ANAEROBIC SLUDGE DIGESTION PROCESS

TEJASREE.VEMURI
Asst. PROFESSOR
SMGG

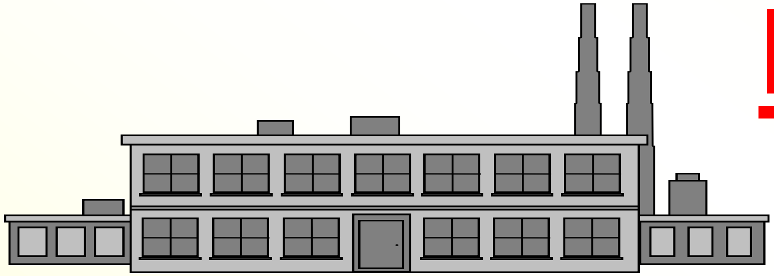
WASTEWATER

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

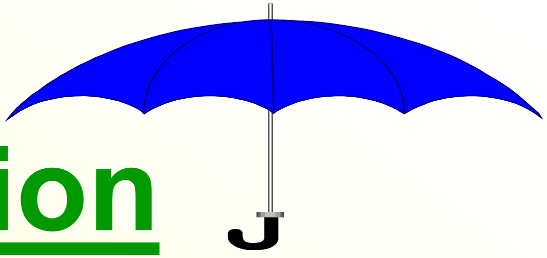
Sources of Wastewater

Domestic

Industrial



Infiltration



CHARACTERISTICS OF WASTEWATER

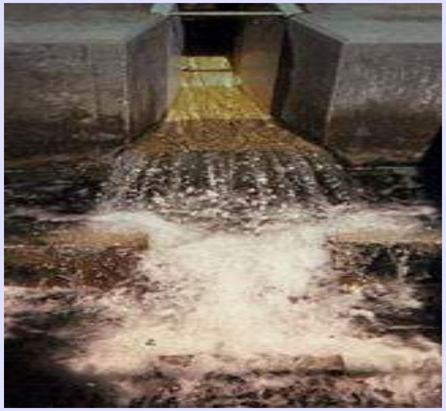
Materials Toxic to Biota

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

Human Health Hazards

- Pathogens
- Nitrate
- Toxic Materials

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



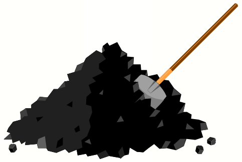
PROTECTION OF NATURAL RESOURCES

PROTECTION OF PUBLIC HEALTH

CHARACTERISTICS OF WASTEWATER

