Anaerobic Sludge Digestion Process

Prepared By
Michigan Department of Environmental Quality
Operator Training and Certification Unit

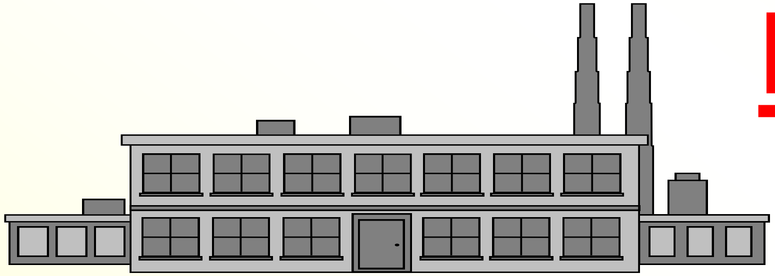
WASTEWATER

Water used to carry waste products away from homes, schools, commercial establishments, and industrial enterprises.

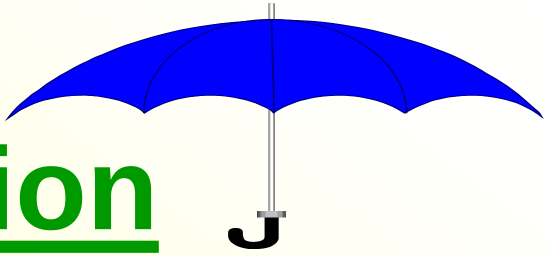
Sources of Wastewater

Domestic

Industrial



Infiltration



CHARACTERISTICS OF WASTEWATER

Materials Toxic to Biota

- Metals
- Ammonia
- Pesticides
- Herbicides
- Chlorine
- Acids/Bases

Human Health Hazards

- Pathogens
- Nitrate
- Toxic Materials

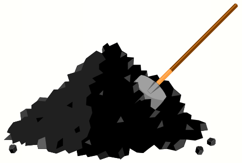
GOAL – PURPOSE – RESPONSIBILITY
Of
“Treating” or Stabilizing Wastewater

PROTECTION OF NATURAL RESOURCES

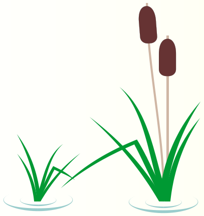
PROTECTION OF PUBLIC HEALTH

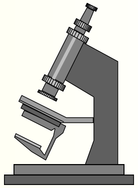
CHARACTERISTICS OF WASTEWATER

Treatment Concerns

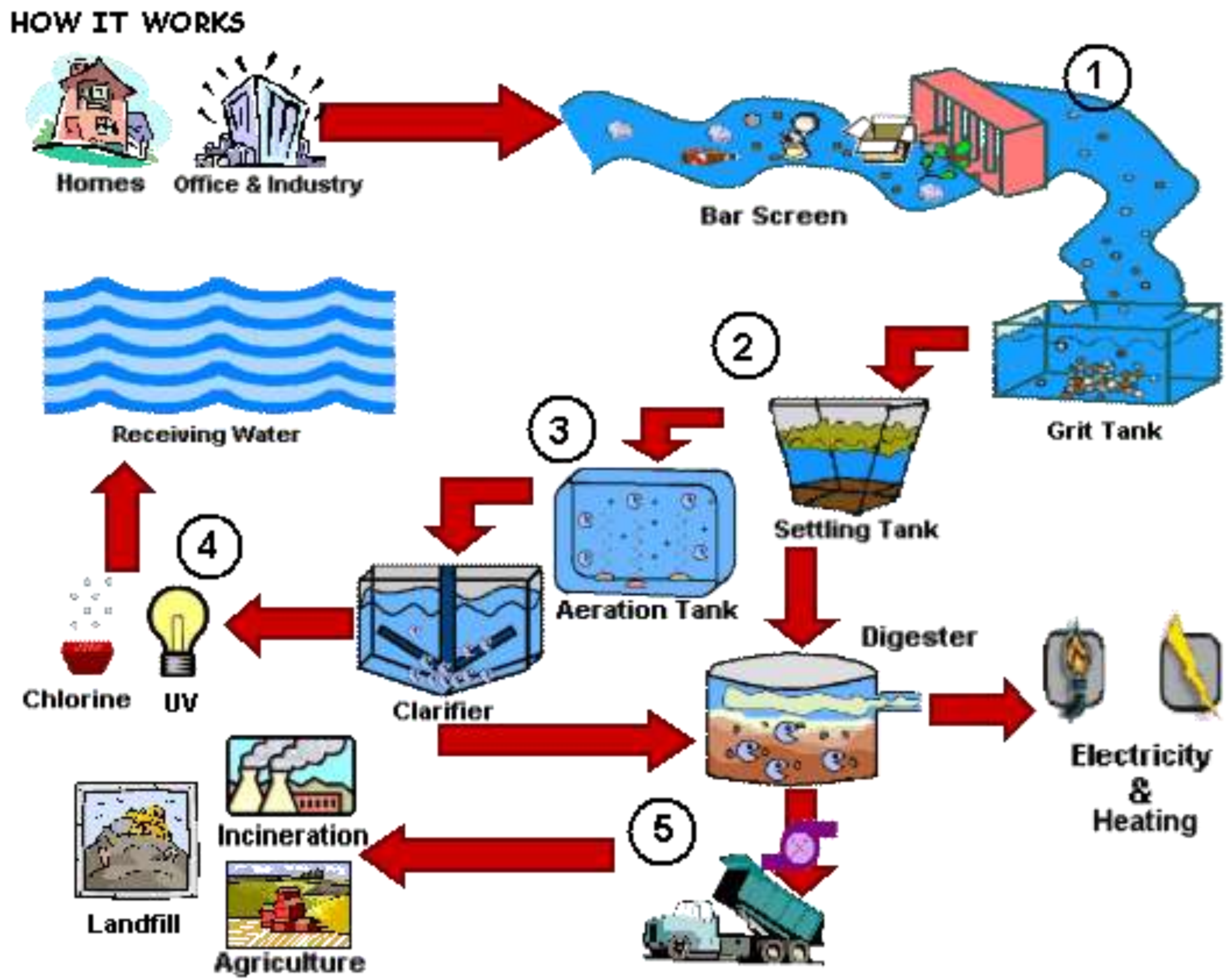
Solids 

 Oxygen Demand

Nutrients 

 Microorganisms

Wastewater “Treatment” Removes These “Pollutants”



Wastewater Treatment Processes

- **Physical / Chemical**
  - screening
  - sedimentation
  - filtration
  - precipitation
  - chemical destruct

- **Biological**
  - waste stabilization lagoon
  - trickling filter
  - rotating biological contactor
  - activated sludge

Treatment Efficiencies

Primary (Physical) Treatment

40 - 60 % Suspended Solids

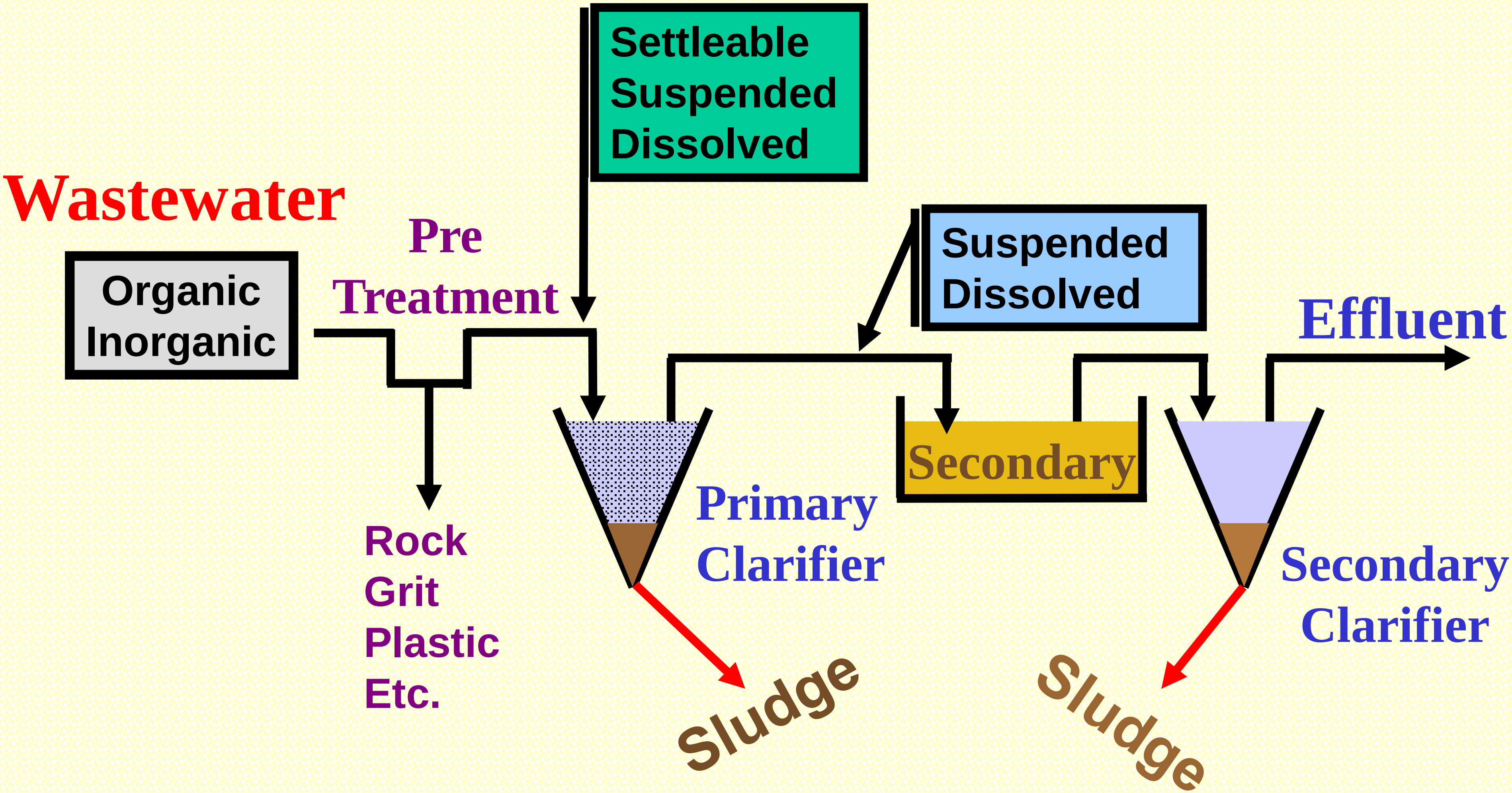
30 - 40 % BOD

Secondary (Biological) Treatment

90+ % Suspended Solids

90+ % BOD

Removal of These "Pollutants" Produces "Residuals" Often called "Sludge"



Note: These residuals are sometimes called "Biosolids", however that term is usually reserved for sludge that has been "stabilized" and meets specific requirements (pathogen reduction, vector attractions, metals concentration)

SLUDGE

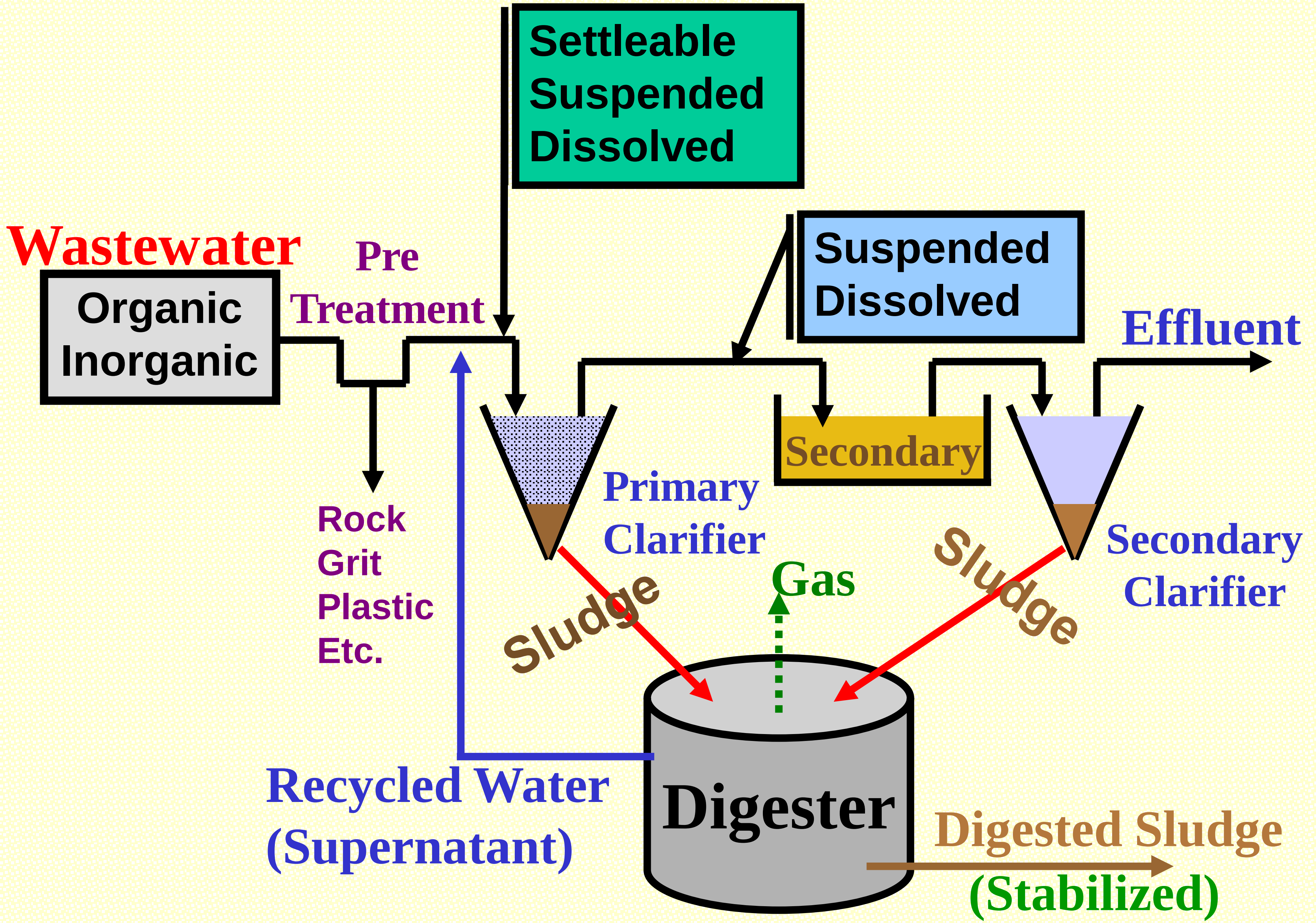
The SETTLEABLE solids separated from liquids during processing.

SLUDGE CHARACTERISTICS

- Organic /Inorganic
- Oxygen Demand
- Odors
- Nutrients
- Pathogens
- Mostly Water

Purpose of ‘Treatment”

- Stabilize Organics
- Eliminate Odors
- Destroy Pathogens
- Reduce Amount of Solids
- Enhance De-watering



Settleable
Suspended
Dissolved
Wastewater
Organic
Inorganic
Pre
Treatment
Suspended
Dissolved
Effluent
Secondary
Rock
Grit
Plastic
Etc.
Primary
Clarifier
Secondary
Clarifier
Sludge
Gas
Sludge
Recycled Water
(Supernatant)
Digester
Digested Sludge
(Stabilized)

TYPES of “TREATMENT”

- Heat and Pressure
- Heat and Chemical
- Lime Stabilization
- Biological Digestion

Types of Digestion

Biological

Bacteria

<u>Aerobic</u>

Use “Free” Oxygen

<u>Anaerobic</u>

No “Free” Oxygen

AEROBIC DIGESTION

AEROBIC DIGESTION

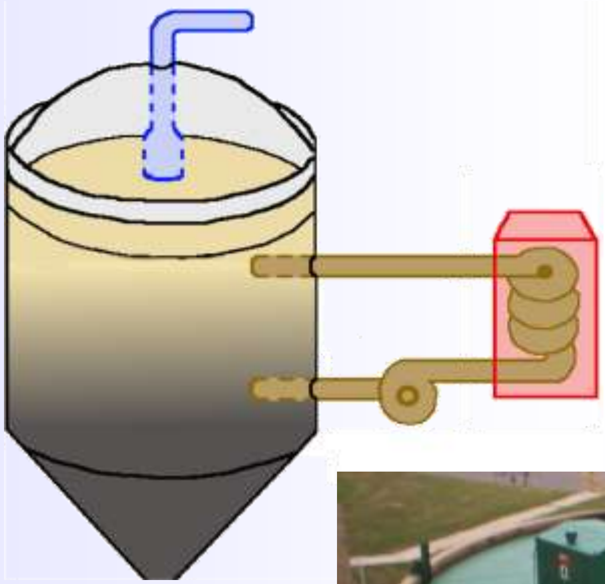
Advantages

- Effective for "secondary" sludge
- Simple operation
- No hazardous gas production

Disadvantages

- Higher operating costs
- High energy demands
- No burnable gas
- Higher organic content

ANAEROBIC DIGESTION



ANAEROBIC DIGESTION

Advantages

- Low operating costs
- Proven effectiveness
- Burnable gas produced

Disadvantages

- Long start-up time
- Affected by changes in loading and conditions
- Explosive gas produced

