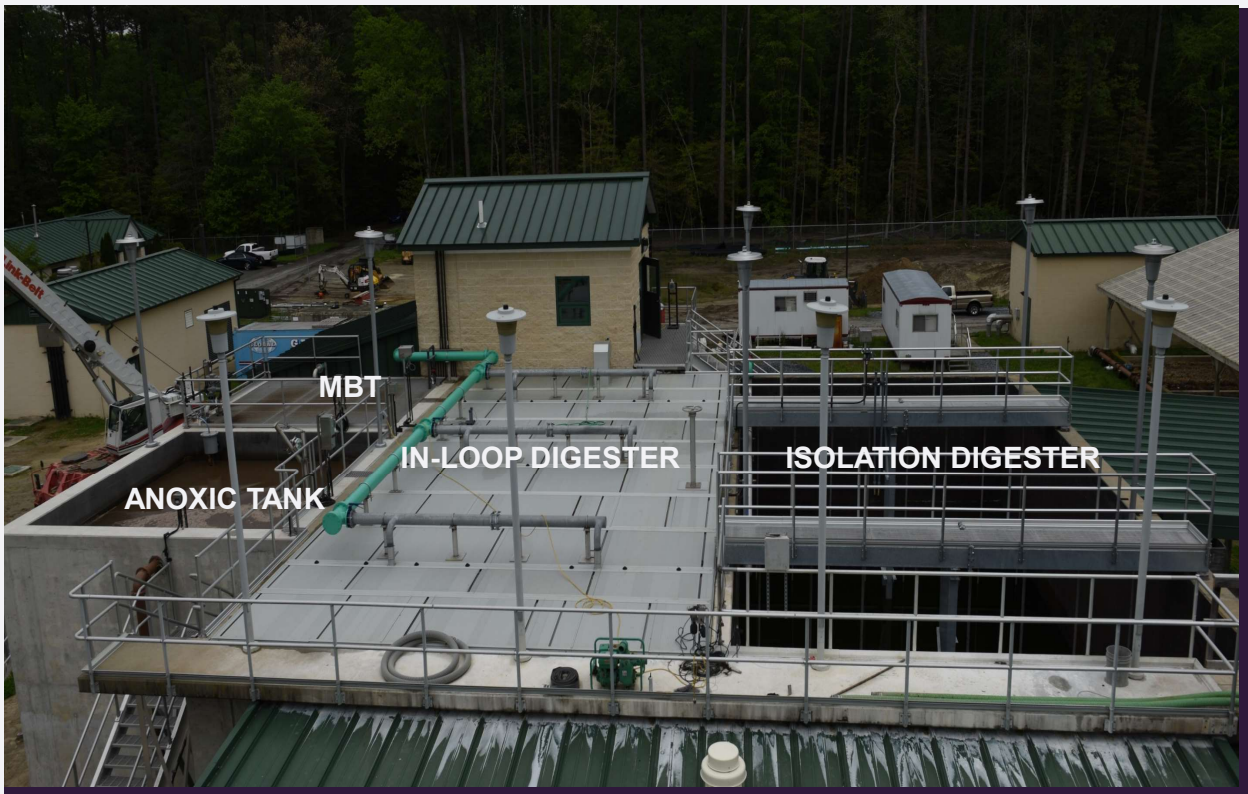
+



BNR 2

Membrane Digestion
Optimized Aerobic Digestion with Membrane Thickening

The FAB 5



1. **SERIES AND BATCH OPERATION:**
   Two digesters in series

2. **THICKENING:**
   Membranes used to thicken WAS and collect permeate with air to prevent P release

3. **AEROBIC/ANOXIC OPERATION:**
   Anoxic Tank built in to achieve DN

4. **TEMPERATURE CONTROL:**
   In-Loop Digester is covered

5. **OPERATIONAL FLEXIBILITY:**
   Pumps on VFDs to control sludge thickness.
   Blowers on VFDs for added airflow control.
   Instrumentation to monitor pH, DO, and ORP.