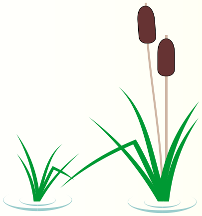
Treatment Concerns

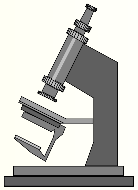
Solids



Oxygen Demand

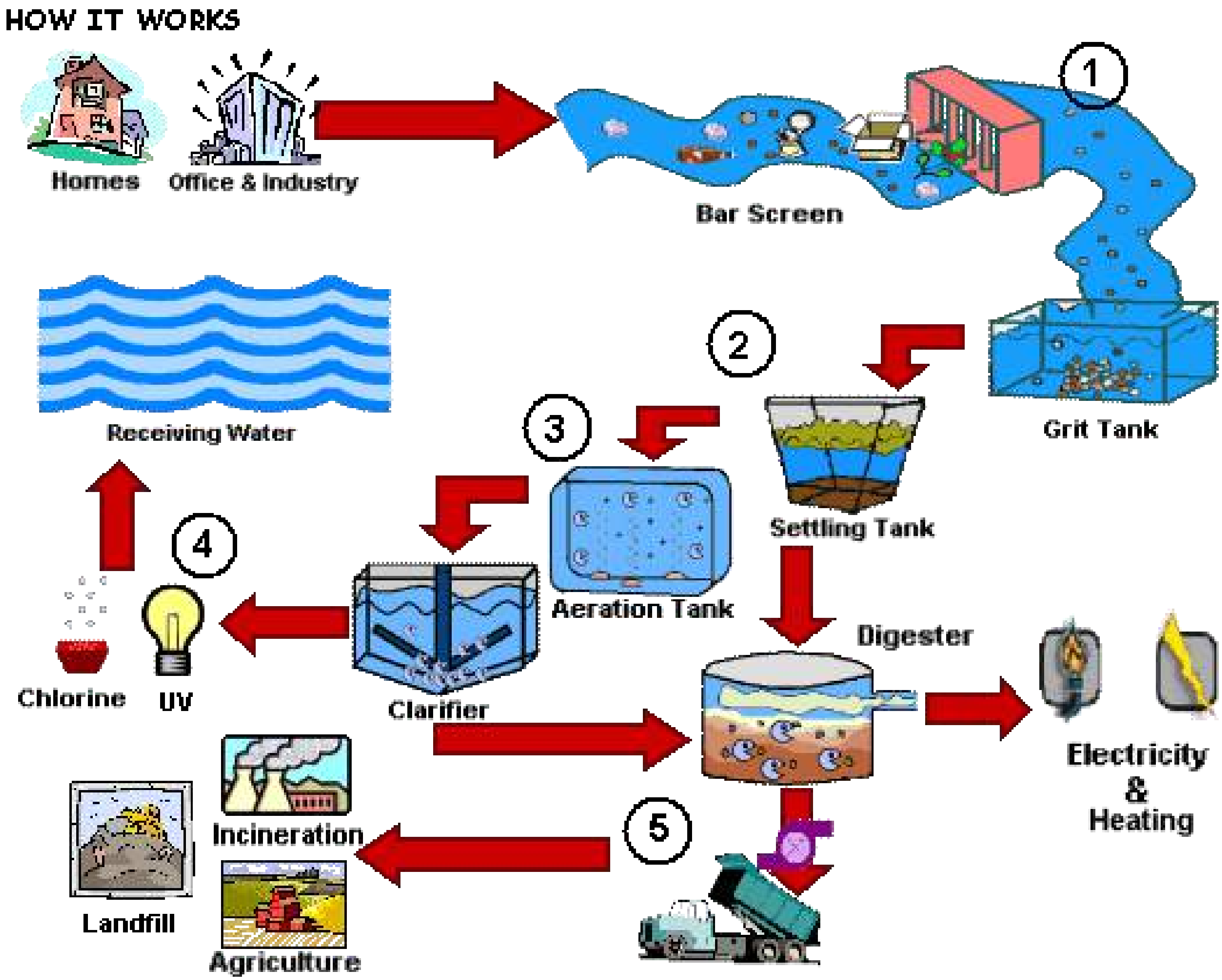
Nutrients





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

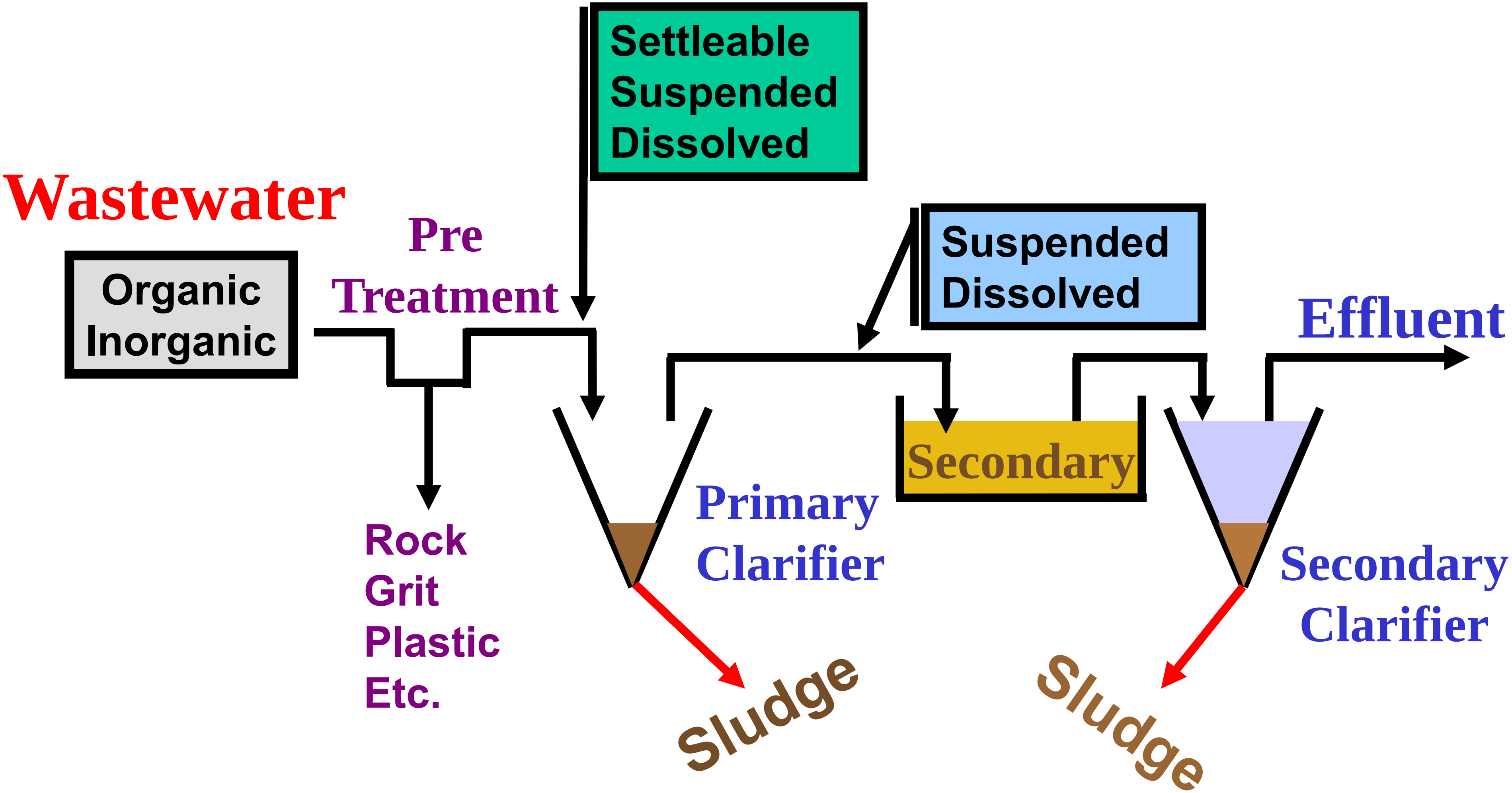
30 - 40 % BOD

Secondary (Biological) Treatment

90+ % Suspended Solids

90+ % BOD

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



Wastewater

Organic
Inorganic

Pre
Treatment

Settleable
Suspended
Dissolved

Rock
Grit
Plastic
Etc.

Primary
Clarifier

Sludge

Suspended
Dissolved

Secondary

Effluent

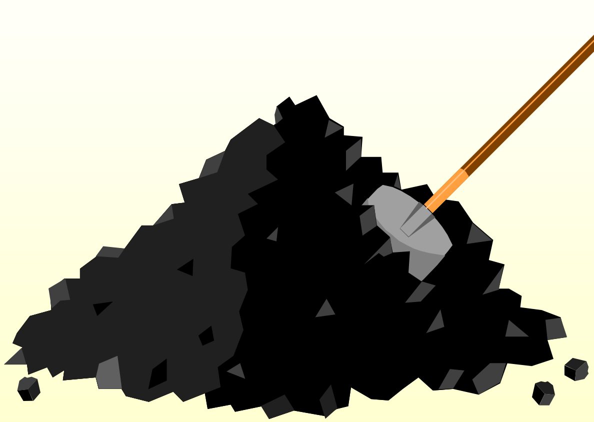
Secondary
Clarifier

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.