ANAEROBIC SLUDGE DIGESTION

DIGESTION PROCESS

Anaerobic Digestion Process

“TWO-STAGE” Process

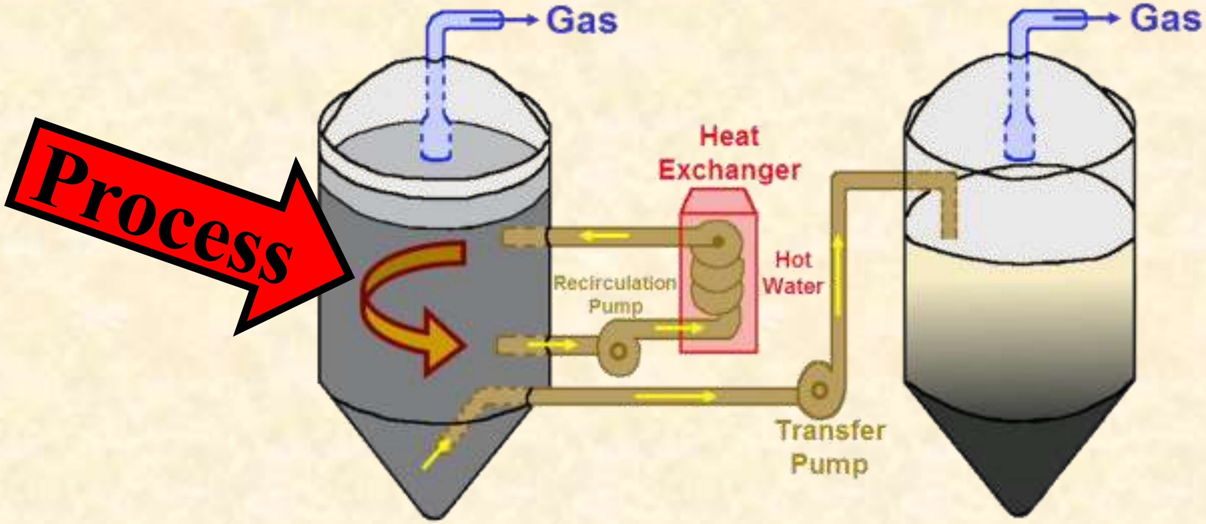
OR

“Two Phase” Process

Anaerobic Digestion Process

“TWO-STAGE” Process

This Does Not Mean Two Tanks



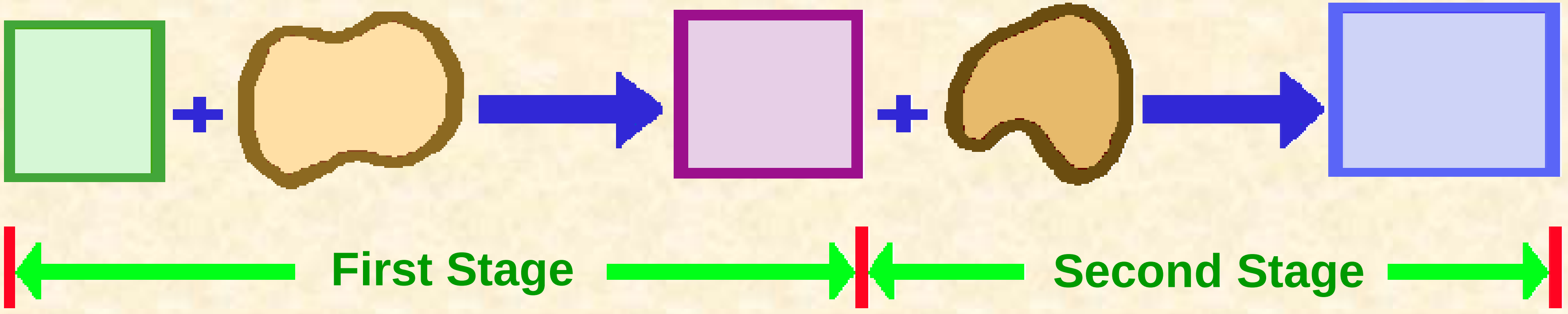
Anaerobic Digestion Process

“TWO-STAGE” Process

OR

“Two Phase” Process

Two Types of Bacteria
Each Relying On The Other



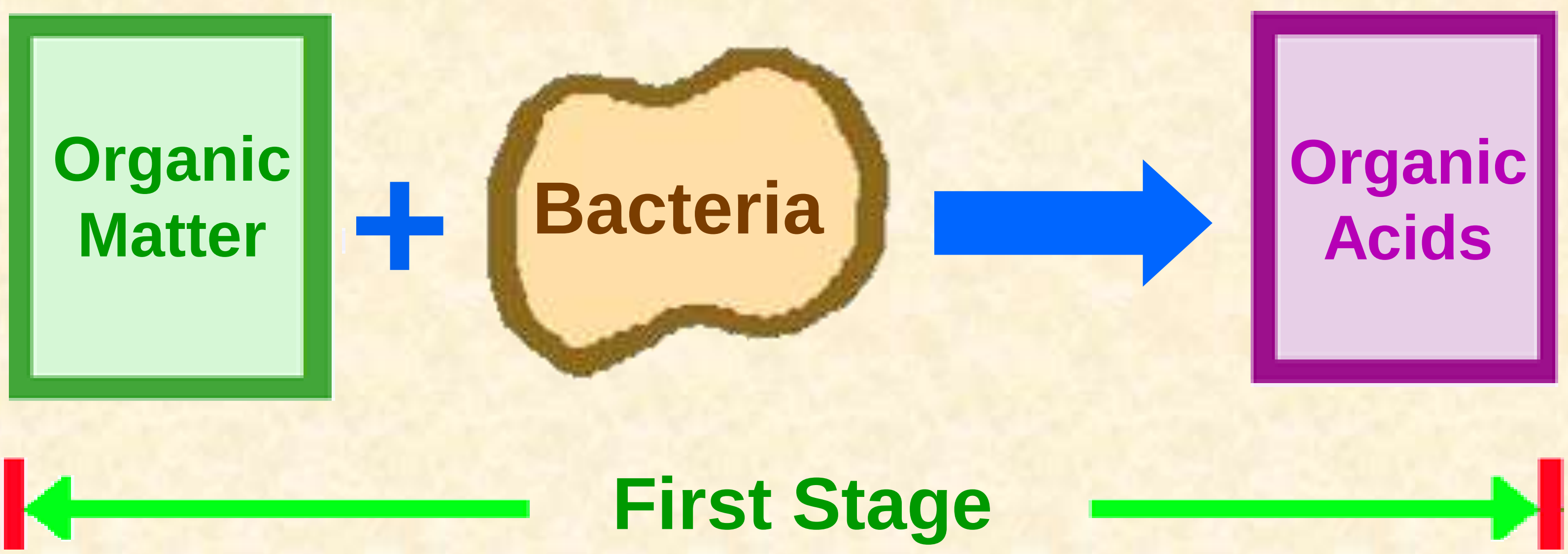
Anaerobic Digestion Process

First

Organic Material Changed

By Acid Forming Bacteria

To Simple Organic Material



Anaerobic Digestion Process

First

Organic Material Changed

By Acid Forming Bacteria

To Simple Organic Material

Also Called Volatile Acids

Organic Acids

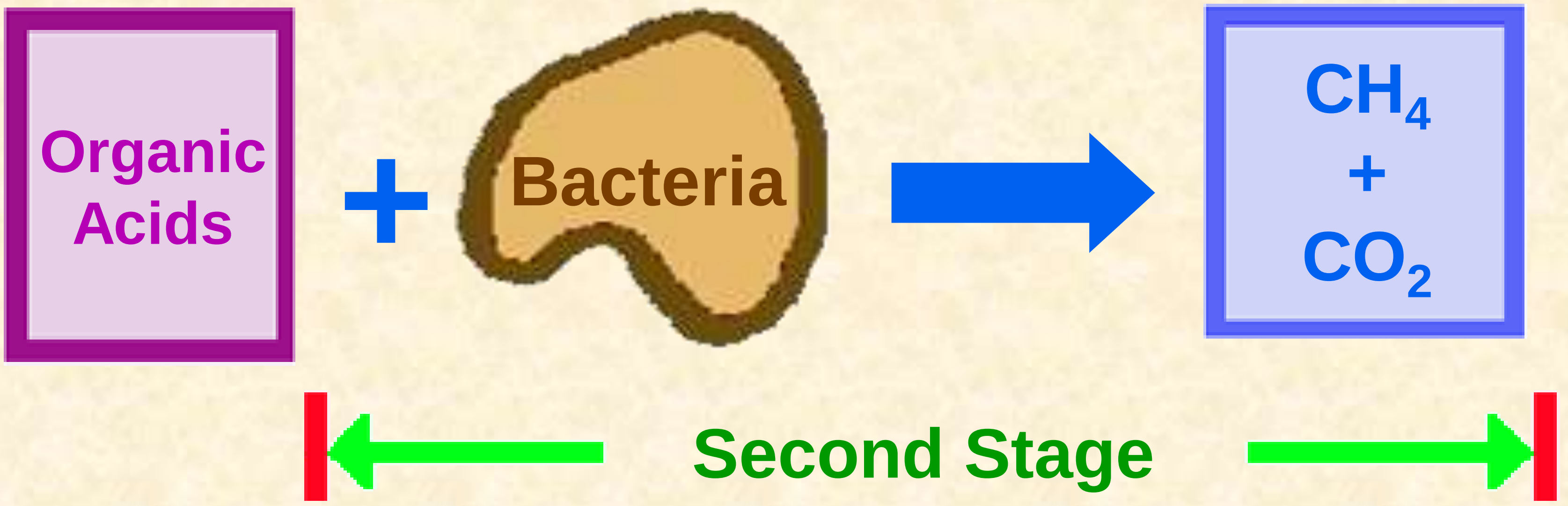
Anaerobic Digestion Process

Second

Methane-Forming Bacteria

Use Organic Acids

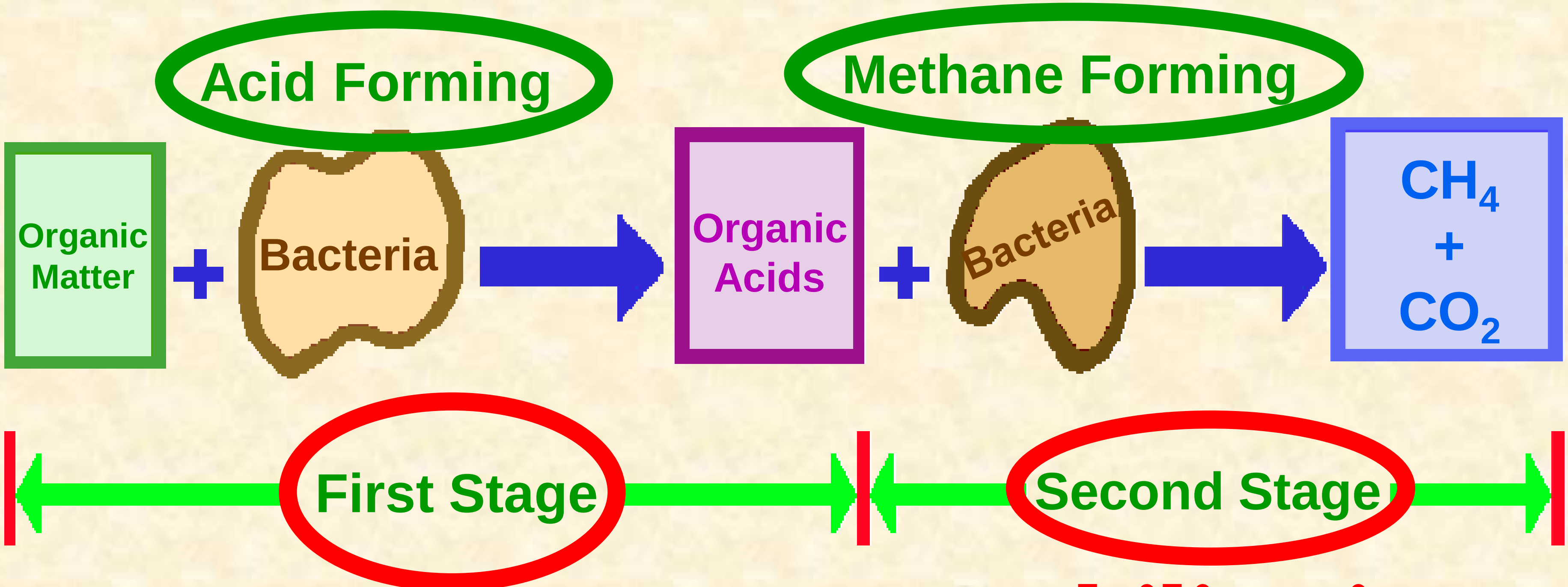
Produce Carbon Dioxide and Methane



Anaerobic Digestion Process

Continuous Process

"TWO-STAGE" Process



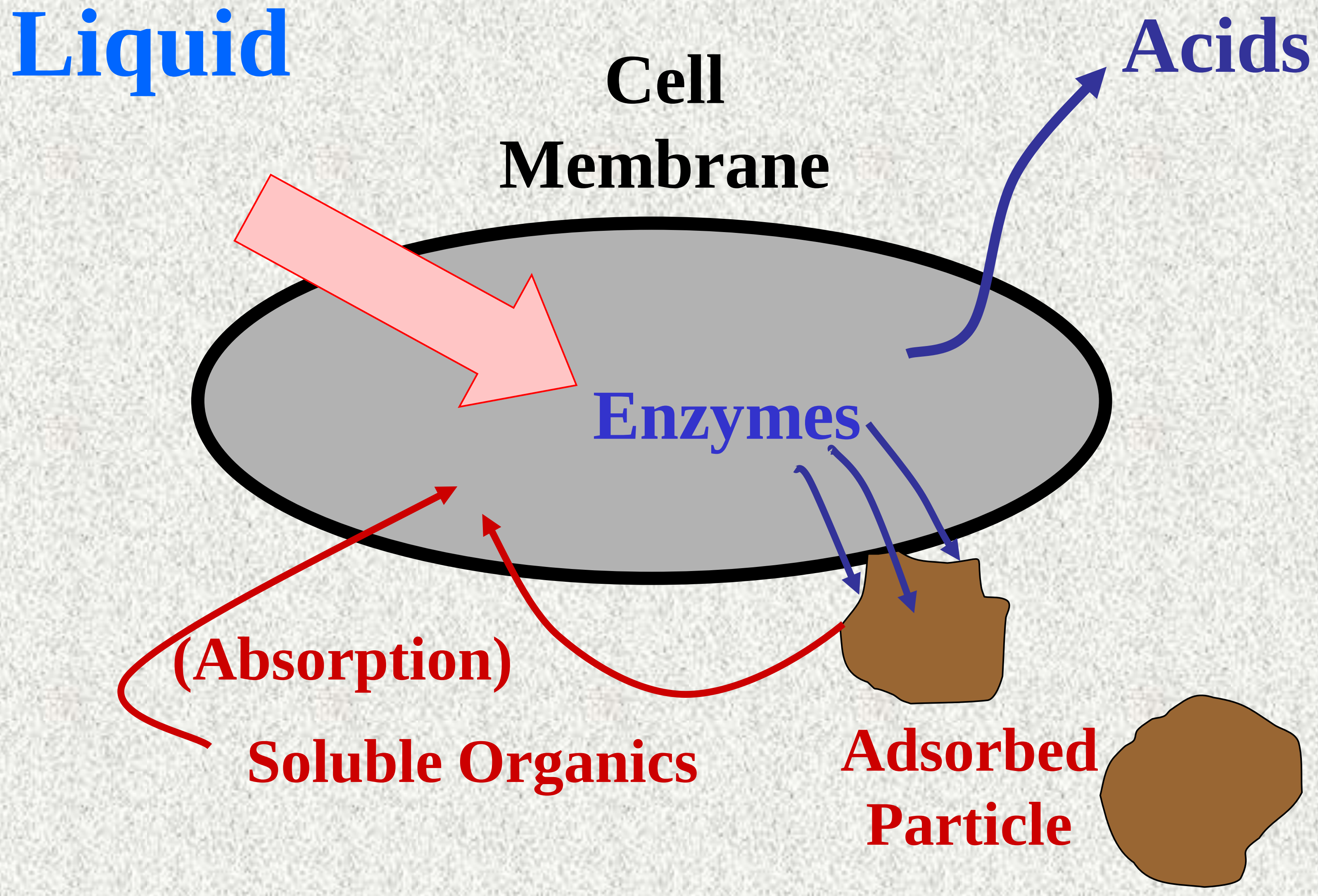
Stabilization

Anaerobic Digestion Process

Type of Food

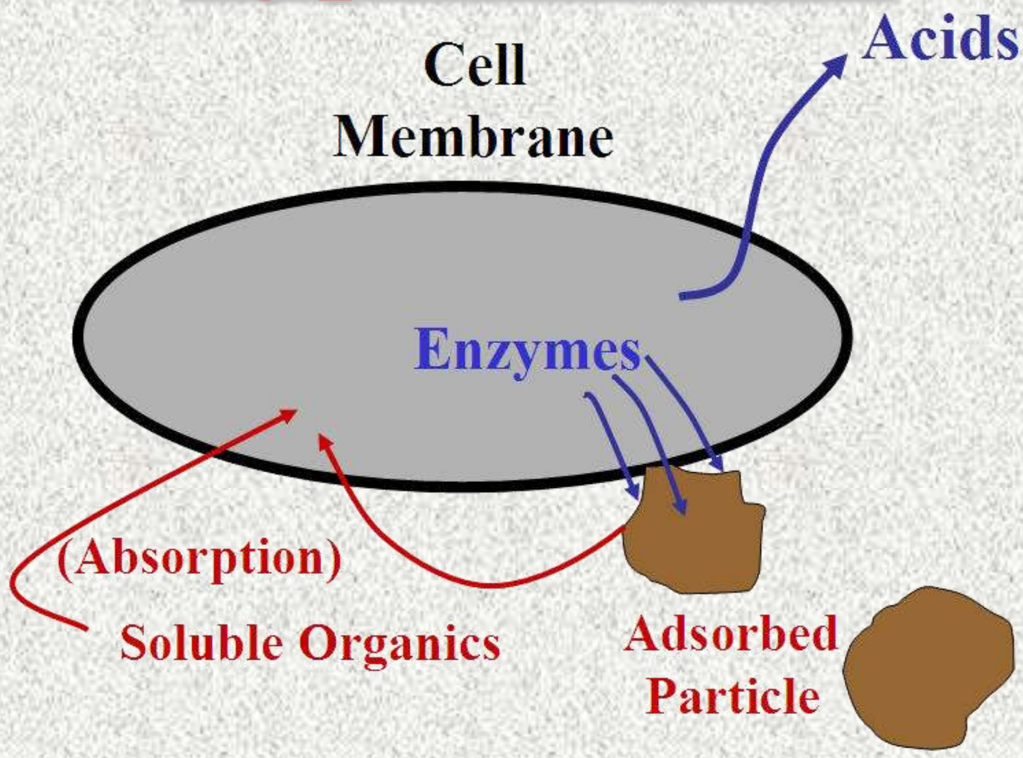
Organic ~~Inorganic~~

Soluble Insoluble



Typical Acid Forming Bacteria

Type of Food



Not All Organic Material Broken Down

Poor Food - Not Readily Degradable

Inert Solids - Plastics, etc.