Membrane Digestion

Optimized Aerobic Digestion with Membrane Thickening

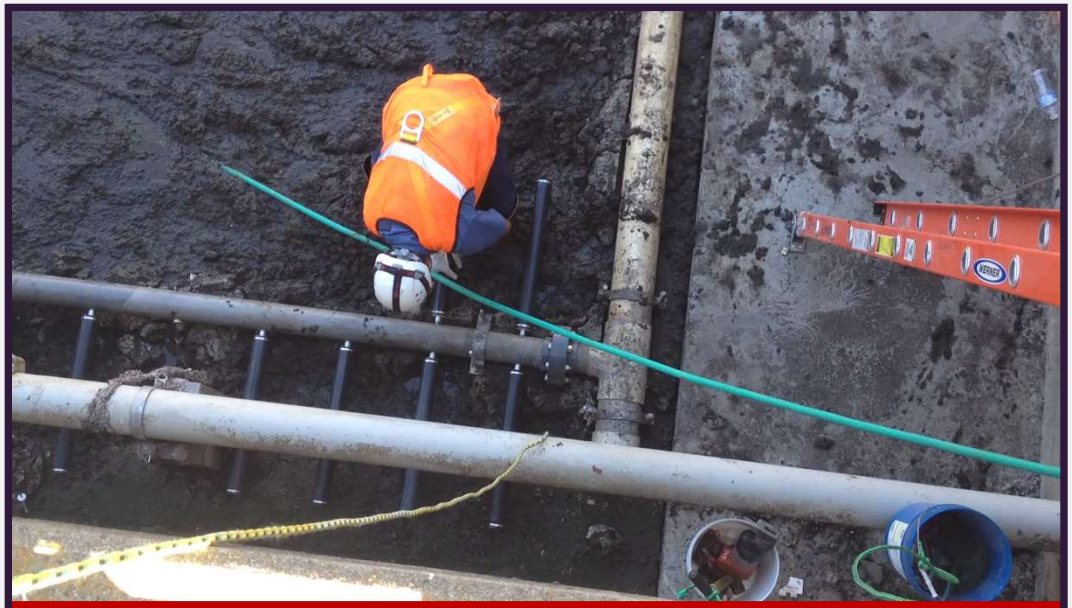
Two Key Ingredients Needed

SINGLE DROP DIFFUSER SYSTEM

SILICON CARBIDE MEMBRANE

Importance of Aeration to Aerobic Digestion

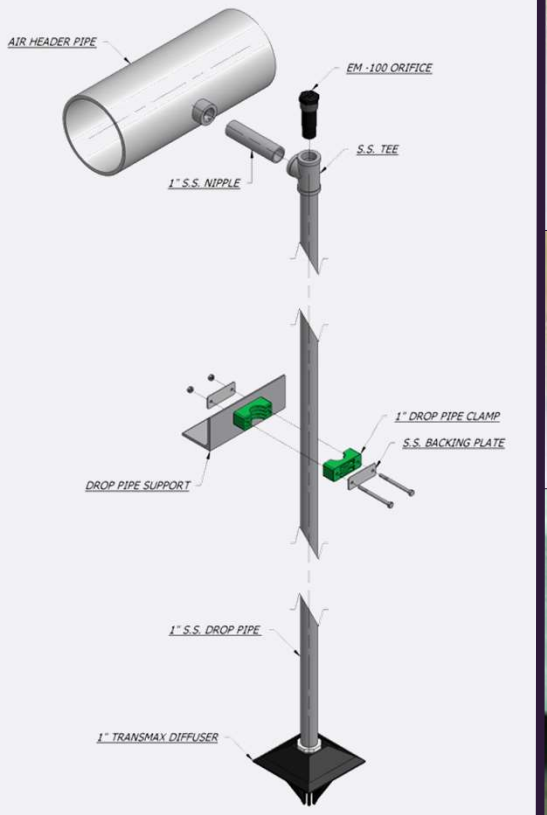
Below water orifices can accelerate fouling in diffusers. What is the impact?



Diffusers get damaged = Added costs to replace diffusers and O&M costs.

Diffusers get clogged = Have to drain tank and clean diffusers. Added O&M Costs

Perfect Diffuser for Thickened Aerobic Digestion
Single Drop Diffuser



TRANSMAX DIFFUSER ASSEMBLY - TYPICAL

- ✓ Non Clog Design
- ✓ Robust (should last at least 20 years)
- ✓ Orifice is accessible and not submerged in liquid level
- ✓ Does not require tanks to be drained or taken out of service for maintenance
- ✓ 1,000+ installations in US

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Perfect Diffuser for Thickened Aerobic Digestion

Shear Tube and Draft Tubes

SHEAR TUBES	DRAFT TUBE
	

When Combined with Single Drops can mix and aerate up to 4% solids

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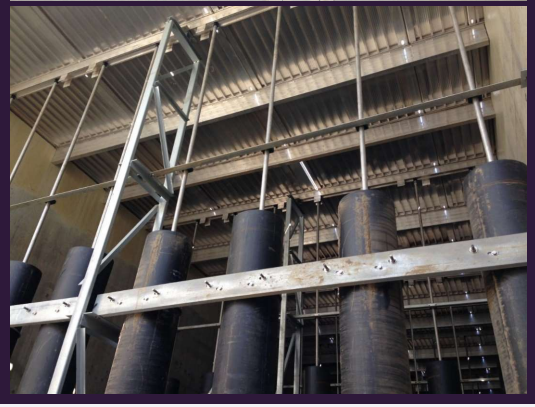
Perfect Diffuser for Thickened Aerobic Digestion