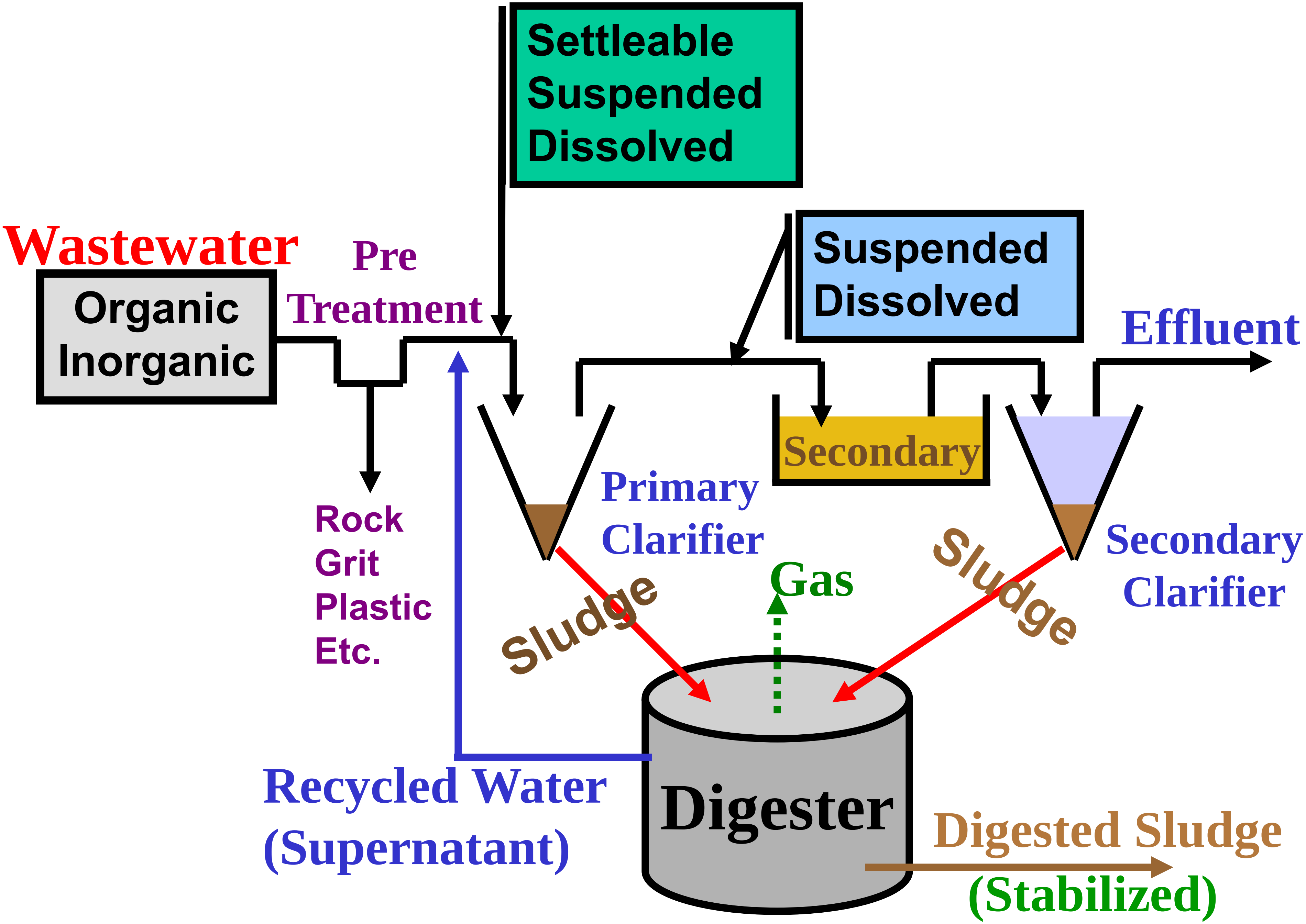


SLUDGE CHARACTERISTICS

- 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

Primary
Clarifier

Rock
Grit
Plastic
Etc.