40 to 60 % of Organics are Reduced

Anaerobic Digestion Process

"TWO-STAGE" Process

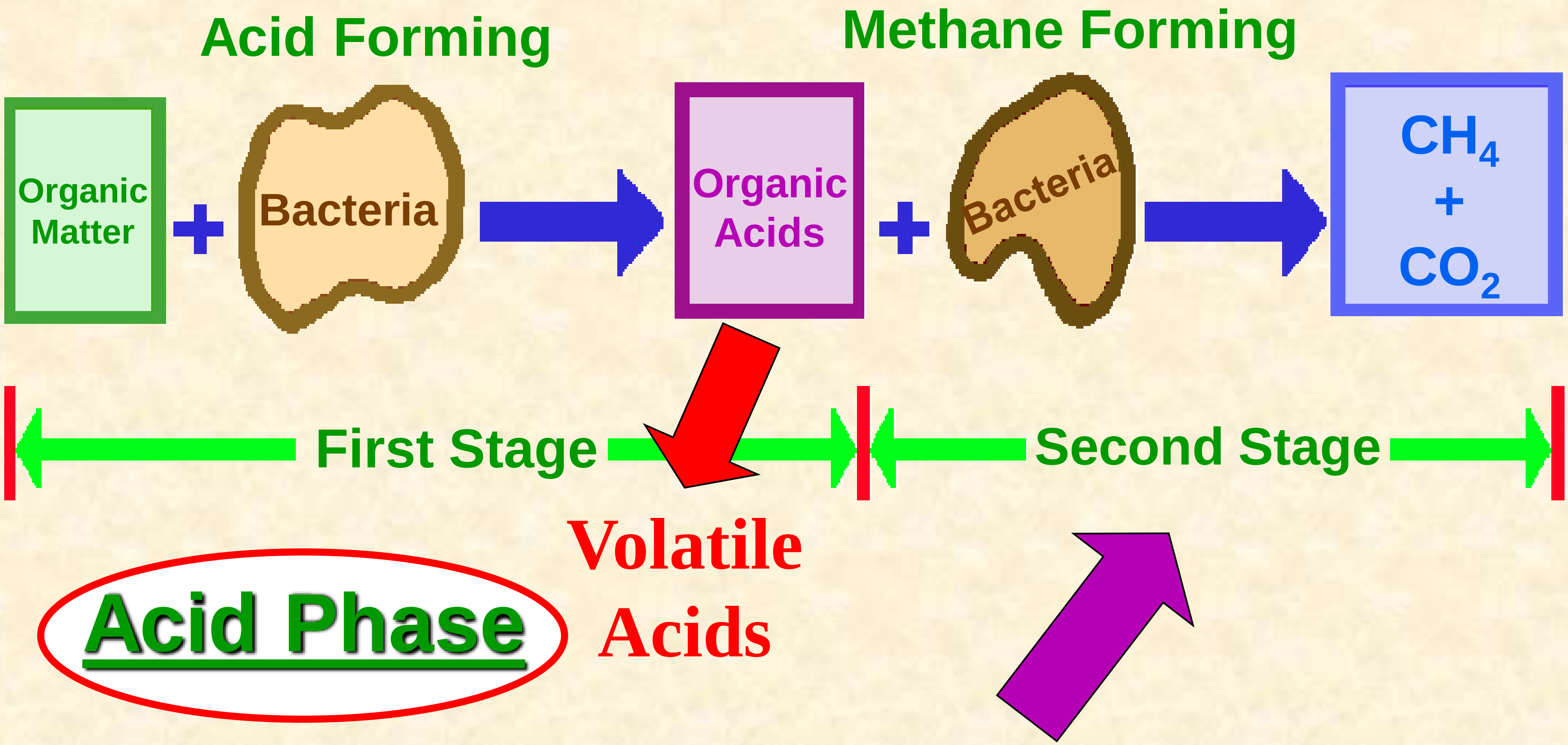
OR

"Two Phase" Process

Two Types of Bacteria
Each Relying On The Other

Must Be In Balance !

Anaerobic Digestion Process



Acids Used at Rate Produced

Anaerobic Digestion Process

Acids Used at Rate Produced

If Not Used - Drop in pH

Start-up

Upset

"Sour"

"Stuck"

Methane Formers Must Be Active

Anaerobic Digestion Process

Methane Formers:

Slow Growers

Very Sensitive to Changes

Loading

pH

Temperature

Digester Operation Depends On Maintaining Proper Environment for METHANE FORMERS

BALANCE !

Anaerobic Digestion Process

Products of Digestion

1. Gases

7 to 12 cubic feet per pound of volatile destroyed

Methane (CH_4)	**65 to 70 %**
Carbon Dioxide (CO_2)	**30 to 35 %**

500 to 600 BTU per cubic foot

Can Be Utilized:

Heating Digester
Heating Buildings
Running Engines
Electrical Power

Anaerobic Digestion Process

Products of Digestion

2. Scum

Lighter Solids

Floating from Gas Entrapment

Builds Up If MIXING Is Inadequate

Not Digested (Separated from Bacteria)

Reduces Digester Capacity

Plugs Piping

Plugs Vents and Flame Traps

Anaerobic Digestion Process

Products of Digestion

3. Supernatant

Liquid That Leaves Digester

Two Sources of Water In Digester:

Water Pumped In

Water Formed During Digestion

Recycled Through Treatment Plant

High In:

Solids

BOD

Ammonia

Anaerobic Digestion Process

Products of Digestion

3. Supernatant

Liquid That Leaves Digester

Should Be Removed Frequently in Small Quantities

Anaerobic Digestion Process

Products of Digestion

4. Digested Sludge

Final Product

Inorganic Solids

Volatile (Organic) Solids - Not Easily Digested

“Stabilized”

Well Digested Sludge

Characteristics

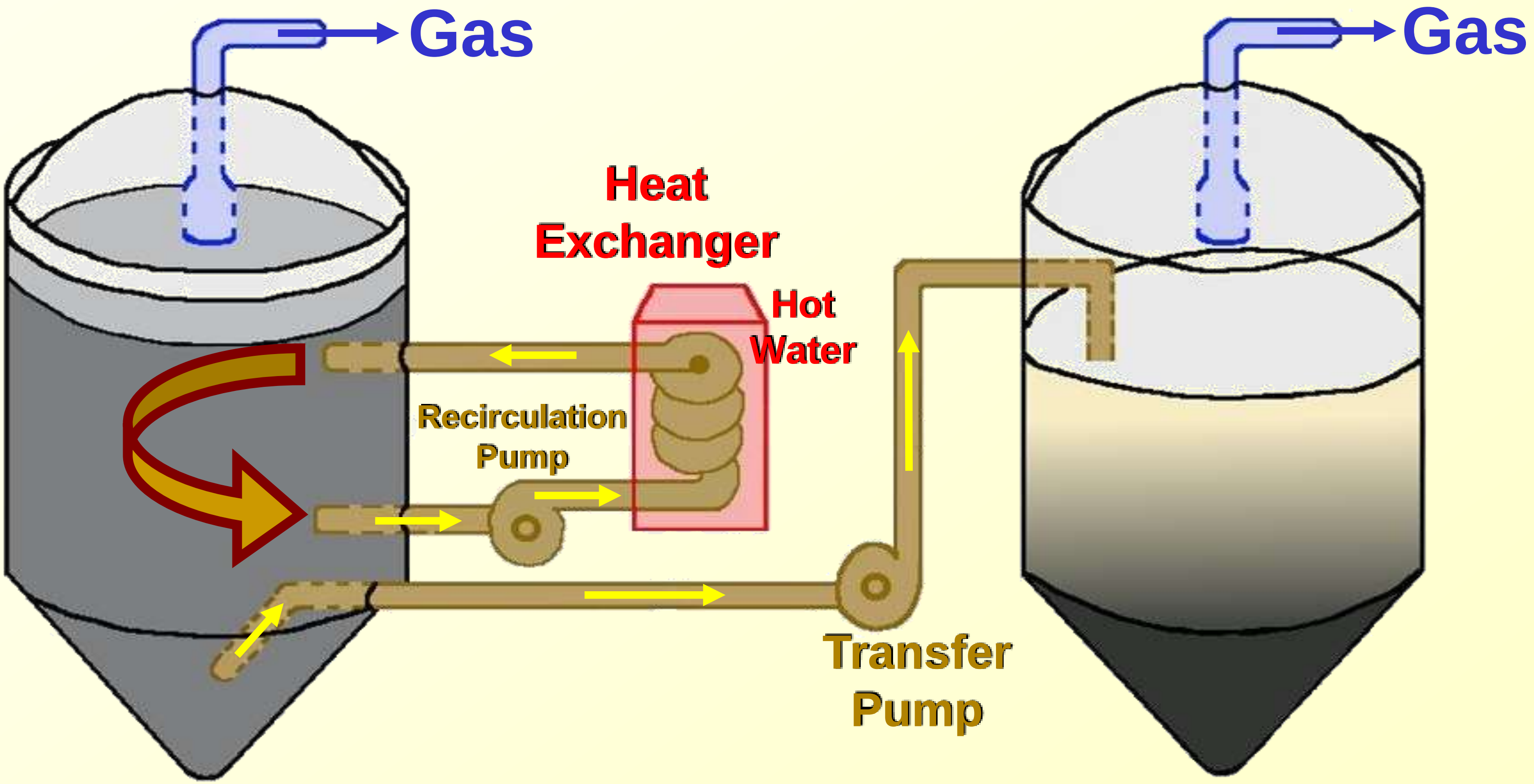
1. Less Solids
2. Lumpy Appearance
3. Black
4. Less Objectionable Odor
5. Volatile Content Reduced

Anaerobic Digestion Process

Products of Digestion

1. Gases
   - Methane (CH_4)
   - Carbon Dioxide (CO_2)
2. Scum
   - Lighter Solids
3. Supernatant
   - Liquid Removed
4. Digested Sludge
   - "Stabilized"

TYPICAL "Two-Stage" ANAEROBIC DIGESTER SYSTEM



Note: Two-Stage System here refers to two separate tanks (One for the treatment process and one for water-solids separation)

Digestion Factors

1. Bacteria
2. Food
3. Loading
4. Contact
5. Environment

Digestion Factors

1. BACTERIA

Naturally Occurring
Must Have Enough
Living Organisms
Two Different Types
BALANCE

The Other Factors –Important Because They Affect the Bacteria

Digestion Factors

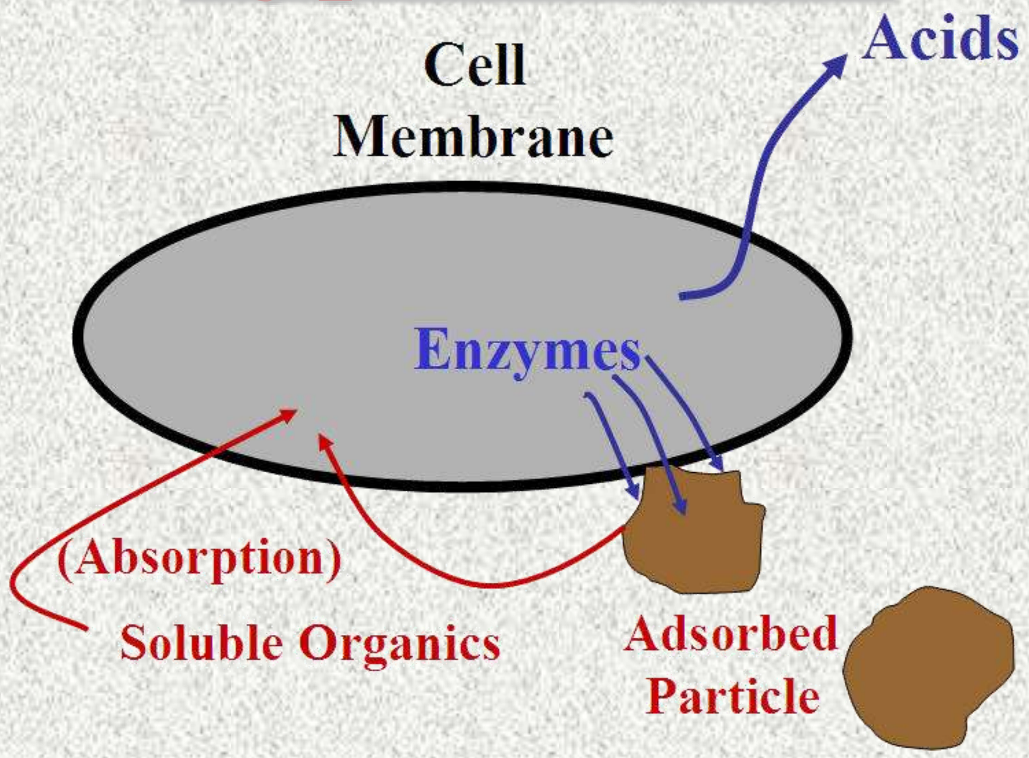
1. BACTERIA

   Balance

2. FOOD

   Volatile Solids

Type of Food



Not All Organic Material Broken Down

Poor Food - Not Readily Degradable

Inert Solids - Plastics, etc.

40 to 60 % of Organics are Reduced

Digestion Factors

1. BACTERIA
   - Balance
2. FOOD
   - Volatile Solids
   - Not All Volatile Material
   - None of the Inorganic

Digestion Factors

1. BACTERIA

   Balance

2. FOOD

   Volatile Solids

3. LOADING

Digestion Factors

3. LOADING

AMOUNT

Applied to the Treatment Process

Related to the SIZE of the System

Digestion Factors

1. BACTERIA
   Balance

2. FOOD
   Volatile Solids

3. LOADING

Amount and Type

Concentration of Sludge (% Total Solids)

Amount Usable in Sludge (%Volatile)

Amount (pounds) of Volatile per Volume Available

Volume (gallons) of Sludge per Volume Available

Digestion Factors

1. BACTERIA
   Balance
2. FOOD
   Volatile Solids
3. LOADING
   Amount and Type
4. CONTACT
   Mixing

Digestion Factors

MIXING

1. CONTACT
   Bacteria and Food

2. HEAT DISTRIBUTION
   Even Throughout

3. MINIMIZE SETTLING
   Reduces Available Volume

4. MINIMIZE SCUM
   Operational Problems

Digestion Factors

MIXING

1. CONTACT
2. HEAT DISTRIBUTION
3. MINIMIZE SETTLING
4. MINIMIZE SCUM

Maximize Digestion Efficiency

Digestion Factors

1. BACTERIA
   Balance
2. FOOD
   Volatile Solids
3. LOADING
   Amount and Type
4. CONTACT
   Mixing
5. ENVIRONMENT
   Happy Bugs

Digestion Factors

ENVIRONMENT

Methane Forming Bacteria
Are
Very Sensitive to Conditions
In the
Digester

Digestion Factors

ENVIRONMENT

1. ANAEROBIC
   No Oxygen
2. TEMPERTURE

TEMPERATURE

Temperature controls activity of bacteria.

Psychrophilic

50° F to 68° F

Mesophilic

68° F to 113° F

Best 85° F to 100° F

Thermophilic

Above 113° F

Best 120° F to 135° F

TEMPERATURE

Temperature controls activity of bacteria.

Mesophilic

68° F to 113° F

Best 85° F to 100° F

Most Anaerobic Digesters Are Operated in the Mesophilic Range

Within the Range, the Bacteria are Very Sensitive to Temperature CHANGE

TEMPERATURE

Temperature controls activity of bacteria.

Mesophilic

68° F to 113° F

Best 85° F to 100° F

Temperature Should Not Be Allowed to
CHANGE
by More Than 1 Degree per Day

(After Start-up)

Digestion Factors

ENVIRONMENT

1. **ANAEROBIC**
   No Oxygen
2. **TEMPERTURE**
   Mesophilic - Constant
3. **pH**
   Best - 6.8 to 7.2
4. **VOLATILE ACIDS**
   Not Excessive
5. **BUFFERS (Alkalinity)**
   Incoming Sludge and Created

Digestion Factors

ENVIRONMENT

1. ANAEROBIC
   No Oxygen
2. TEMPERTURE
   Mesophilic - Constant
3. pH
   Best - 6.8 to 7.2
4. VOLATILE ACIDS
   Not Excessive
5. BUFFERS (Alkalinity)
   Incoming Sludge and Created

ACID Production INCREASED

OR

ALKALINITY DECREASED

Sudden Changes

Toxic Materials

Start-up

Digestion Factors

ENVIRONMENT

1. **ANAEROBIC**
   No Oxygen
2. **TEMPERTURE**
   Mesophilic - Constant
3. **pH**
   Best - 6.8 to 7.2
4. **VOLATILE ACIDS**
   Not Excessive
5. **BUFFERS (Alkalinity)**
   Incoming Sludge and Created
6. **TOXIC MATERIALS**
   Inhibit Biological Activity

OPERATION AND CONTROL

BALANCE !