Airbeam Cover

This Aeration System Provides Optimum Odor and Temperature Control Performance

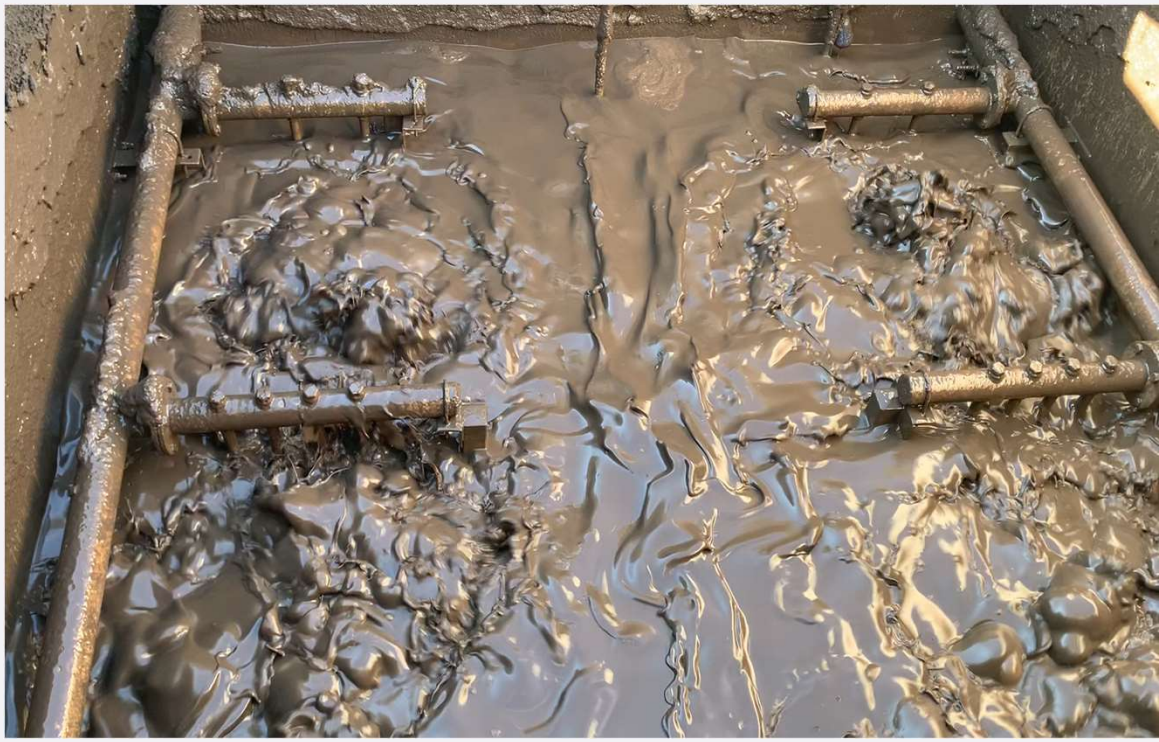


Silicon Carbide Membranes

Silicon Carbide Ceramic Membranes (SiC) - Distinct Performance Advantages

Ceramic membranes offer distinct performance advantages

- Completely hydrophilic
- Extremely durable
- High solids tolerance
- High temperature and chemical tolerance



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Silicon Carbide Membranes

SiC Membrane Components

SiC Flat Plate

SiC Membrane Module (40 Plates)

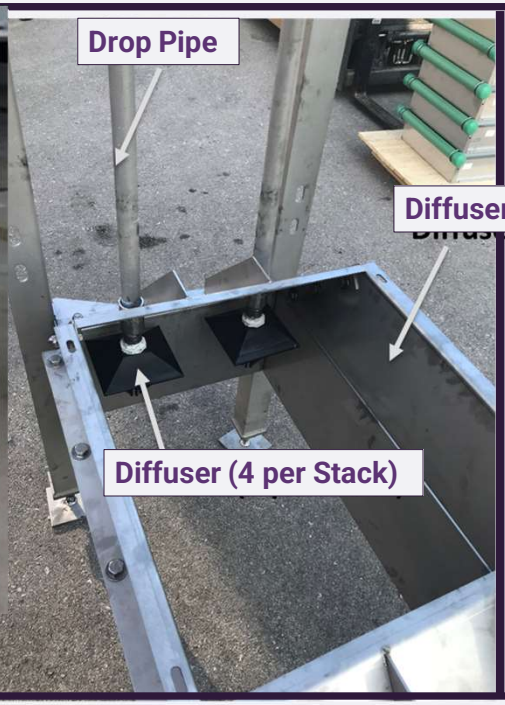
SiC Membrane Stack

Silicon Carbide (SiC) Membrane Components

Silicon Carbide Membranes

How Does Membrane Thickening Work?