Sludge

Gas

Sludge

Secondary
Clarifier

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

Aerobic

Use “Free” Oxygen

Anaerobic

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

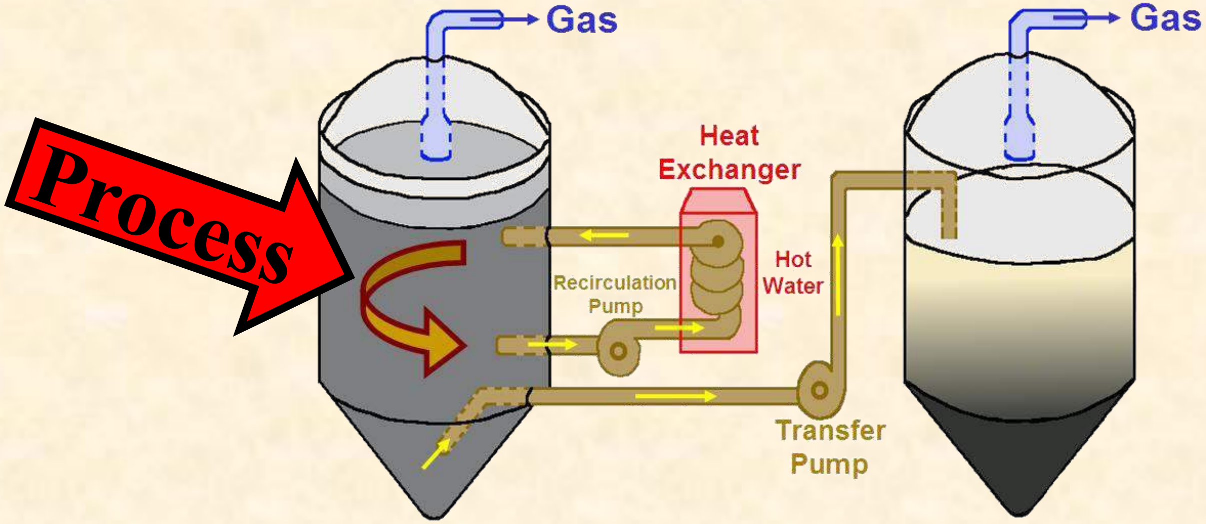
OR

“Two Phase” Process

Anaerobic Digestion Process

“TWO-STAGE” Process

This Does Not Mean Two Tanks



Process

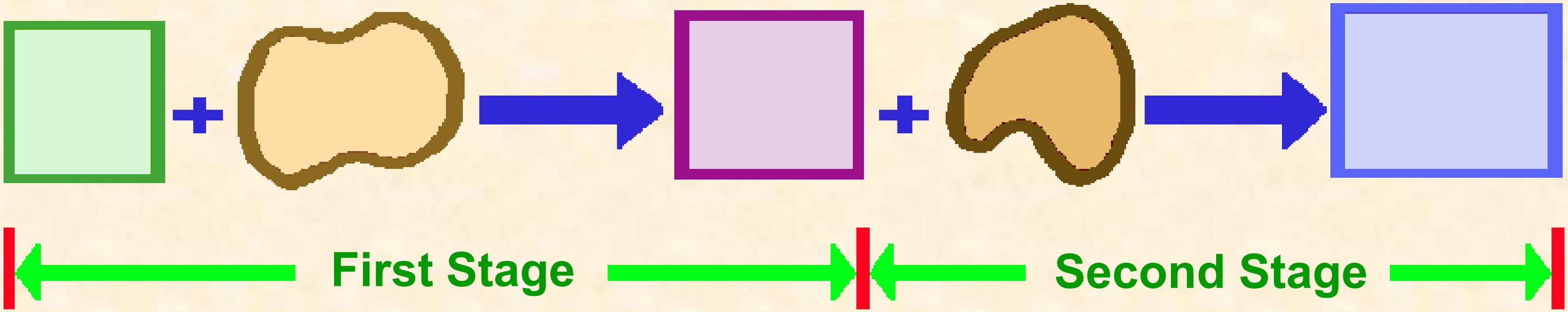