Maintaining Suitable Conditions

Maintaining Definite Ranges and Ratios

Organic (Solids) Loading
Alkalinity
Volatile Acids
Temperature
Mixing

Digestion Factors

1. BACTERIA
2. FOOD
3. LOADING
4. CONTACT
5. ENVIRONMENT

OPERATION AND CONTROL

1. BACTERIA

Maintain Adequate Quantity

- Don’t Remove Too Much
- Don’t Displace Too Much
- Plan For Re-Start

OPERATION AND CONTROL

2. FOOD

Minimize Amount of Inorganics Entering

- **Industrial Discharges**
- **Grit Systems**

Eliminate Toxic Material

OPERATION AND CONTROL

3. LOADING

AMOUNT

Applied to the Treatment Process

Related to the SIZE of the System

3. LOADING

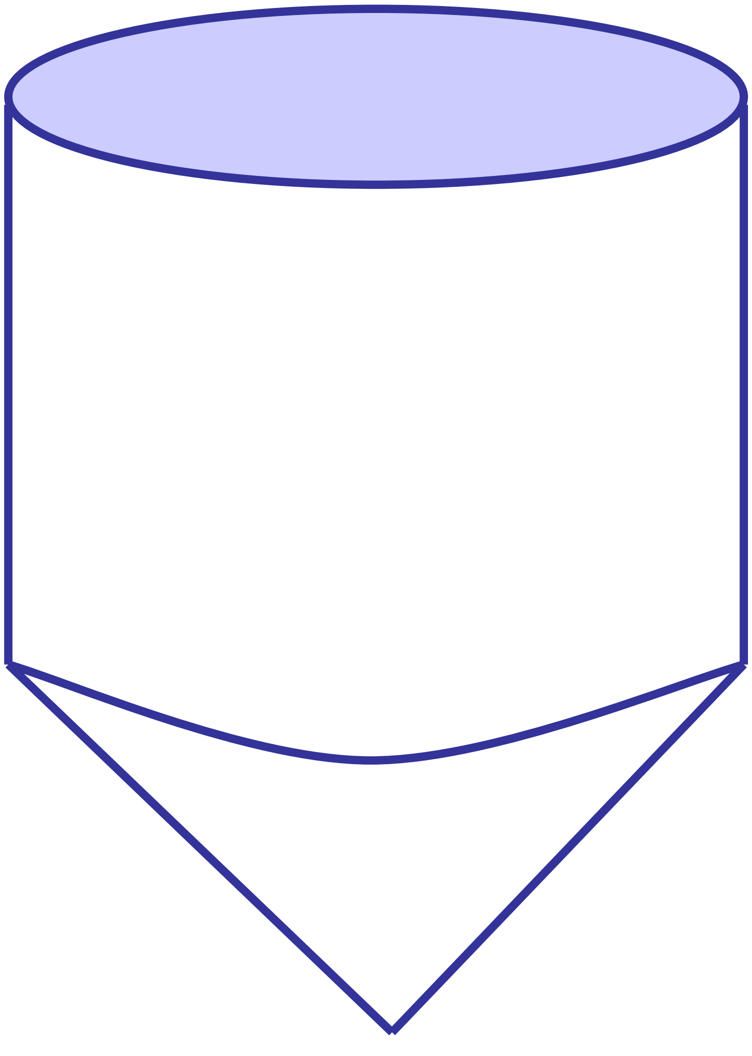
AMOUNT

Applied to the Treatment Process

Related to the SIZE of the System

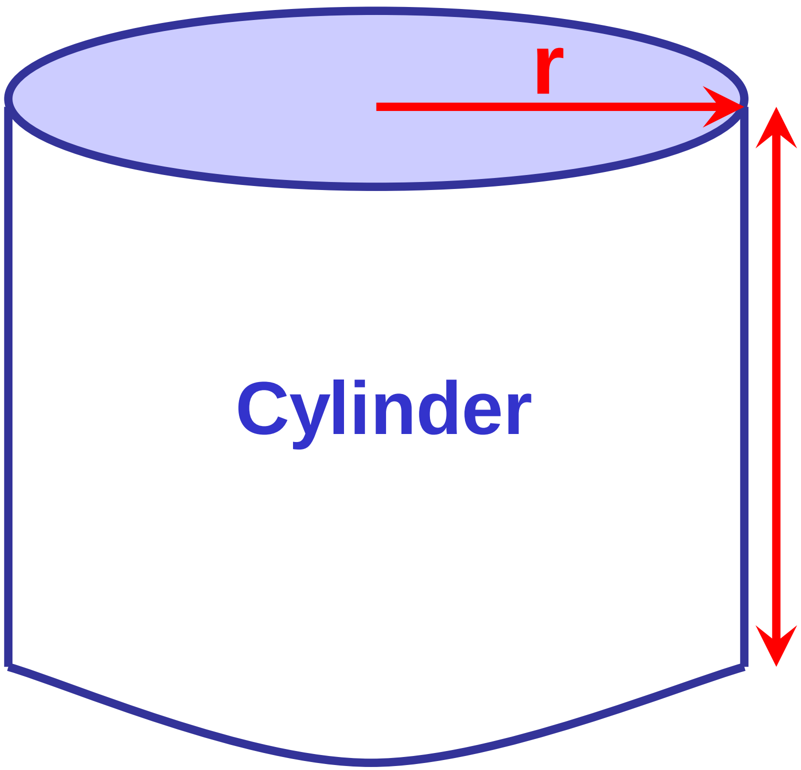
For An Anaerobic Digestion System – The SIZE Is The VOLUME Available for Digestion

(Volume - Cubic Feet OR Gallons)



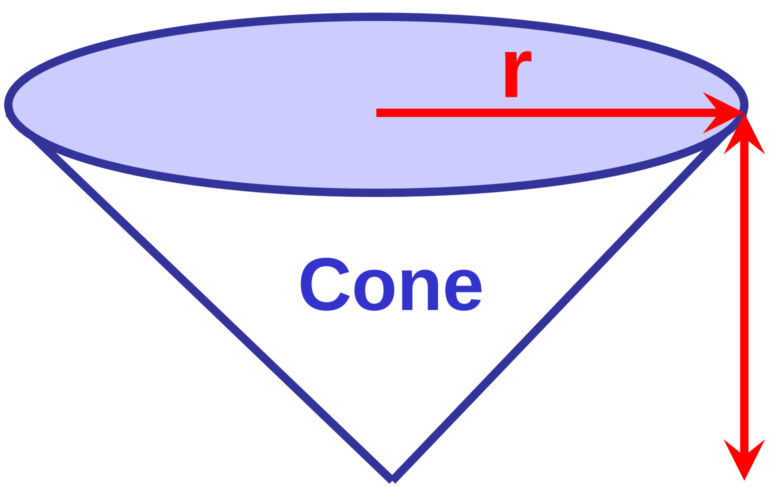
Calculation of Digester Volume

?



$$\text{Volume}_{\text{cylinder}} =$$

$$\Pi\ r^2 h_1$$



$$\text{Volume}_{\text{cone}} =$$

$$\tfrac{1}{3}\ \Pi\ r^2 h_2$$

Digester Volume Example Problem

The diameter of a digester is 54 feet.
The side water depth (SWD) is 22 feet.
The cone depth is 12 feet.
Calculate the volume in cubic feet and gallons.

$$Volume_{cylinder} = \Pi\ r^2 h_1$$

$$= 3.14 \ X \ 27\ ft \ X \ 27\ ft \ X \ 22\ ft$$

$$= 50{,}360\ ft^3$$

$$Volume_{cone} = \tfrac{1}{3}\ \Pi\ r^2 h_2$$

$$= \tfrac{1}{3}\ X \ 3.14 \ X \ 27\ ft \ X \ 27\ ft \ X \ 12\ ft$$

$$= 9{,}156\ ft^3$$

Digester Volume Example Problem

$$\text{Total Volume} = \text{Volume}_{cylinder} + \text{Volume}_{cone}$$

$$= 50{,}360\ ft^3 + 9{,}156\ ft^3$$

$$= 59{,}516\ ft^3$$

$$\text{Total Volume (gallons)} =$$

$$\text{cubic feet} \times 7.48\ gal/ft^3$$

$$= 59{,}516\ ft^3 \times 7.48\ gal/ft^3$$

$$= 445{,}180\ \text{gallons}$$

Digester Volume Practice Problems

1. **The diameter of a digester is 50 feet.**
   The side water depth (SWD) is 20 feet.
   The cone depth is 10 feet.
   Calculate the volume in cubic feet and gallons.

2. **Calculate the volume in gallons of a digester 35 feet in diameter, 12 feet SWD and a cone depth of 6 feet.**

Work Calculations on Separate Paper
Answers Given on Next Slides

Digester Volume Practice Problem

1. The diameter of a digester is 50 feet.
   The side water depth (SWD) is 20 feet.
   The cone depth is 10 feet.
   Calculate the volume in cubic feet and gallons.

$$\text{Volume}_{cylinder} = \Pi\, r^2 h_1$$

$$= 3.14 \text{ X } 25 \text{ ft X } 25 \text{ ft X } 20 \text{ ft}$$

$$= 39{,}250 \text{ ft}^3$$

$$\text{Volume}_{cone} = \tfrac{1}{3}\, \Pi\, r^2 h_2$$

$$= \tfrac{1}{3} \text{ X } 3.14 \text{ X } 25 \text{ ft X } 25 \text{ ft X } 10 \text{ ft}$$

$$= 6{,}542 \text{ ft}^3$$

Digester Volume Practice Problems

1. The diameter of a digester is 50 feet.
   The side water depth (SWD) is 20 feet.
   The cone depth is 10 feet.
   Calculate the volume in cubic feet and gallons.

$$\text{Total Volume} = \text{Volume}_{cylinder} + \text{Volume}_{cone}$$

$$= 39{,}250 \text{ ft}^3 + 6{,}542 \text{ ft}^3$$

$$= 45{,}792 \text{ ft}^3$$

$$\text{Total Volume (gallons)} = \text{cubic feet} \times 7.48 \text{ gal/ft}^3$$

$$= 45{,}792 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3$$

$$= 342{,}524 \text{ gallons}$$

Digester Volume Practice Problems

2. Calculate the volume in gallons of a digester 35 feet in diameter, 12 feet SWD and a cone depth of 6 feet.

$$\text{Volume}_{cylinder} = \Pi r^2 h_1$$

$$= 3.14 \text{ X } 17.5 \text{ ft X } 17.5 \text{ ft X } 12 \text{ ft}$$

$$= \underline{11{,}539.5 \text{ ft}^3}$$

$$\text{Volume}_{cone} = \tfrac{1}{3} \Pi r^2 h_2$$

$$= \tfrac{1}{3} \text{ X } 3.14 \text{ X } 17.5 \text{ ft X } 17.5 \text{ ft X } 6 \text{ ft}$$

$$= \underline{1{,}923 \text{ ft}^3}$$

Digester Volume Practice Problems

2. Calculate the volume in gallons of a digester 35 feet in diameter, 12 feet SWD and a cone depth of 6 feet.

$$\text{Total Volume} = \text{Volume}_{cyl} + \text{Volume}_{cone}$$

$$= 11{,}539.5\ ft^3 + 1{,}923\ ft^3$$

$$= 13{,}462.5\ ft^3$$

$$\text{Total Volume (gallons)} = \text{cubic feet} \times 7.48\ gal/ft^3$$

$$= 13{,}462.5\ ft^3 \times 7.48\ gal/ft^3$$

$$= 100{,}700\ \text{gallons}$$

“LOADING”

Amount Applied to the Treatment Process

Related to the SIZE of the System

Hydraulic Loading

Amount of Sludge Added
Volume (gallons)

Organic Loading

Amount of VOLATILE Solids added
Weight (pounds)

Digester Hydraulic Loading

AVERAGE TIME

(in Days)

that the liquid stays in the digester

Digester Hydraulic Loading

AVERAGE TIME (in Days) that the liquid stays in the digester

Minimum Time Required:

Proper Digestion

- Convert Solids
- Acids to Gas

Varies

- Digester Efficiency
- Type of Waste

Holding Time Increased by Thickening

Digester Hydraulic Loading

AVERAGE TIME

(in Days)

that the liquid stays in the digester

$$\text{Hydraulic Loading} = \frac{\text{Digester Volume}}{\text{Feed Volume}}$$

$$\text{Hydraulic Loading} = \frac{\text{Gallons}}{\text{Gallons/Day}}$$

Detention Time

DET. TIME (Days) =

$$\frac{\text{Gallons}}{\text{Gallons / Day)}}$$

EXAMPLE

At an average pumping rate of 4,000 gallons per day into a 140,000 gallon digester, the detention time would be:

$$\text{Detention Time} = \frac{140{,}000 \text{ gallons}}{4{,}000 \text{ gallons/day}}$$

= 35 Days

Detention Time Practice Problems

1. Calculate the Detention Time for a 120,000 gallon digester that receives 3,200 gallons of sludge per day.

2. Calculate the Detention Time for a 260,000 gallon digester that receives 7,200 gallons of sludge per day.

3. Calculate the Detention Time for a 12,000 cubic foot digester that receives 2,500 gallons of sludge per day.

Work Calculations on Separate Paper
Answers Given on Next Slides

Detention Time Practice Problems

1. **Calculate the Detention Time for a 120,000 gallon digester that receives 3,200 gallons of sludge per day.**

$$\text{Detention Time} = \frac{\text{Digester Volume (Gal)}}{\text{Pumping Rate (Gal/Day)}}$$

$$= \frac{120{,}000 \text{ gallons}}{3{,}200 \text{ gallons/day}}$$

= 37.5 Days

Detention Time Practice Problems

2. **Calculate the Detention Time for a 260,000 gallon digester that receives 7,200 gallons of sludge per day.**

$$\text{Detention Time} = \frac{\text{Digester Volume (Gal)}}{\text{Pumping Rate (Gal/Day)}}$$

$$= \frac{260{,}000 \text{ gallons}}{7{,}200 \text{ gallons/day}}$$

$$= 36.1 \text{ Days}$$

Detention Time Practice Problems

3. **Calculate the Detention Time for a 12,000 cubic foot digester that receives 2,500 gallons of sludge per day.**

$$\text{Detention Time} = \frac{\text{Digester Volume (Gal)}}{\text{Pumping Rate (Gal/Day)}}$$

$$= \frac{12{,}000 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3}{2{,}500 \text{ gallons/day}}$$

$$= \frac{89{,}760 \text{ gallons}}{2{,}500 \text{ gal/day}}$$

$$\boxed{= 35.9 \text{ Days}}$$

“LOADING”

Amount Applied to the Treatment Process

Related to the SIZE of the System

Hydraulic Loading

Amount of Sludge Added
Volume (gallons)

Detention Time

$$\frac{\text{Digester Volume}}{\text{Feed Volume}} \quad \textbf{OR} \quad \frac{\text{Gallons}}{\text{Gallons/Day}}$$

“LOADING”

Amount Applied to the Treatment Process

Related to the SIZE of the System

Hydraulic Loading

Amount of Sludge Added
Volume (gallons)

Organic Loading

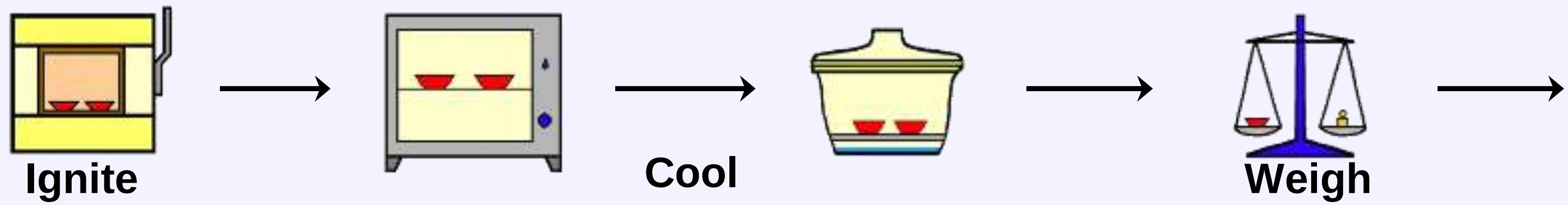
Amount of VOLATILE Solids added
Weight (pounds)

PERCENT TOTAL SOLIDS

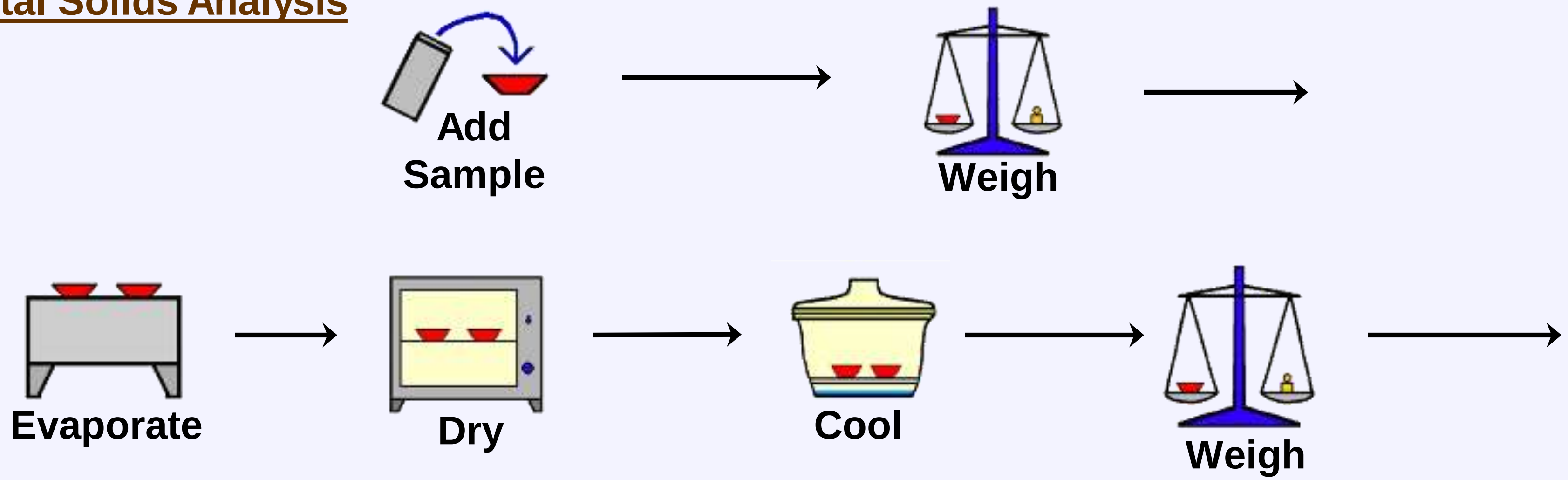
Outline of Solids Analysis Procedure

SLUDGE SOLIDS PROCEDURE

Evaporating Dish Preparation



Total Solids Analysis



Percent Total Solids

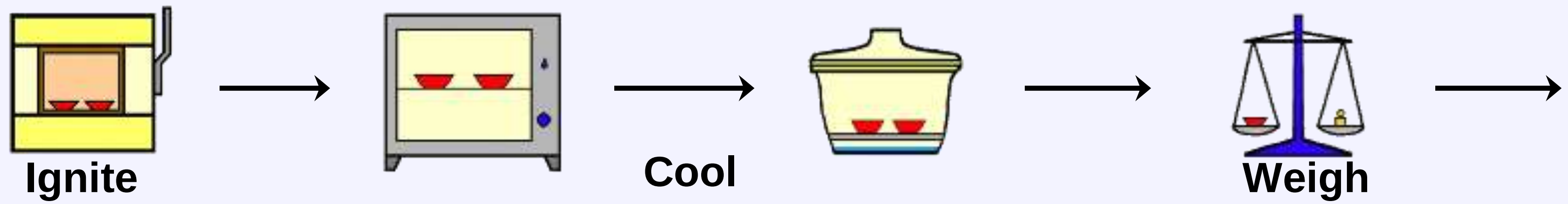
$$\% = \frac{\text{Amount in Question}}{\text{Total Amount Possible}} \times 100\%$$

$$\%\ \text{Total Solids} = \frac{\text{Wt. Of (Dry) Solids}}{\text{Wt. Of (Wet) Sample}} \times 100\%$$