Diffuser Base and Skirt



- Solids are rejected by membrane and biofilm. Permeate moves through plenum to common manifold and drawn out under vacuum.
- Single drop air diffusers are incorporated with the stack for membrane scour
- Permeate is recycled to head of the plant or sent directly to disinfection

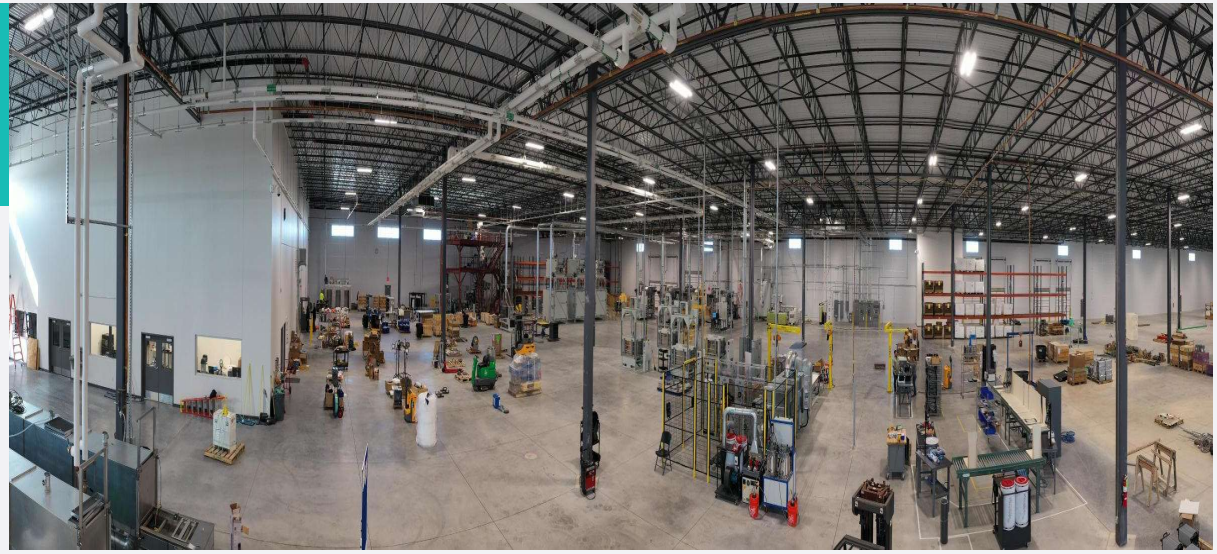
How Does Sludge Get Thickened With a Membrane?

Silicon Carbide Membranes

SiC Membrane Technology

The Silicon Carbide Membrane Unit
Each Module Contains 40 Plates for Total Filtration Area of 65 ft²
2 mm Screening
Silicon Carbide (SiC)
Flux = 30 gfd @ 20 C and 2% Solids
Flux = 15 gfd @ 20 C and Greater than 3% Solids
Pore Size – 0.1 mm
Expected Life = 10-20 Years

First SiC manufacturing plant in USA, March 1st 2023



Membrane Thickening Aerobic Digestion History

- It combines our years expertise on both membranes and aerobic digestion
- First US install of this product was Dundee, MI in 2005 with flat plate membranes
- Largest installation at Cayce, South Carolina (25 MGD Plant)
- Have 50+ installations (SiC and Polymeric combined)

Membrane Thickened Digestion Process

Life Cycle Cost Comparison with Traditional Digester Systems

Traditional Digester

Membrane Thickening Digestion

Membrane Thickened Digestion Year Life Cycle Costs

MBT Digestion vs Conventional Aerobic Digestion

Conventional Aerobic Digestion

DESIGN CONDITIONS	
Class B Biosolids	
Process Air Requirement of 2 lb O2/lb VS destroyed	
20 Year Life Cycle	
Sludge is dewatered with belt press to 16% cake solids and land applied	
DESIGN PARAMETERS	
Plant Flow (MGD)	4
BOD Conecentration (mg/L)	250
Sludge Yield (lb WAS/lb BOD)	0.7
WAS Loading Rate (ppd)	5,838
Required SRT (days)	42