Anaerobic Digestion Process

“TWO-STAGE” Process

OR

“Two Phase” Process

Two Types of Bacteria
Each Relying On The Other



First Stage

Second Stage

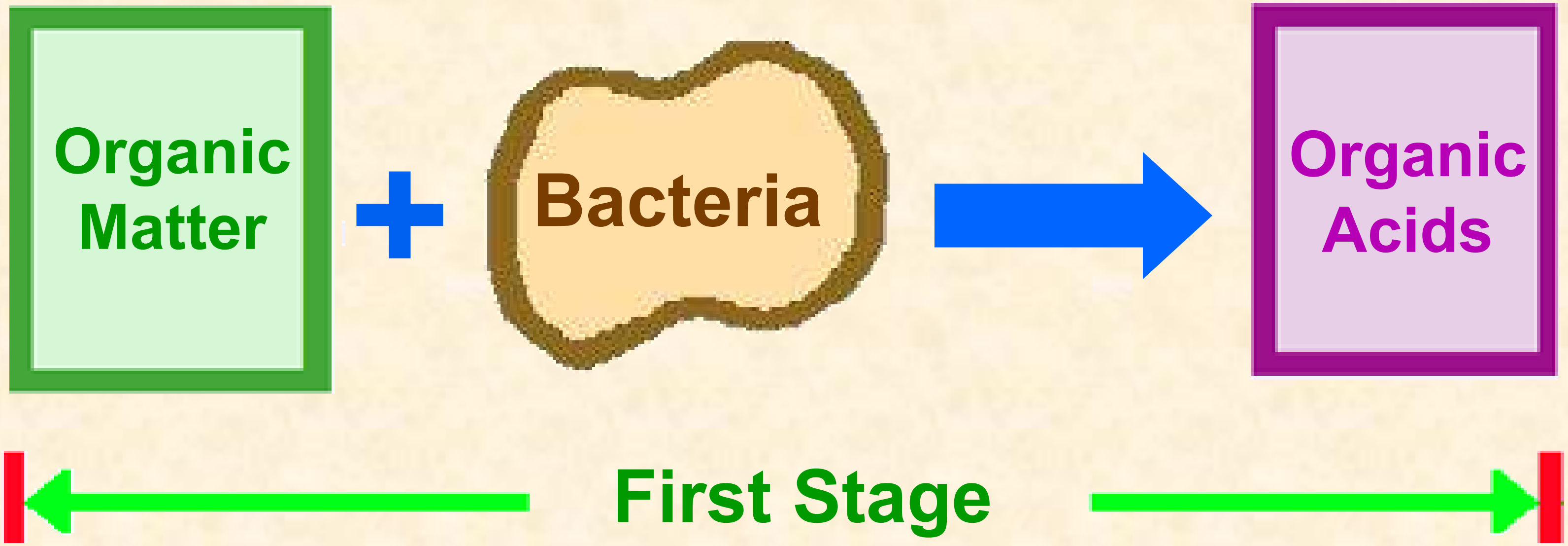
Anaerobic Digestion Process

First

Organic Material Changed

By Acid Forming Bacteria

To Simple Organic Material



Organic Matter + Bacteria → Organic Acids