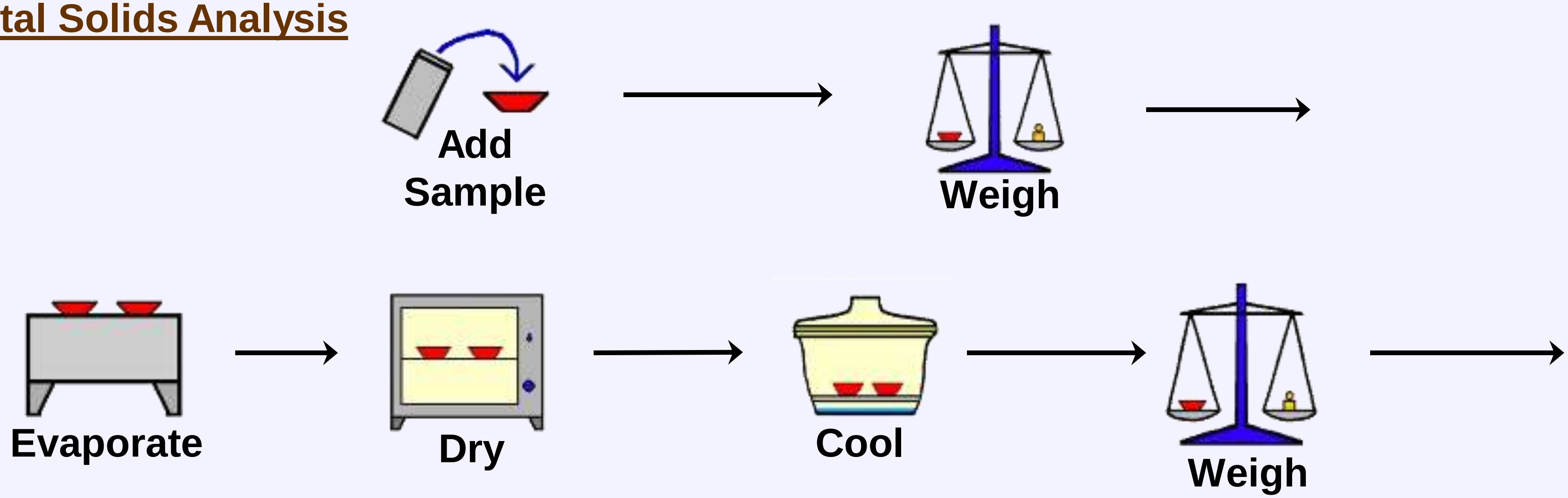
$$\%\ \text{Total Solids} = \frac{\text{Dry}}{\text{Wet}} \times 100\%$$

SLUDGE SOLIDS PROCEDURE

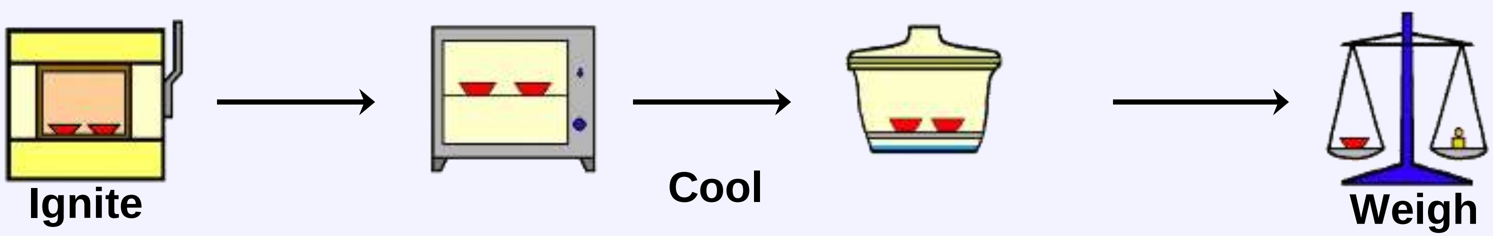
Evaporating Dish Preparation



Total Solids Analysis



Volatile Solids Analysis

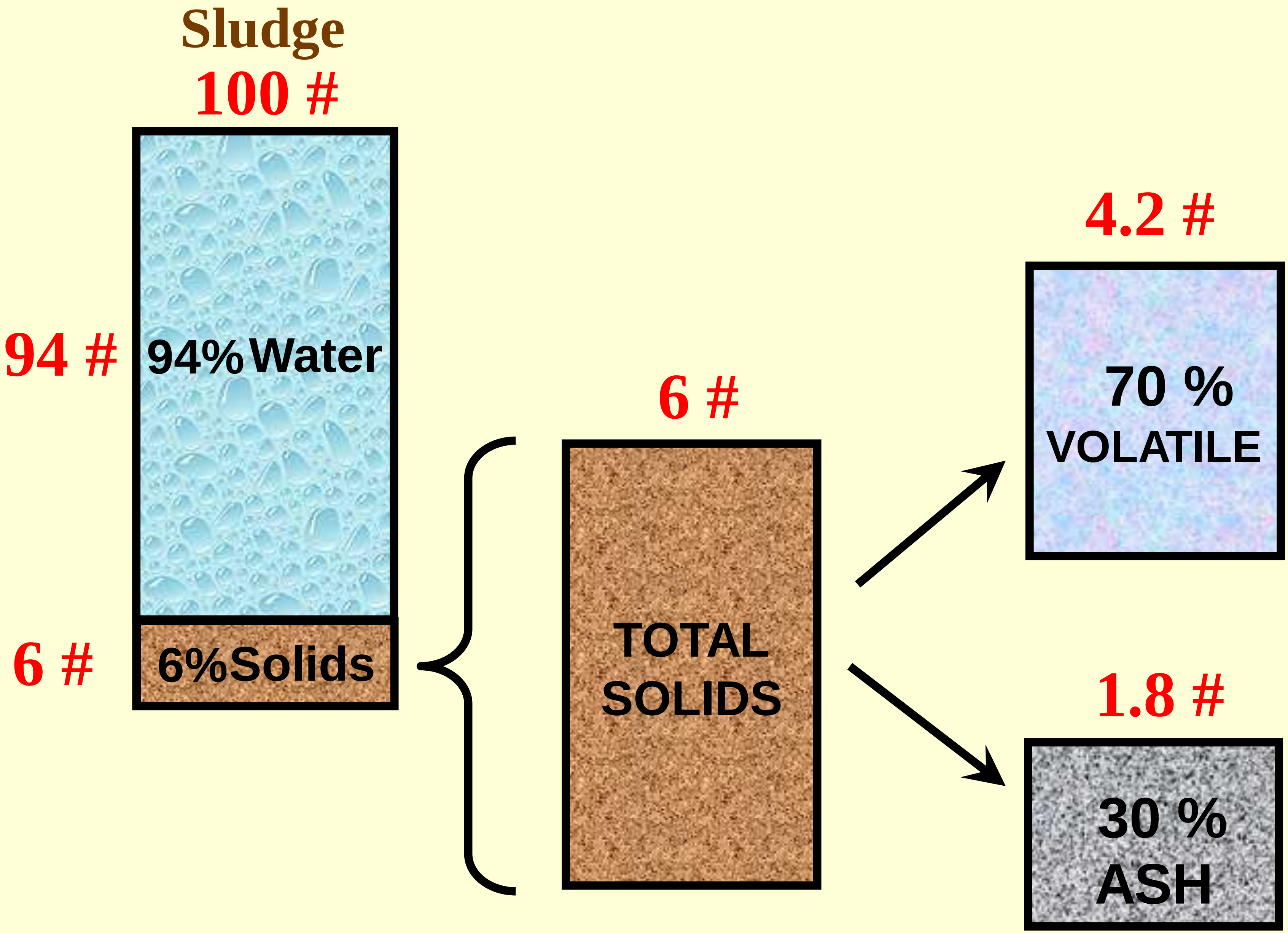


Percent Volatile Solids

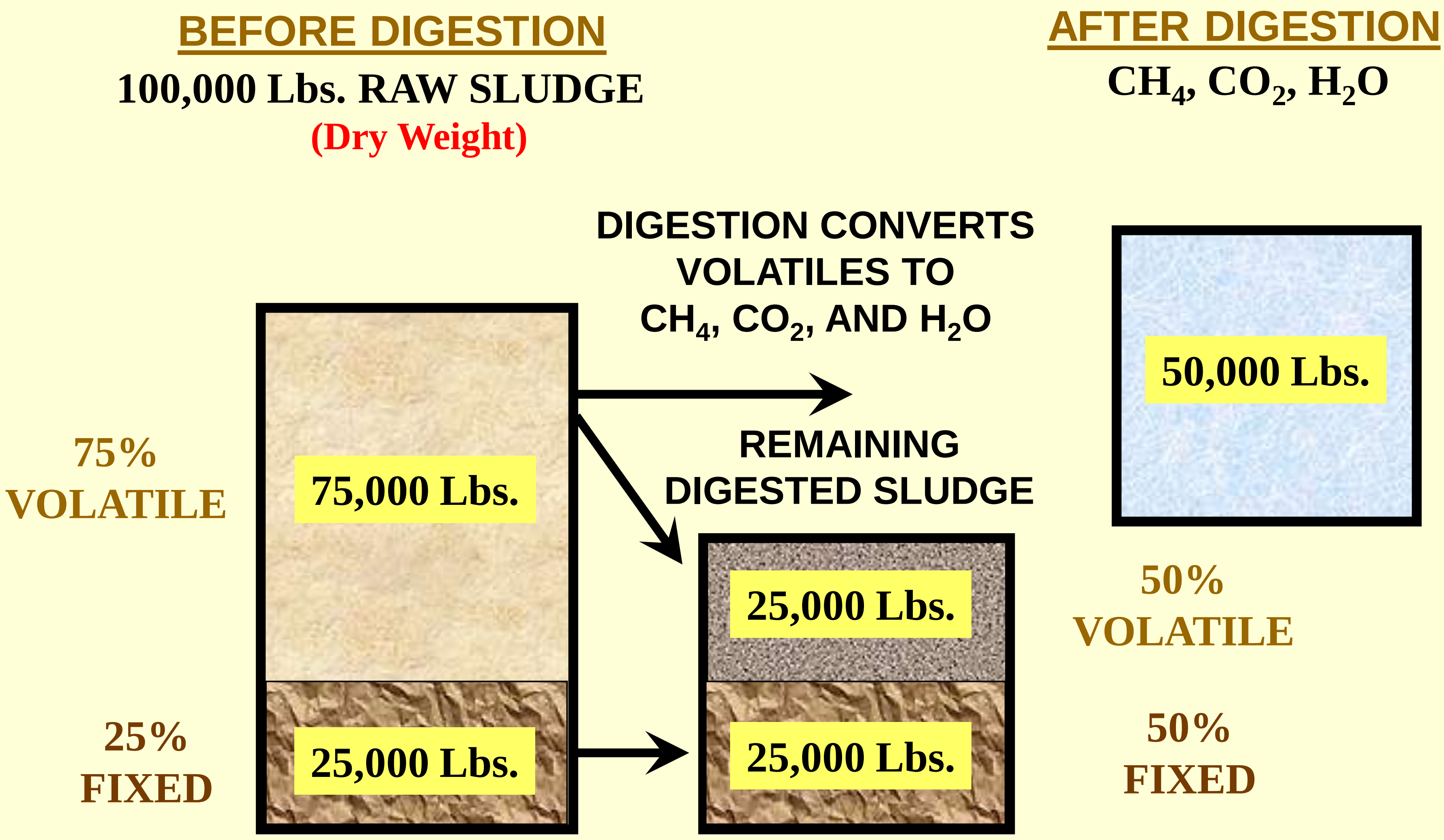
$$\% = \frac{\text{Amount in Question}}{\text{Total Amount Possible}} \times 100\%$$

$$\%\ \text{Volatile Solids} = \frac{\text{Wt. Of Volatile Solids}}{\text{Wt. Of Dry Solids}} \times 100\%$$

$$\%\ \text{Volatile Solids} = \frac{\text{Dry} - \text{Ash}}{\text{Dry}} \times 100\%$$



SLUDGE SOLIDS DIAGRAM



TYPICAL RESULTS OF THE DIGESTION PROCESS

"LOADING"

Amount Applied to the Treatment Process

Related to the SIZE of the System

Organic Loading

Amount of VOLATILE Solids added

Weight (pounds)

SLUDGE POUNDS CALCULATIONS

SLUDGE POUNDS CALCULATIONS

Given the following information, calculate the pounds of dry solids and the pounds of volatile solids:

VOLUME OF SLUDGE	8,000 GALLONS
SOLIDS CONCENTRATION	4.2%
VOLATILE SOLIDS	82%

<u>LBS DRY SOLIDS</u> =

$$\text{GALS WET} \times 8.34\,\frac{\text{LBS}}{\text{GAL}} \times \%\ \text{SOLIDS}$$

$$= 8{,}000\ \cancel{\text{GAL}} \times 8.34\,\frac{\text{LBS}}{\cancel{\text{GAL}}} \times \frac{4.2}{100}$$

$$= 8{,}000 \times 8.34 \times 0.042$$

= 2,802 POUNDS DRY SOLIDS

SLUDGE POUNDS CALCULATIONS

Given the following information, calculate the pounds of dry solids and the pounds of volatile solids:

VOLUME OF SLUDGE	8,000 GALLONS
SOLIDS CONCENTRATION	4.2%
VOLATILE SOLIDS	82%

<u>LBS VOLATILE SOLIDS</u> =

LBS DRY SOLIDS X % VOLATILE SOLIDS

$$= \quad 2{,}802 \text{ LBS DRY SOLIDS} \times \frac{82}{100}$$

$$= 2{,}802 \times 0.82$$

= 2,298 POUNDS VOLATILE SOLIDS

SLUDGE POUNDS CALCULATIONS

1. **Given the following information, calculate the pounds of dry solids and the pounds of volatile solids:**

VOLUME OF SLUDGE	7,500 GALLONS
SOLIDS CONCENTRATION	3.6%
VOLATILE SOLIDS	78%

2. **Given the following information, calculate the pounds of dry solids and the pounds of volatile solids:**

VOLUME OF SLUDGE	6,000 GALLONS
SOLIDS CONCENTRATION	3.0%
VOLATILE SOLIDS	73%

Work Calculations on Separate Paper
Answers Given on Next Slides

SLUDGE POUNDS CALCULATIONS

1. **Given the following information, calculate the pounds of dry solids and the pounds of volatile solids:**

VOLUME OF SLUDGE	7,500 GALLONS
SOLIDS CONCENTRATION	3.6%
VOLATILE SOLIDS	78%

LBS DRY SOLIDS =

$$\text{GALS WET} \times 8.34\,\frac{\text{LBS}}{\text{GAL}} \times \%\ \text{SOLIDS}$$

$$= 7{,}500\ \cancel{\text{GAL}} \times 8.34\,\frac{\text{LBS}}{\cancel{\text{GAL}}} \times \frac{3.6}{100}$$

$$= 7{,}500 \times 8.34 \times 0.036$$

= 2,252 POUNDS DRY SOLIDS

SLUDGE POUNDS CALCULATIONS

1. Given the following information, calculate the pounds of dry solids and the pounds of volatile solids:

VOLUME OF SLUDGE	7,500 GALLONS
SOLIDS CONCENTRATION	3.6%
VOLATILE SOLIDS	78%

LBS VOLATILE SOLIDS =

LBS DRY SOLIDS X % VOLATILE SOLIDS

$$= \quad 2{,}252 \text{ LBS DRY SOLIDS} \times \frac{78}{100}$$

$$= 2{,}252 \times 0.78$$

= 1,756.6 POUNDS VOLATILE SOLIDS

SLUDGE POUNDS CALCULATIONS

2. **Given the following information, calculate the pounds of dry solids and the pounds of volatile solids:**

VOLUME OF SLUDGE	6,000 GALLONS
SOLIDS CONCENTRATION	3.0%
VOLATILE SOLIDS	73%

LBS DRY SOLIDS =

$$\text{GALS WET} \times 8.34\,\frac{\text{LBS}}{\text{GAL}} \times \%\ \text{SOLIDS}$$

$$= 6{,}000\ \cancel{\text{GAL}} \times 8.34\,\frac{\text{LBS}}{\cancel{\text{GAL}}} \times \frac{3.0}{100}$$

$$= 6{,}000 \times 8.34 \times 0.030$$

= 1501 POUNDS DRY SOLIDS

SLUDGE POUNDS CALCULATIONS

2. **Given the following information, calculate the pounds of dry solids and the pounds of volatile solids:**

VOLUME OF SLUDGE	6,000 GALLONS
SOLIDS CONCENTRATION	3.0%
VOLATILE SOLIDS	73%

LBS VOLATILE SOLIDS =

LBS DRY SOLIDS X % VOLATILE SOLIDS

$$= \text{1,501 LBS DRY SOLIDS} \times \frac{73}{100}$$

$$= 1{,}501 \times 0.73$$

= 1,095.7 POUNDS VOLATILE SOLIDS

ORGANIC LOADING CALCULATIONS

Organic (Solids) Loading Rate

Amount of Volatile Solids Added per Day
Compared to the Size (volume) of the Digester

$$\text{Organic Loading Rate} = \frac{\text{Amount of V.S.}}{\text{Volume of Digester}}$$

Pounds of Volatile Solids per Day per Cubic Foot

0.02 to 0.10 # Vol. Solids/Day/Ft^3

Sometimes as
Pounds of Volatile Solids per Day per 1000 Cubic Feet

20 to 100 # Vol. Solids/Day/1000Ft^3

Digester Organic Loading

AMOUNT

of Organic Solids added to a digester

related to the

SIZE

of the digester.

$$\text{O.L.} = \frac{\text{Amount of Organic Solids}}{\text{Digester Volume}}$$

$$\text{O.L.} = \frac{\text{Volatile Solids, pounds /day}}{\text{Digester Volume, cubic feet}}$$

Digester Organic Loading

Data:

Digester Volume	= 30,000 ft^3
Raw sludge pumped	= 9,000 gal/day
Raw sludge solids concentration	= 4.0 %
Raw sludge volatile solids	= 70.0 %

Calculate the organic loading into the digester in lbs of volatile solids per day per ft^3

LBS VOLATILE SOLIDS =

GAL PUMPED X 8.34 lbs/gal X % Solids (decimal) X % Volatile (decimal)

= 9,000 gal/day X 8.34 lbs/gal X 0.04 x 0.70

= 2,102 lbs/day

$$\text{ORGANIC LOADING} = \frac{2{,}102\ \text{lbs/day}}{30{,}000\ \text{ft}^3}$$

$$\boxed{= 0.07\ \text{lbs/day/ft}^3}$$

Digester Organic Loading

Practice Problems

1. Data:

Digester Volume	=	21,500 ft^3
Raw sludge pumped	=	5,500 gal/day
Raw sludge solids concentration	=	3.1 %
Raw sludge volatile solids	=	76 %

Calculate the organic loading into the digester in lbs of volatile solid per day per ft^3.