Standard Aerobic Digestion – Decant to 2% solids

Membrane Digestion System – Thicken to 3% solids

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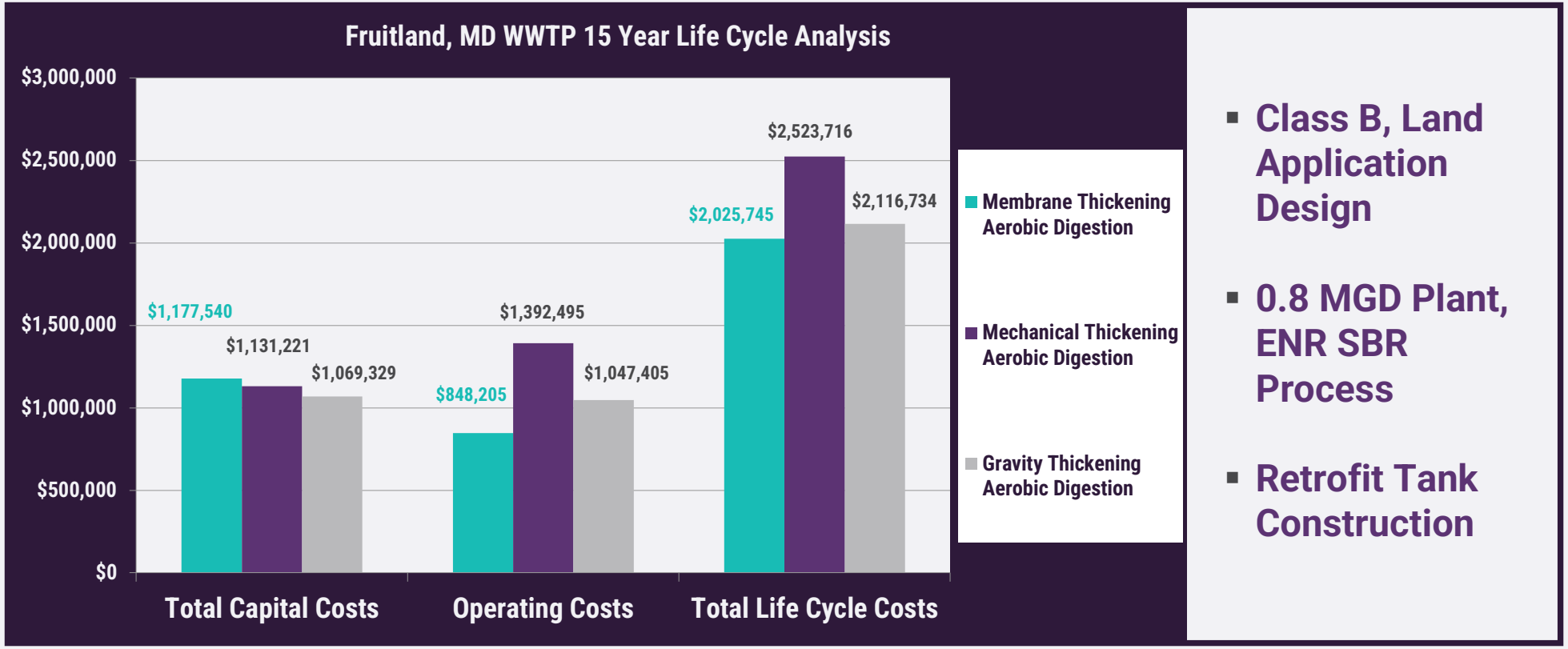
Membrane Thickened Digestion 20 Year Life Cycle Costs

Membrane Thickened Digestion vs Conventional Aerobic Digestion

20 YEAR LIFE CYCLE COST COMPARISONS		
MEMBRANE THICKENING AEROBIC DIGESTION		
Equipment Costs	$1,500,000	
Process Tank Costs	$926,667	Concrete Costs are $1,000/cubic yard
Total Capital	$2,426,667	Includes Equipment, Building, and Process Tank Costs
Operating	$264,000	Includes Chemical and Operating Costs
Membrane Replacement Costs	$144,000	
Disposal	$1,116,582	Based on $50/ton and $4/lb polymer
Energy	$1,631,126	Based on $0.06/KWH
Total Costs	**$5,582,374**	
STANDARD AEROBIC DIGESTION		
Equipment Costs	$500,000	
Process Tank Costs	$1,326,000	Concrete Costs are $1,000/cubic yard
Total Capital	$1,826,000	Includes Equipment, Building, and Process Tank Costs
Operating	$468,000	Includes Chemical and Operating Costs
Disposal	$1,151,484	Based on $50/ton and $4/lb polymer
Energy	$2,195,747	Based on $0.06/KWH
Total Costs	**$5,641,231**	

Membrane Thickened Digestion Process

Life Cycle Cost Analysis: Retrofit Example



- Class B, Land Application Design
- 0.8 MGD Plant, ENR SBR Process
- Retrofit Tank Construction

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Life Cycle Analysis by Consulting Engineer

Sidestream Performance Comparison

Membrane Digestion vs Conventional

Membrane Thickening Process – Permeate			
Facility	**Total P (mg/L)**	**Ammonia (mg/L)**	**TN (mg/L)**
Cayce, SC	1.14	-	<5.0
Dundee, MI	1.09	0.22	<1.0
Union Rome, OH	5.0	<0.1	<1.0
Dickinson, ND	4	2.17	<5.0

Aerobic Digestion – Decant			
Facility	**Total P (mg/L)**	**Ammonia (mg/L)**	**TN (mg/L)**
North Branch, MN	104	23.30	41.10
Lyon, CO	64.4	26.00	48.50

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Solids Management
Are we done after the solids are digested?