First Stage

Anaerobic Digestion Process

First

Organic Material Changed

By Acid Forming Bacteria

To Simple Organic Material

Also Called Volatile Acids

Organic Acids

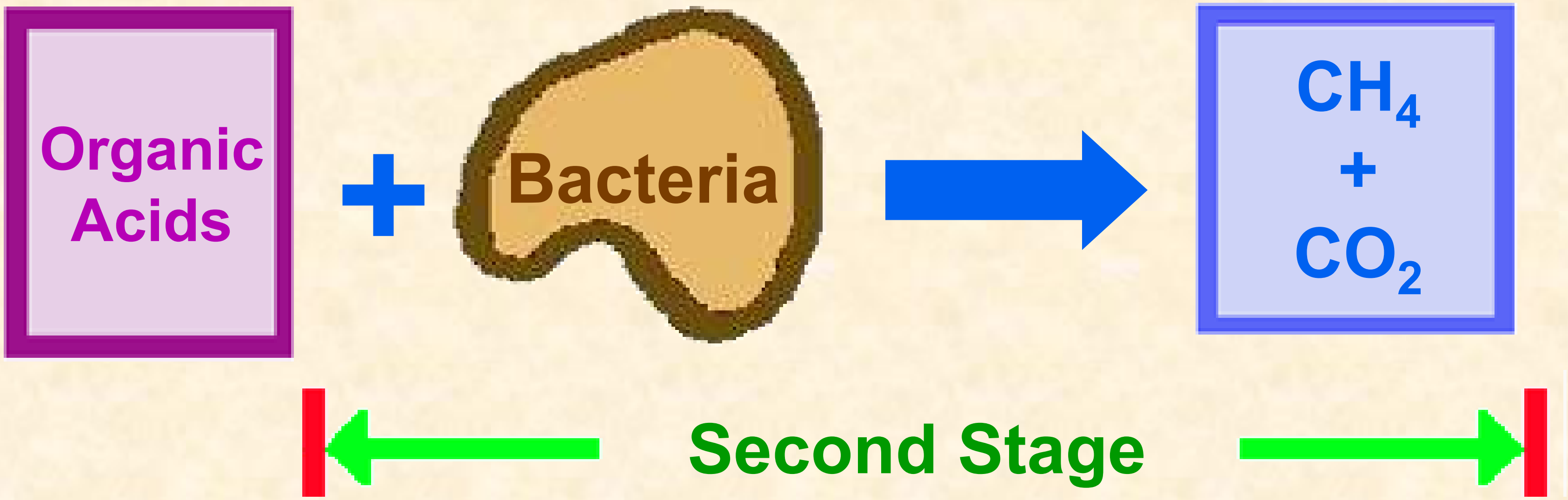
Anaerobic Digestion Process

Second

Methane-Forming Bacteria

Use Organic Acids

Produce Carbon Dioxide and Methane



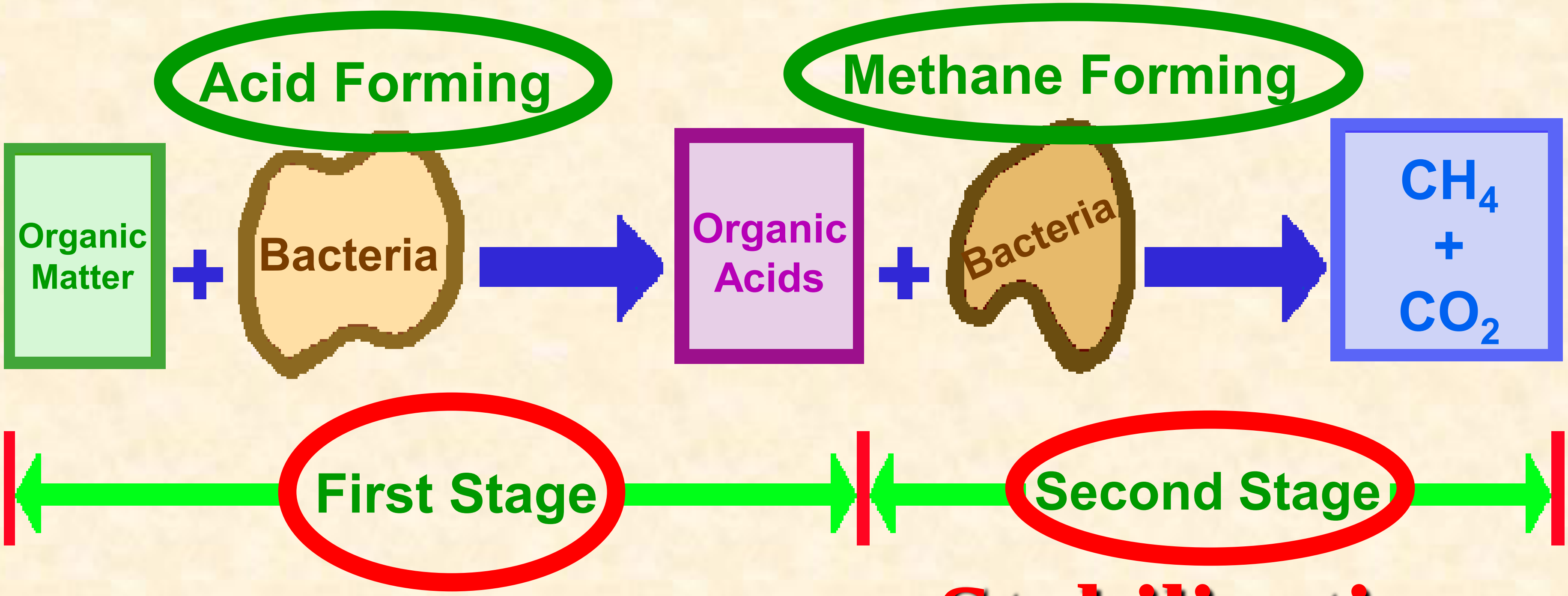