2. Data:

Digester Volume	=	11,000 ft^3
Raw sludge pumped	=	4,600 gal/day
Raw sludge solids concentration	=	3.5 %
Raw sludge volatile solids	=	74 %

Calculate the organic loading into the digester in lbs of volatile solid per day per ft^3.

Work Calculations on Separate Paper
Answers Given on Next Slides

Digester Organic Loading

Practice Problems

1. Data:

Digester Volume	= 21,500 ft^3
Raw sludge pumped	= 5,500 gal/day
Raw sludge solids concentration	= 3.1 %
Raw sludge volatile solids	= 76 %

Calculate the organic loading into the digester in lbs of volatile solid per day per ft^3.

LBS VOLATILE SOLIDS =

GAL PUMPED X 8.34 lbs/gal X % Solids (decimal) X % Volatile (decimal)

= 5,500 gal/day X 8.34 lbs/gal X 0.031 x 0.76

= 1,080.7 lbs/day

$$\text{ORGANIC LOADING} = \frac{1{,}080.7 \text{ lbs/day}}{21{,}500 \text{ ft}^3}$$

$$\boxed{= 0.050 \text{ lbs/day/ft}^3}$$

Digester Organic Loading

Practice Problems

2. Data:

Digester Volume	= 11,000 ft^3
Raw sludge pumped	= 4,600 gal/day
Raw sludge solids concentration	= 3.5 %
Raw sludge volatile solids	= 74 %

Calculate the organic loading into the digester in lbs of volatile solid per day per ft^3.

LBS VOLATILE SOLIDS =

GAL PUMPED X 8.34 lbs/gal X % Solids (decimal) X % Volatile (decimal)

= 4,600 gal/day X 8.34 lbs/gal X 0.035 x 0.74

= 993.6 lbs/day

$$\text{ORGANIC LOADING} = \frac{993.6 \text{ lbs/day}}{11{,}000 \text{ ft}^3}$$

$$\boxed{= 0.090 \text{ lbs/day/ft}^3}$$

Organic (Solids) Loading Rate

(page 28)

Amount of Volatile Solids Added per Day
Compared to the Size (volume) of the Digester

$$\text{Organic Loading Rate} = \frac{\text{Amount of V.S.}}{\text{Volume of Digester}}$$

Pounds of Volatile Solids per Day per Cubic Foot

0.02 to 0.10 # Vol. Solids/Day/Ft^3

Sometimes as
Pounds of Volatile Solids per Day per 1000 Cubic Feet

20 to 100 # Vol. Solids/Day/1000Ft^3

OPERATION AND CONTROL

3. LOADING

Pump Thick Sludge

(High % Total Solids)

Excess Water Requires More Heat
Excess Water Reduces Holding Time
Excess Water Removes Bacteria and Buffers

Pump Several Times per Day

Uniform Digester Loading
Uniform Plant Operations

OPERATION AND CONTROL

3. LOADING

% Total Solids

% Total Volatile Solids

Organic (Solids) Loading

Hydraulic Loading

OPERATION AND CONTROL

1. BACTERIA
2. FOOD
3. LOADING
4. CONTACT

CONTACT (MIXING)

1. CONTACT
   Bacteria and Food

2. HEAT DISTRIBUTION
   Even Throughout

3. MINIMIZE SETTLING
   Reduces Available Volume

4. MINIMIZE SCUM
   Operational Problems

OPERATION AND CONTROL

1. BACTERIA
2. FOOD
3. LOADING
4. CONTACT
5. ENVIRONMENT

TEMPERATURE

Temperature controls activity of bacteria.

Psychrophilic

50° F to 68° F

Mesophilic

68° F to 113° F

Best 85° F to 100° F

Thermophilic

Above 113° F

Best 120° F to 135° F

OPERATION AND CONTROL

ENVIRONMENT

Temperature Control

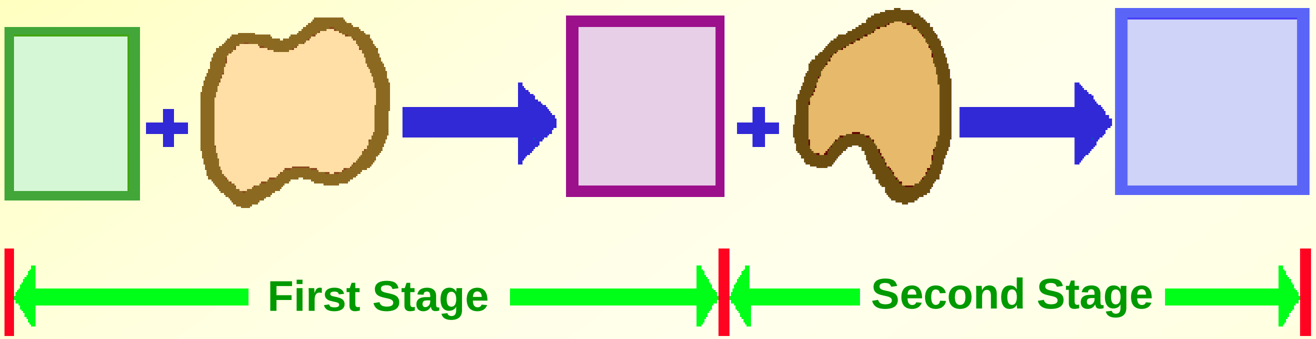
90 to 95^{0} F

Methane Formers Very Sensitive to Changes

Good Mixing Essential

SUMMARY

Balance



Poor Mixing

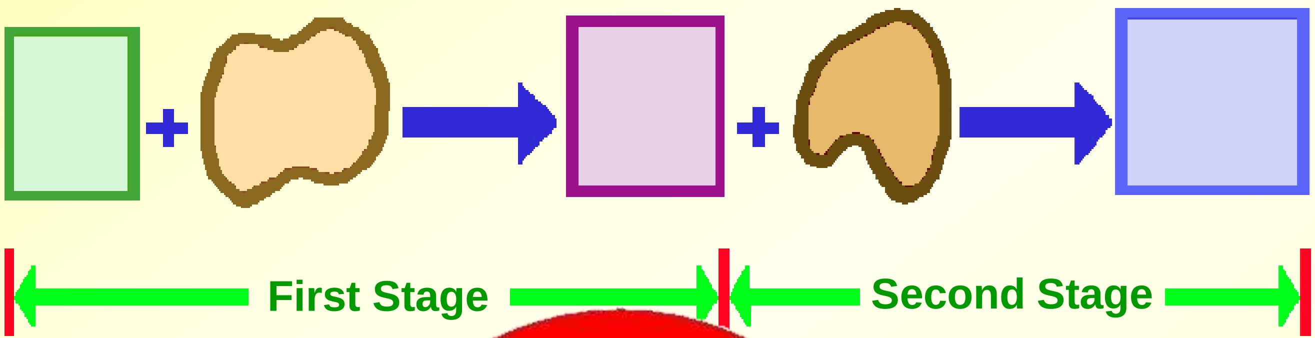
Over Loading

Excess Water

Temperature

SUMMARY

Balance



Poor Mixing

Over Loading

Excess Water

Temperature

OPERATION AND CONTROL

ENVIRONMENT

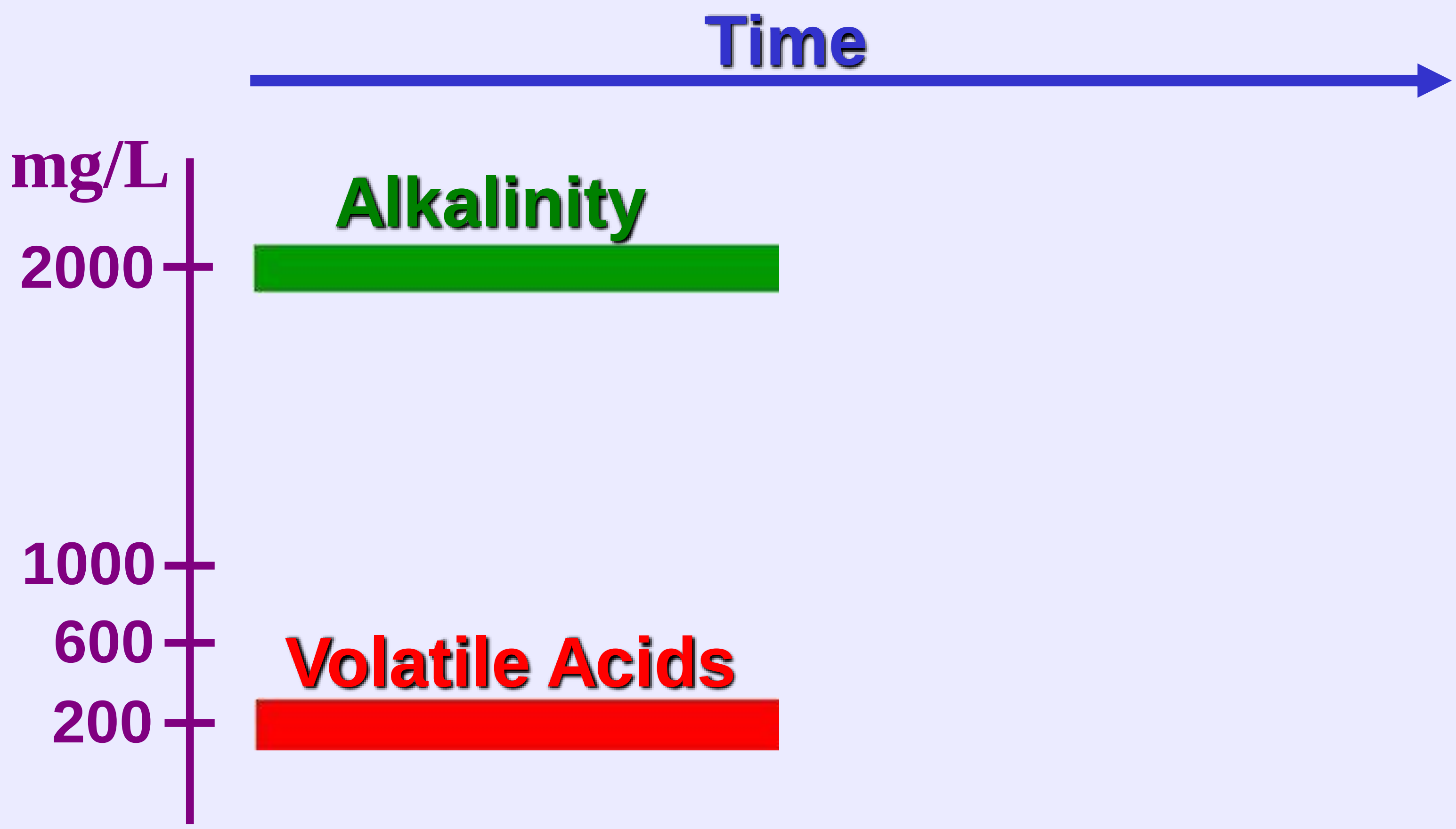
Volatile Acid/Alkalinity Relationship

Ratio

$$\frac{\text{Volatile Acids, mg/L}}{\text{Alkalinity, mg/L}}$$

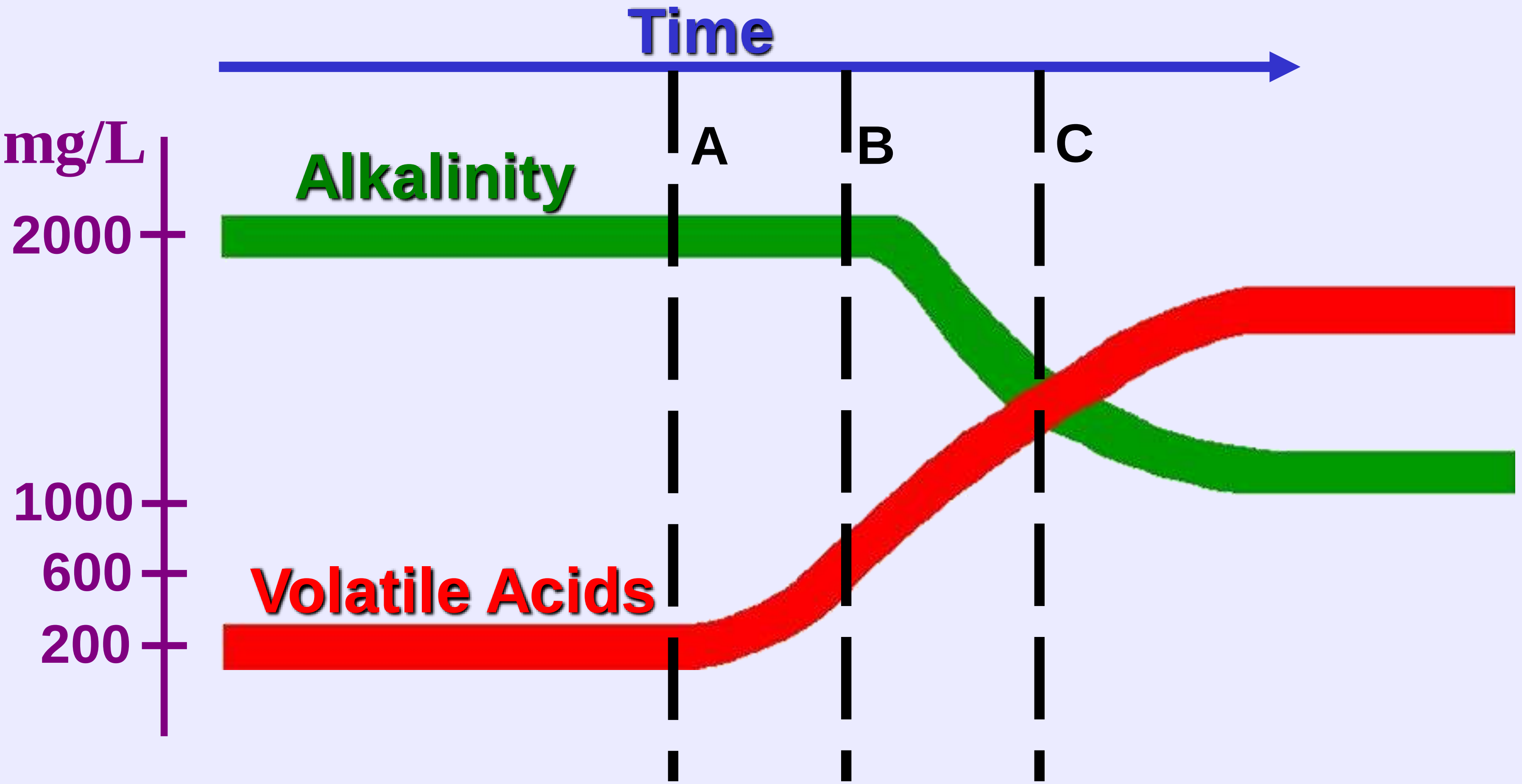
$$\frac{140 \text{ mg/L}}{2{,}800 \text{ mg/L}} = 0.05$$

I. Relationship of Volatile Acids to Alkalinity



Graph of Digester With Good Buffering Capacity
(Low V.A. at 200 mg/L Compared to Alk. of 2000 mg/L)