Solids Management is critical! Typically 50% of Plants O&M Expenditures

Aerobic Digester

Sludge Dewatering
- Polymers can cost up to $50/dry ton solids
- Significant O&M required

Solids Disposal
- Limited Disposal Options
- Landfills limiting how much solids they are accepting
- Disposal can cost up to $100/wet ton of solids

Reduced Disposal and Improved Dewatering Operations
McFarland Creek, OH Facility

McFarland Creek WWTP Improved Dewatering Operations

Annual BFP run time w/o Membrane Digestion	8,736 hours
Annual BFP run time with Membrane Digestion	3,744 hours
Reduction BFP run time	57.14%

MORE EFFICIENCY MEANS BETTER RESULTS……

41% Reduction in CUBIC YARDS PRODUCED

36.5% Reduction in DRY TONS PRODUCED

41% Cost Reduction in POLYMER ($18,000 Annual Savings)
41% Cost Saving in SLUDGE DISPOSAL ($34,465 Annual Savings)
1.37% Improved Dewatering Cake (18.85% vs 17.48%)

Membrane Thickened Digestion Process

Improved solids management

Reduced Solids Disposal

- Improves digestion by increasing capacity of reactors
- Can improve dewatering operations: reduces polymer, disposal, and run time
- Reduced hauling costs

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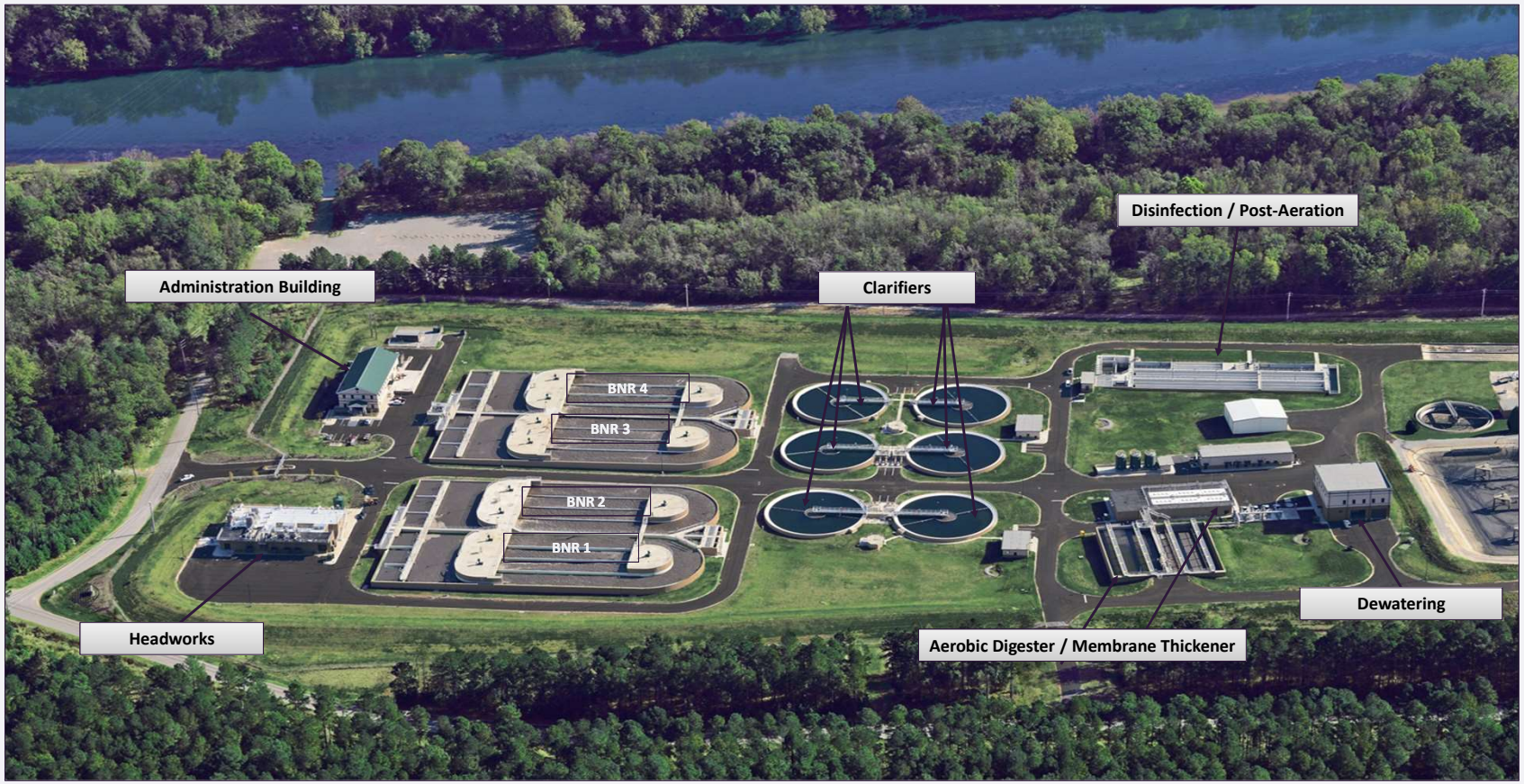
Membrane Thickened Aerobic Digestion Process
Cayce, SC Case Study