Organic Acids + Bacteria → CH_4 + CO_2

Second Stage

Anaerobic Digestion Process

Continuous Process

"TWO-STAGE" Process



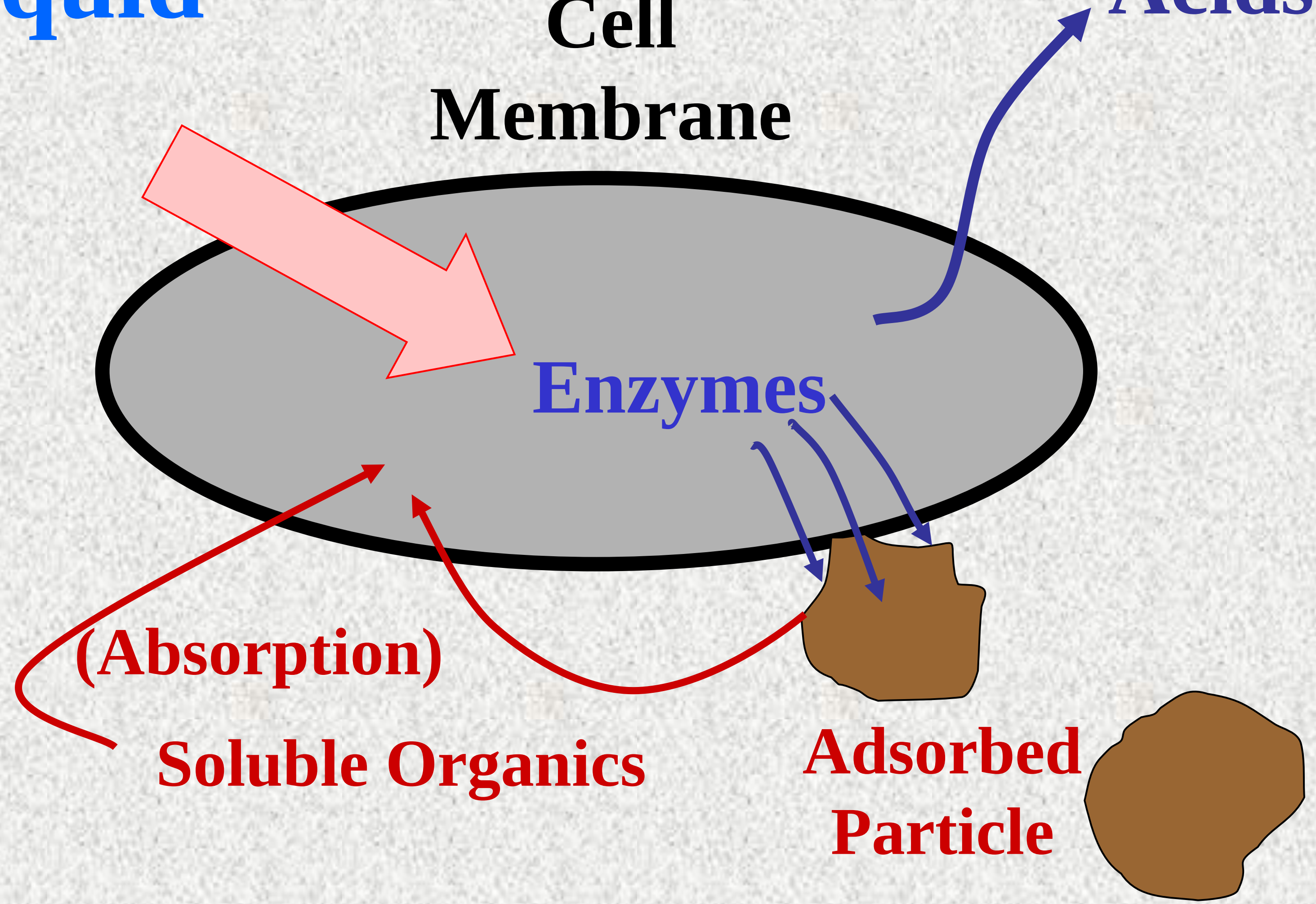
Stabilization

Anaerobic Digestion Process

Type of Food

Organic ~~Inorganic~~

Soluble Insoluble



Liquid

Cell
Membrane

Acids

Enzymes

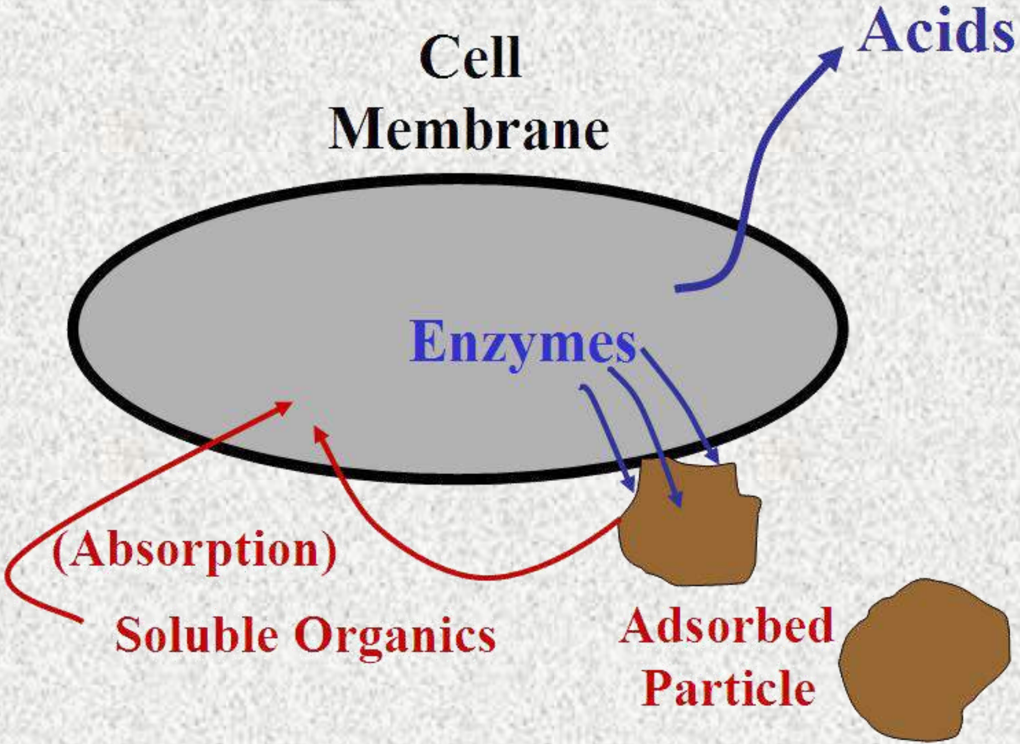
(Absorption)