I. Relationship of Volatile Acids to Alkalinity

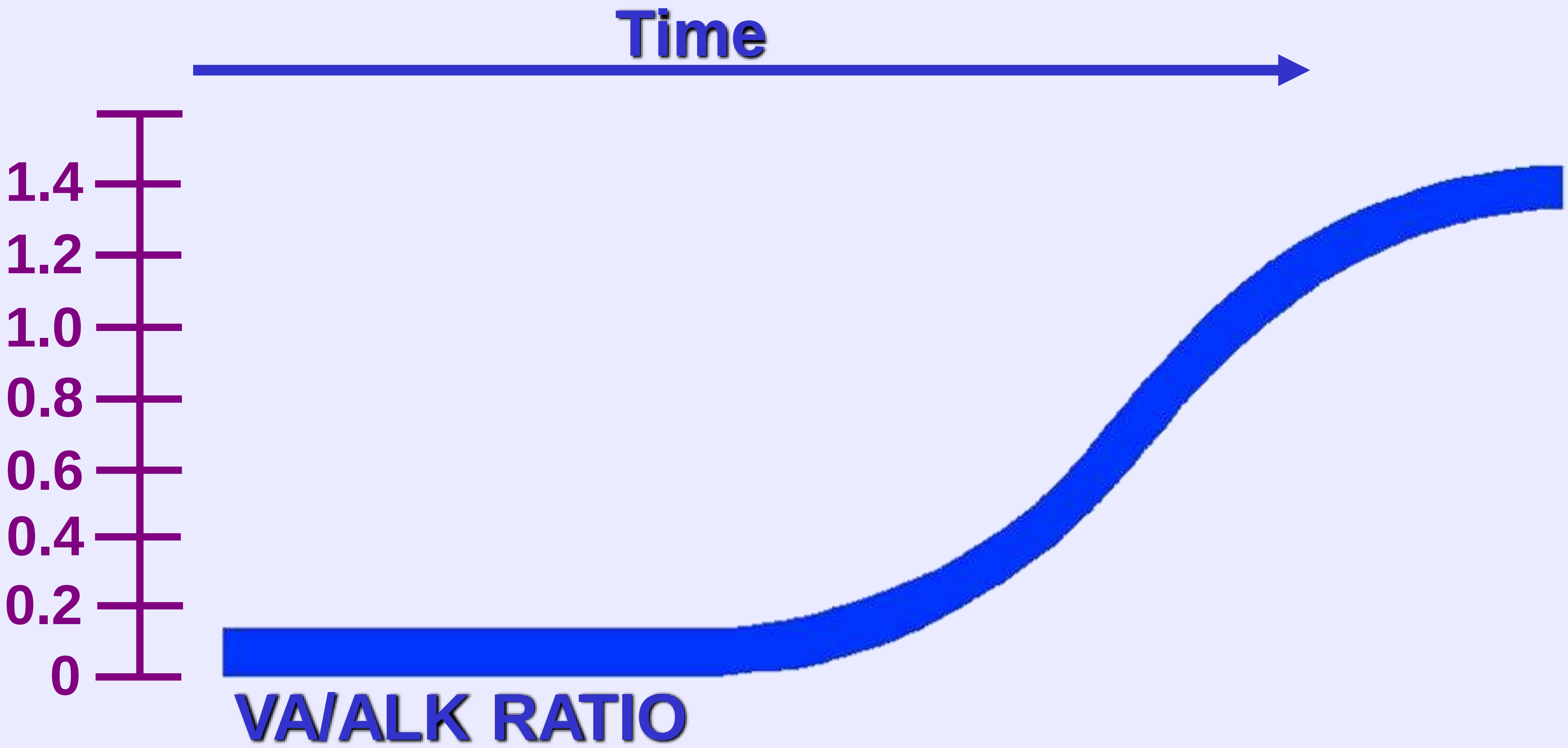


At Time A Something has Happened to Cause the Volatile Acids to Increase

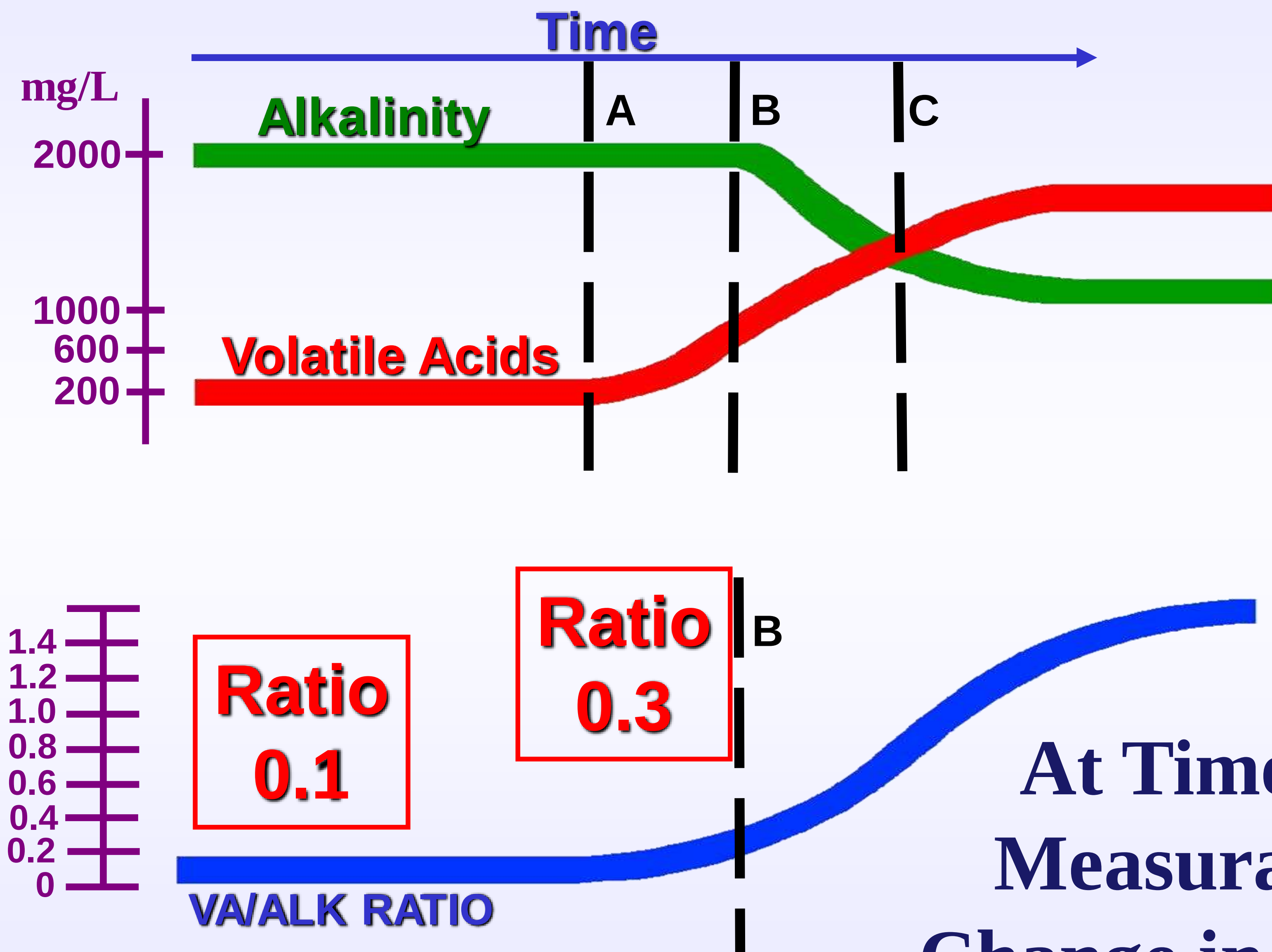
Followed by a Decrease in Alkalinity at Time B