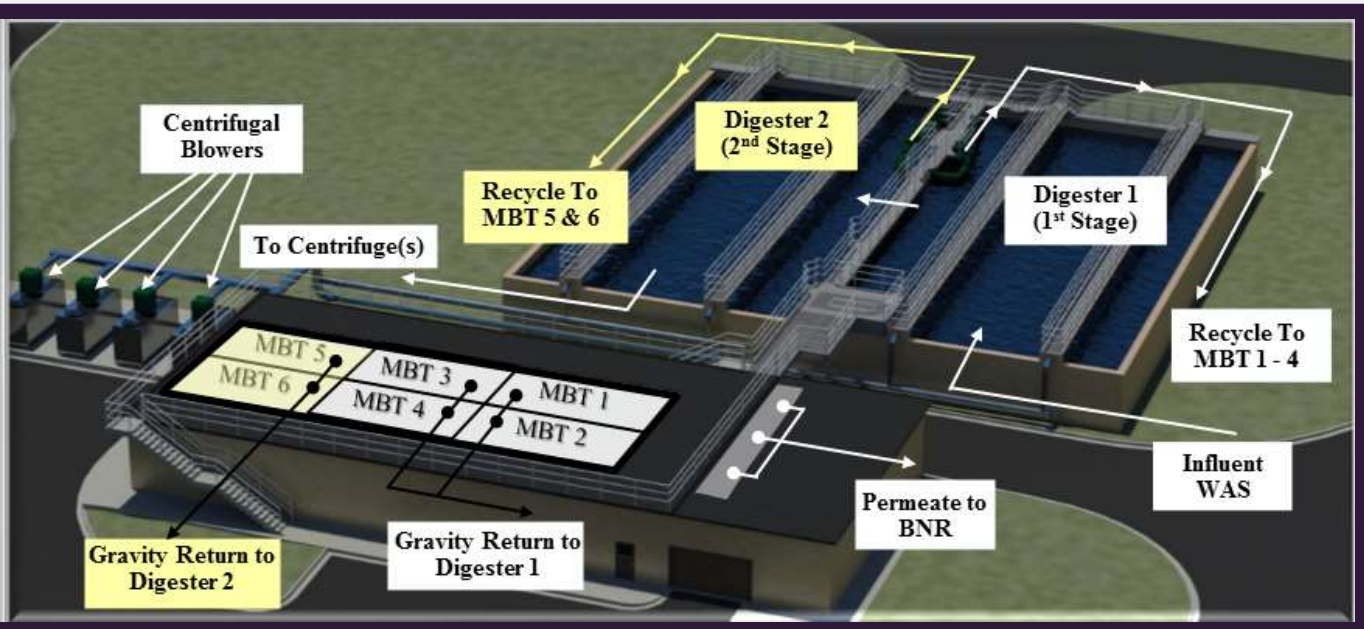


Membrane Thickened Aerobic Digestion Process
Cayce, SC Case Study – 25 MGD with TP less 1

Background and Design Criteria

- Start-up Flow = 8 MGD, Design Flow = 25 MGD
- Phosphorus limits important factor in selection of solids handling process
- Conventional Aerobic Digestion w/settling and decanting cycles lead to release of captured phosphorus in solution
- Compliment BNR process designed for phosphorus removal and minimize expenses to remove twice

Membrane Thickened Aerobic Digestion Process
Cayce, SC Case Study



Start-up Plant Flow	-	8 MGD
Intermediate Plant Flow	-	12 MGD
Design Influent Plant Flow	-	25 MGD
WAS concentration	-	10,000 mg/l
Design digestion SRT	-	20 days

Dig. 1 Loops w/MBT 1 – 4 Thickening To 2%
Dig. 2 Loops w/MBT 5 & 6 Thickening To 4%

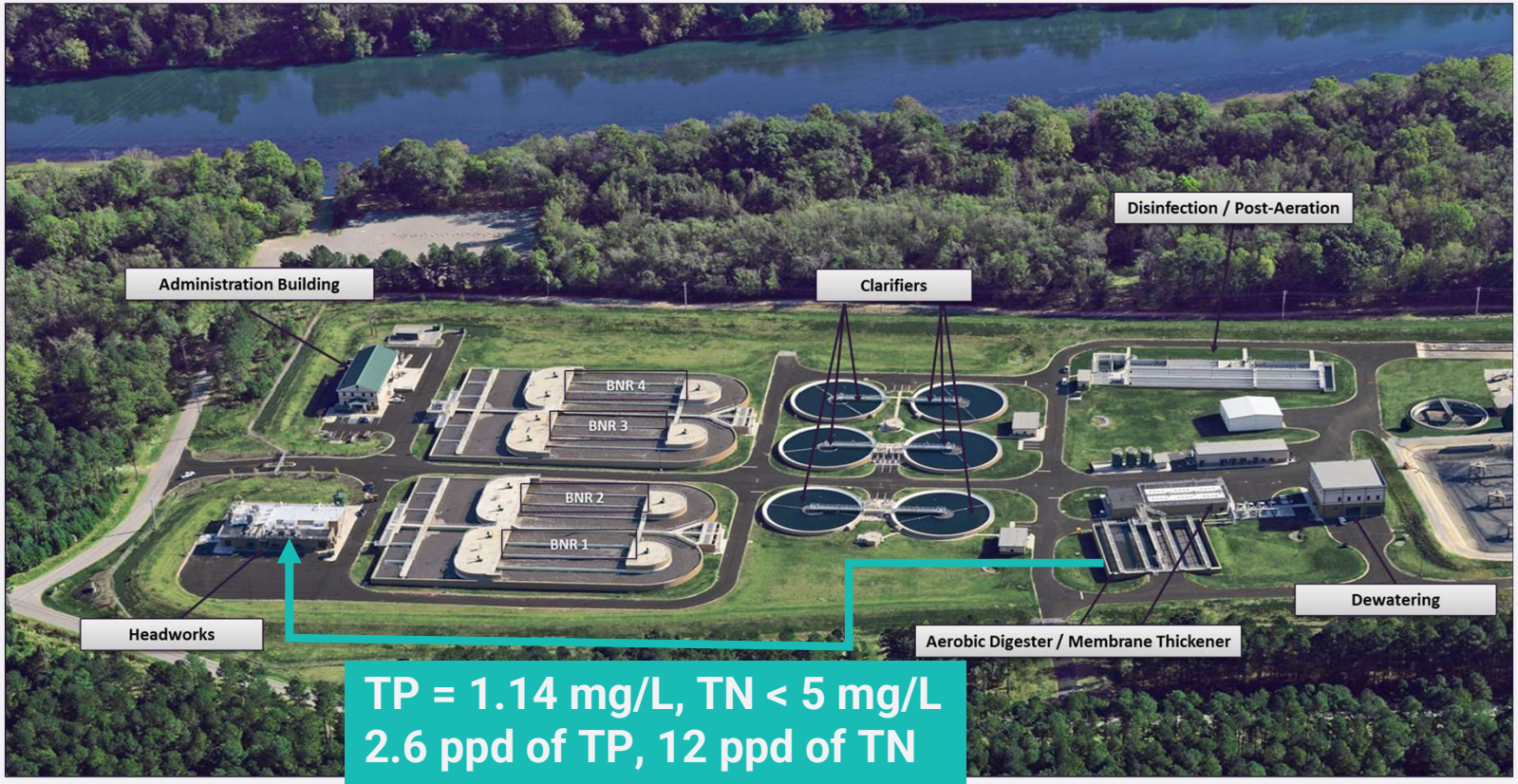
Membrane Thickened Aerobic Digestion Process

Cayce, SC Case Study

Effluent Phosphorous Data from the Membrane Digestion Permeate Collection Pipe for the Month of January 2014

Date	Phosphorus (mg/l)
01/01/14	2.10
01/03/14	1.40
01/06/14	1.60
01/10/14	1.10
01/14/14	0.80
01/20/14	0.50
01/22/14	1.10
01/24/14	1.20
01/27/14	0.50
Aver. January	1.14

Membrane Thickened Aerobic Digestion Process
Cayce, SC Case Study



TP = 1.14 mg/L, TN < 5 mg/L
2.6 ppd of TP, 12 ppd of TN

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Membrane Thickened Aerobic Digestion Process
Cayce, SC Case Study

- ✓ **2014 – AAEE**
  Grand Prize Award
  Small Firm American Academy of Environmental Engineers

- ✓ **2014 – ACEC**
  Engineering Excellence Award
  American Council of Engineering Companies of SC

Membrane Thickened Aerobic Digestion Process
Cayce, SC Case Study

Benefits:

1. Eliminated Construction of a thickener building
2. Reduced number and size of digesters by operating at 4% TS
3. Provided flexibility for a gradual flow increase.
4. Reduced O&M by eliminating use of polymers required for thickening
5. Class B Biosolids Stabilization
6. Permeate can be re-used

THESE FACTORS LEAD TO SUBSTANTIAL COST SAVINGS!

Membrane Thickened Digestion Process is Ideal for BNR Plants

Ideal to protect BNR-1

- High Quality Permeate
- Typical TN and TP of 5 mg/L or less without chemical addition (~1%-5% of overall plant flow)
- Reuse quality that can be recycled to head of plant, combined with effluent, or sent to disinfection
- Protects effluent quality of BNR Process