At Time C the Digester has Become Sour

II. Volatile Acids / Alkalinity Ratio

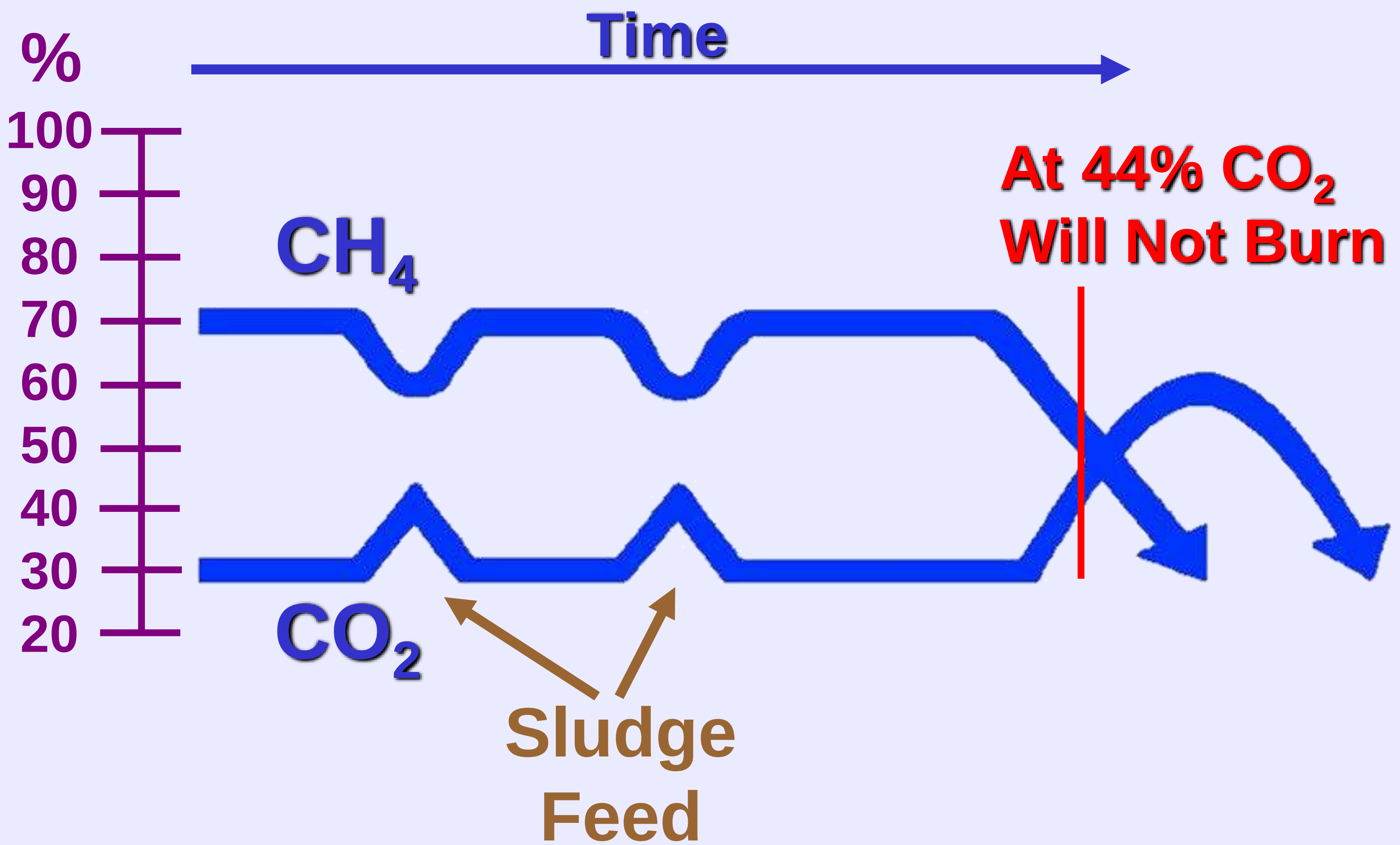


Comparing Graph I to Graph II

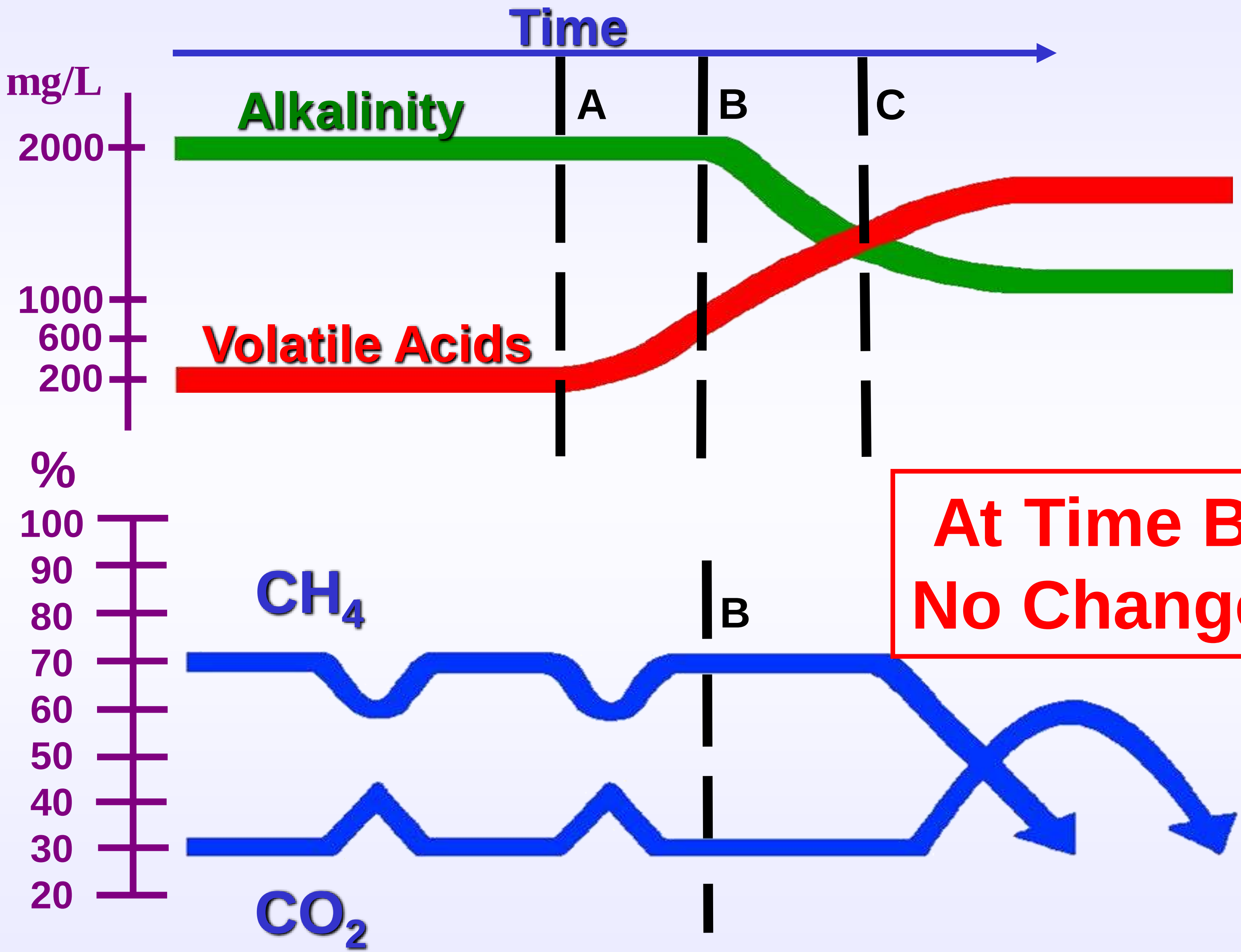


At Time B Measurable Change in Ratio

III. Relationship of Methane and Carbon Dioxide

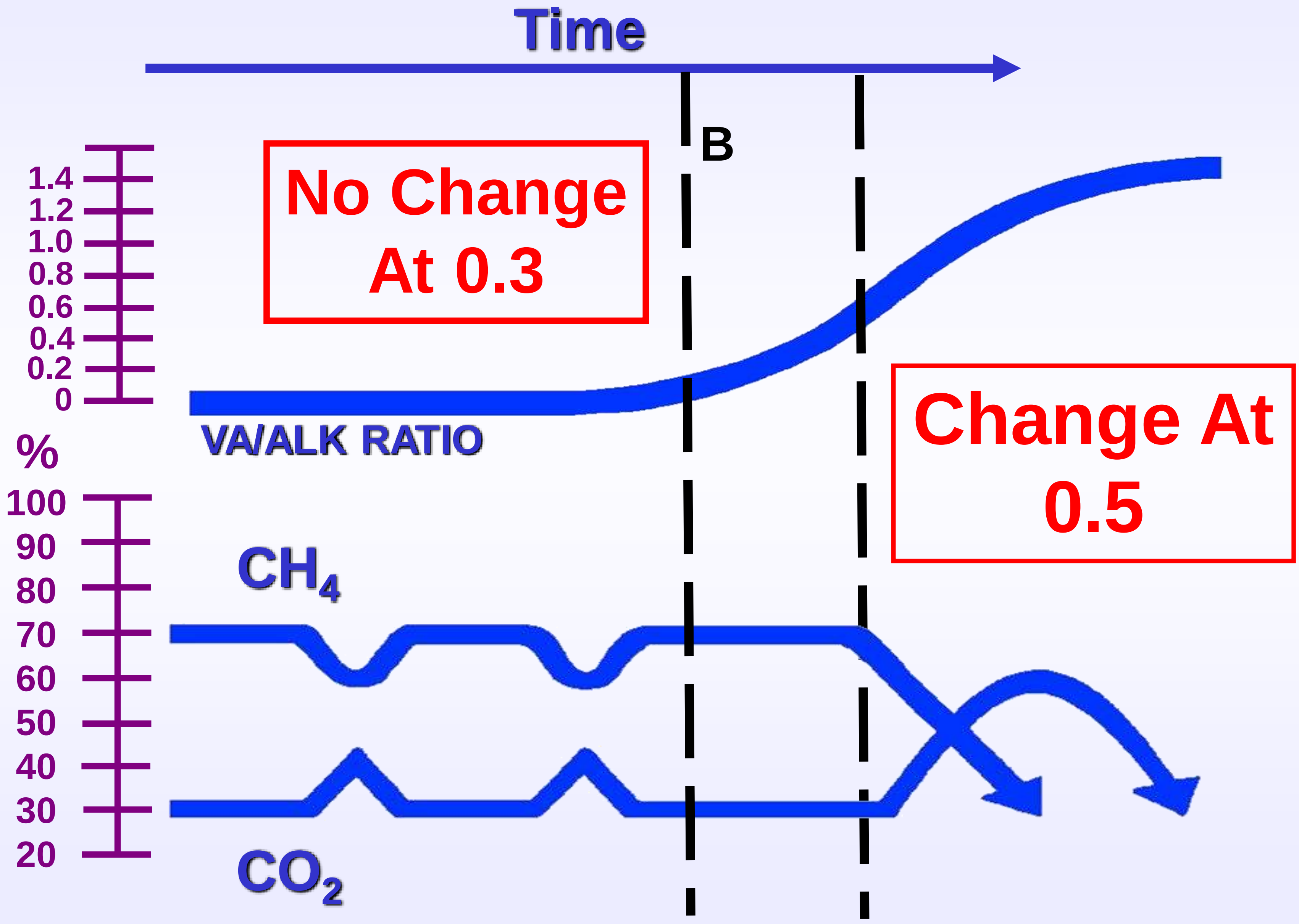


Comparing Graph I to Graph III



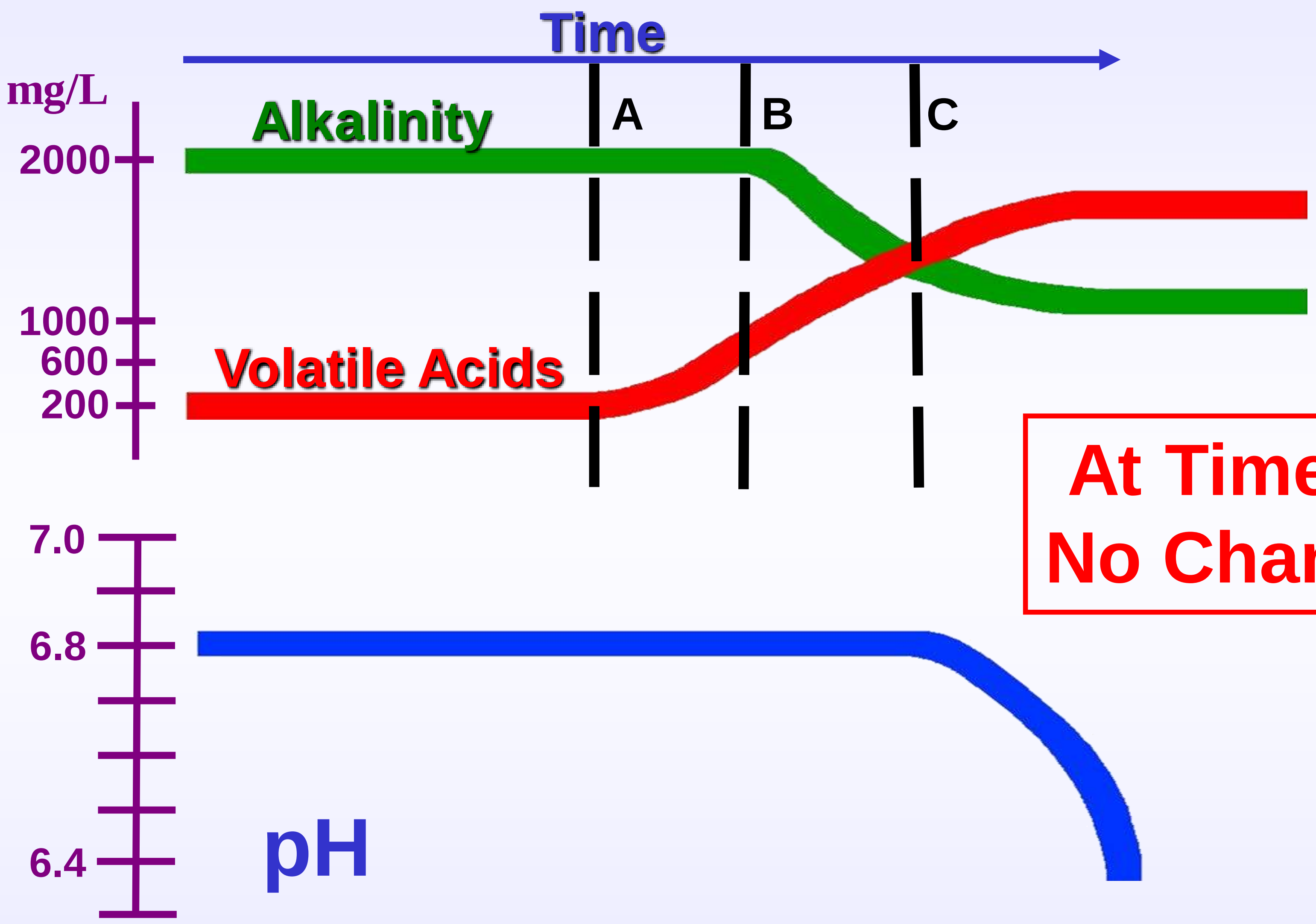
At Time B
No Change

Comparing Graph II to Graph III



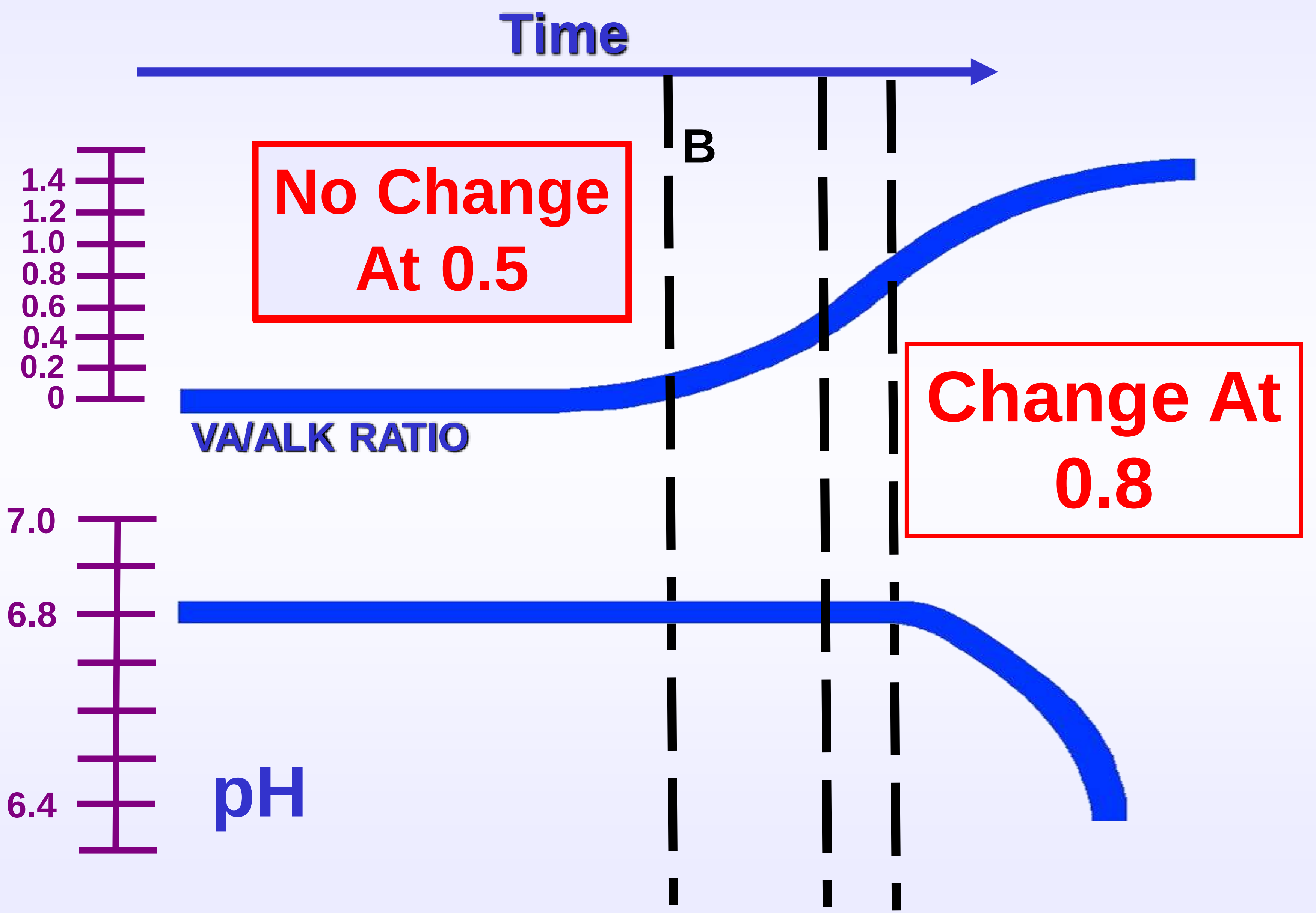
IV. Relationship of pH Change

Comparing Graph I to Graph IV



At Time B
No Change

Comparing Graph II to Graph IV



<u>OPERATION</u> <u>AND</u> <u>CONTROL</u>

ENVIRONMENT

Order of Measurable Changes When A Digester is <u>BECOMING</u> Upset

1. An Increase in VA/Alk. Ratio
2. An Increase in % CO_2
3. Inability of Digester Gas to Burn
4. A Decrease in pH

OPERATION AND CONTROL

ENVIRONMENT

Volatile Acid/Alkalinity Ratio

First Measurable Change

Volatile Acids - Low Compared to Alkalinity

Best Operation - Ratio Below 0.4

OPERATION AND CONTROL

ENVIRONMENT

Volatile Acid/Alkalinity Ratio

Response To Increase

Extend Mixing Time

Heat More Evenly

Decrease Sludge Withdrawal Rate

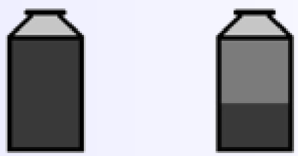
Return Sludge From Secondary Digester

*Add Alkalinity (Bicarbonate)

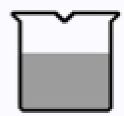
VOLATILE ACIDS AND TOTAL ALKALINITY

Outline of Procedure

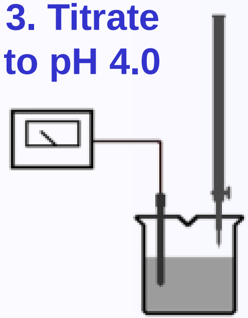
1. Separate Solids



2. Measure 50 mL

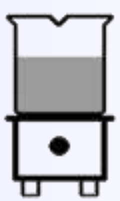


3. Titrate to pH 4.0



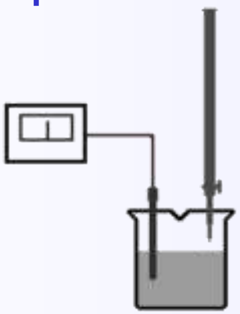
4. Record mL used, Then Titrate to pH 3.3

5. Lightly Boil Sample 3 Min.



6. Cool in Water Bath

7. Titrate from pH 4.0 to 7.0



Digester Efficiency

Reduction
Of
Volatile Solids

% Reduction of Volatile Solids

% Reduction of Volatile Solids =

$$\frac{\%\text{Volatiles In} - \%\text{ Volatiles Out}}{\%\text{ Volatile In} - (\%\text{ Volatile In} \times \%\text{ Volatile Out})} \times 100\%$$

% Reduction of Volatile Solids =

$$\frac{\text{In} - \text{Out}}{\text{In} - (\text{In} \times \text{Out})} \times 100\ \%$$

NOTE: % Must be as Decimals

72% = 72/100 = .72

% Reduction of Volatile Solids

% Reduction of Volatile Solids =

$$\frac{\%\text{Volatiles In} - \%\text{ Volatiles Out}}{\%\text{ Volatile In} - (\%\text{ Volatile In} \times \%\text{ Volatile Out})} \times 100\%$$

EXAMPLE:

Volatile Solids in Raw Sludge = 68%
Volatile Solids in Digested Sludge = 45%

% Reduction of Volatile Solids =

$$\frac{0.68 - 0.45}{0.68 - (0.68 \times 0.45)} \times 100\%$$

$$\frac{0.68 - 0.45}{0.68 - 0.31} \times 100\% = \frac{0.23}{0.37} \times 100\%$$

$$= 62\%$$

% Reduction of Volatile Solids

1. Calculate the percent reduction of volatile solids in a digester with the following data:

   73%Vol. Solids in the raw sludge
   51%Vol. Solids in the digested sludge

2. Calculate the percent reduction of volatile solids in a digester with the following data:

   73.4%Vol. Solids in the raw sludge
   50.5%Vol. Solids in the digested sludge

Work Calculations on Separate Paper
Answers Given on Next Slides

1. Calculate the percent reduction of volatile solids in a digester with the following data:

73%Vol. Solids in the raw sludge
51%Vol. Solids in the digested sludge

% Reduction of Volatile Solids =

$$\frac{\text{In - Out}}{\text{In - (In X Out)}} \text{ X } 100\ \%$$

$$= \frac{.73 - .51}{.73 - (\,.73 \text{ X } .51)} \text{ X } 100\ \%$$

$$= \frac{.73 - .51}{.73 - .372} \text{ X } 100\ \%$$

$$= \frac{.22}{.358} \text{ X } 100\ \% \quad \boxed{= 61.5\ \%}$$

2. Calculate the percent reduction of volatile solids in a digester with the following data:

73.4%Vol. Solids in the raw sludge
50.5%Vol. Solids in the digested sludge

% Reduction of Volatile Solids =

$$\frac{\text{In - Out}}{\text{In - (In X Out)}} \text{ X } 100\ \%$$

$$= \frac{.734 - .505}{.734 - (\ .734 \text{ X } .505)} \text{ X } 100\ \%$$

$$= \frac{.734 - .505}{.734 - .371} \text{ X } 100\ \%$$

$$= \frac{.229}{.363} \text{ X } 100\ \%$$

$$\boxed{= 63.1\ \%}$$

Gas Production

Digesters Produce Methane and Carbon Dioxide

Normal: 25% to 35% CO_2 by Volume

As the Bacteria Break Down the Volatile Organics

CHANGE - Indicator of Conditions

Gas Production

Digesters Produce Methane and Carbon Dioxide

Normal: 65% to 70% Methane by Volume

Burns: > 56% Methane

Usable as Fuel: > 62% Methane

Can Be Used To:

- **Heat the Digester**
- **Power Engines**
- **Heat Buildings**

Gas Production

Digesters Produce
Methane and Carbon Dioxide

Normal: 65% to 70% Methane by Volume

Burns: > 56% Methane

Usable as Fuel: > 62% Methane

Healthy Digester Should Produce:
7 to 12 cubic feet/pound vol. solids Destroyed

GAS PRODUCTION CALCULATION

Data:

Raw sludge pumped in per day	= 9,000 gallons
Raw sludge solids concentration	= 4%
Raw sludge volatile solids	= 65%
% Volatile Solids Reduction	= 48%
Gas production per day	= 8,000 ft^3

What is the gas production in terms of cubic feet per pound of volatile solids destroyed?

LBS VOLATILE SOLIDS =

GAL PUMPED X 8.34 lbs/gal X % Solids (decimal) X % Volatile (decimal)

= 9,000 gal/day X 8.34 lbs/gal X 0.04 x 0.65

= 1,951.6 lbs/day

48% of the Volatile Solids were Destroyed

1,951.6 lbs X .48 = 937 lbs Vol. Solids Destroyed

GAS PRODUCTION CALCULATION

Data:

Raw sludge pumped in per day	= 9,000 gallons
Raw sludge solids concentration	= 4%
Raw sludge volatile solids	= 65%
% Volatile Solids Reduction	= 48%
Gas production per day	= 8,000 ft^3

What is the gas production in terms of cubic feet per pound of volatile solids destroyed?

Gas Production, cu.ft. / lb vol. solids Destroyed =

$$\frac{\text{8,000 cu. ft.}}{\text{937 lbs Vol. Solids Destroyed}}$$

= 8.5 cu ft / lb vol. solids destroyed

GAS PRODUCTION

1. Data:

Raw sludge pumped in per day	= 7,200 gallons
Raw sludge solids concentration	= 4%
Raw sludge volatile solids	= 67%
% Volatile Solids Reduction	= 53%
Gas production per day	= 7,850 ft^3

What is the gas production in terms of cubic feet per pound of volatile solids destroyed?

2. Data:

Raw sludge pumped in per day	= 2,300 gallons
Raw sludge solids concentration	= 3.4%
Raw sludge volatile solids	= 72.6%
% Volatile Solids Reduction	= 49.3%
Gas production per day	= 2,800 ft^3

What is the gas production in terms of cubic feet per pound of volatile solids destroyed?

Work Calculations on Separate Paper
Answers Given on Next Slides

GAS PRODUCTION

1. Data:

Raw sludge pumped in per day	= 7,200 gallons
Raw sludge solids concentration	= 4%
Raw sludge volatile solids	= 67%
% Volatile Solids Reduction	= 53%
Gas production per day	= 7,850 ft^3

What is the gas production in terms of cubic feet per pound of volatile solids destroyed?

Gas Production, cu.ft. / lb vol. solids Destroyed =

$$\frac{\text{Cubic Feet Gas}}{\text{Lbs. Vol. Solids Destroyed}}$$

% Vol. Slds. Destroyed (decimal) X Lbs. Vol. Slds. In

$$= \frac{7{,}850\ ft^3}{.53\ \text{X}\ 7{,}200\ \text{gal/day}\ \text{X}\ 8.34\ \text{lbs/gal}\ \text{X}\ 0.04\ \text{x}\ 0.67}$$

Lbs. Vol. Solids In

$$= \frac{7{,}850\ ft^3}{852.9\ \#\ \text{Vol. Slds. Destroyed}}$$

= 9.2 ft^3/Lb. Vol. Slds. Destroyed

GAS PRODUCTION

2. Data:

Raw sludge pumped in per day	= 2,300 gallons
Raw sludge solids concentration	= 3.4%
Raw sludge volatile solids	= 72.6%
% Volatile Solids Reduction	= 49.3%
Gas production per day	= 2,800 ft^3

What is the gas production in terms of cubic feet per pound of volatile solids destroyed?

$$\text{Gas Production, cu.ft. / lb vol. solids Destroyed} = \frac{\text{Cubic Feet Gas}}{\text{\% Vol. Slds. Destroyed (decimal) X Lbs. Vol. Slds. In}}$$

$$= \frac{2{,}800\ ft^3}{.493 \ \text{X}\ 2{,}300\ \text{gal/day}\ \text{X}\ 8.34\ \text{lbs/gal}\ \text{X}\ 0.034\ \text{x}\ 0.726}$$

$$= \frac{2{,}800\ ft^3}{233.4\ \text{\# Vol. Slds. Destroyed}} \boxed{= 12.0\ ft^3\text{/Lb. Vol. Slds. Destroyed}}$$

Anaerobic Digestion Process

Methane Formers:

Slow Growers

Very Sensitive to Changes

Loading

pH

Temperature

Digester Operation Depends On Maintaining Proper Environment for METHANE FORMERS

BALANCE !

ANAEROBIC SLUDGE DIGESTION PROCESS

Prepared By
Michigan Department of Environmental Quality
Operator Training and Certification Unit