Soluble Organics

Adsorbed
Particle

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

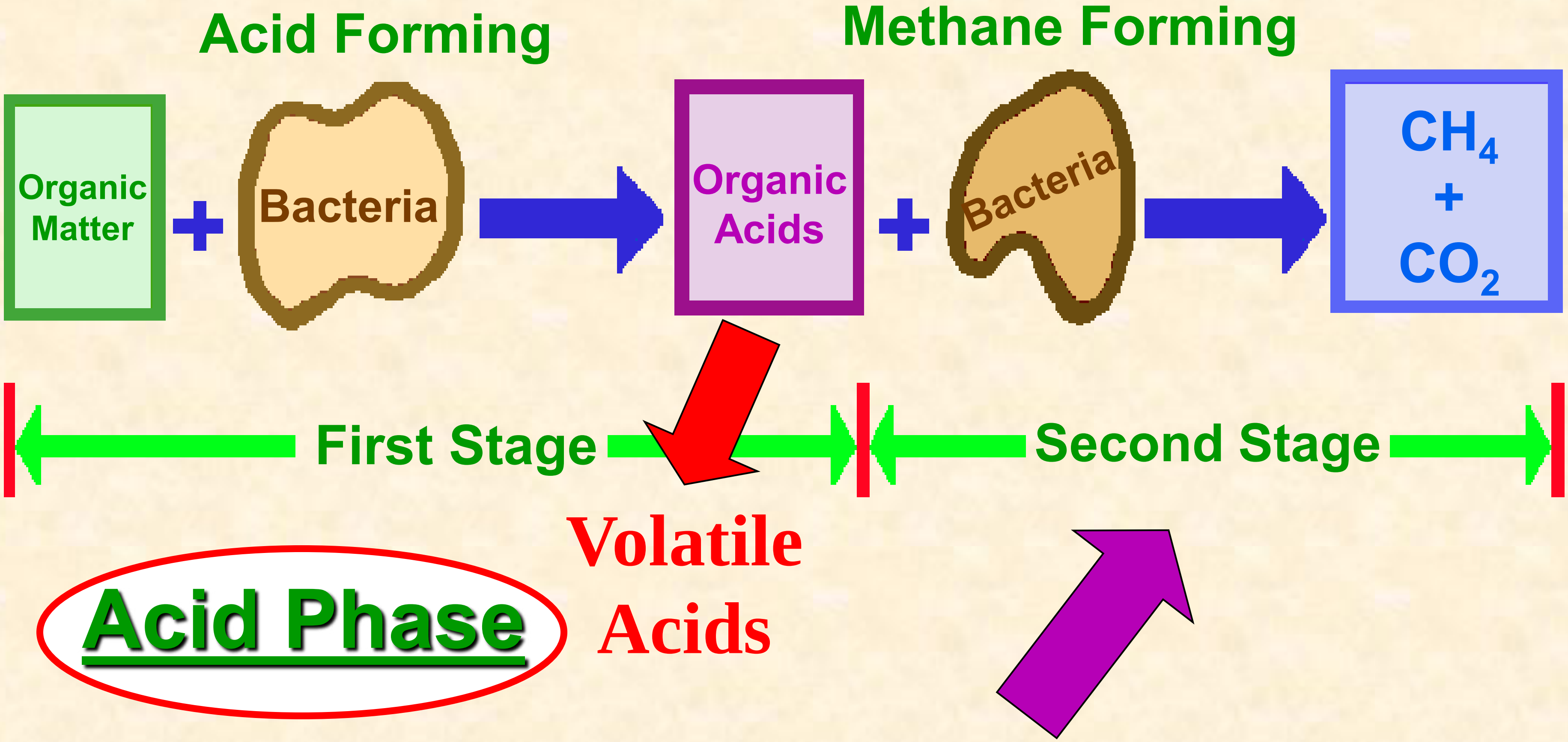
OR

"Two Phase" Process

Two Types of Bacteria
Each Relying On The Other

Must Be In Balance !

Anaerobic Digestion Process



Acid Forming

Methane Forming

Organic Matter + Bacteria → Organic Acids + Bacteria → CH_4 + CO_2

First Stage

Second Stage

Volatile Acids

Acid Phase

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

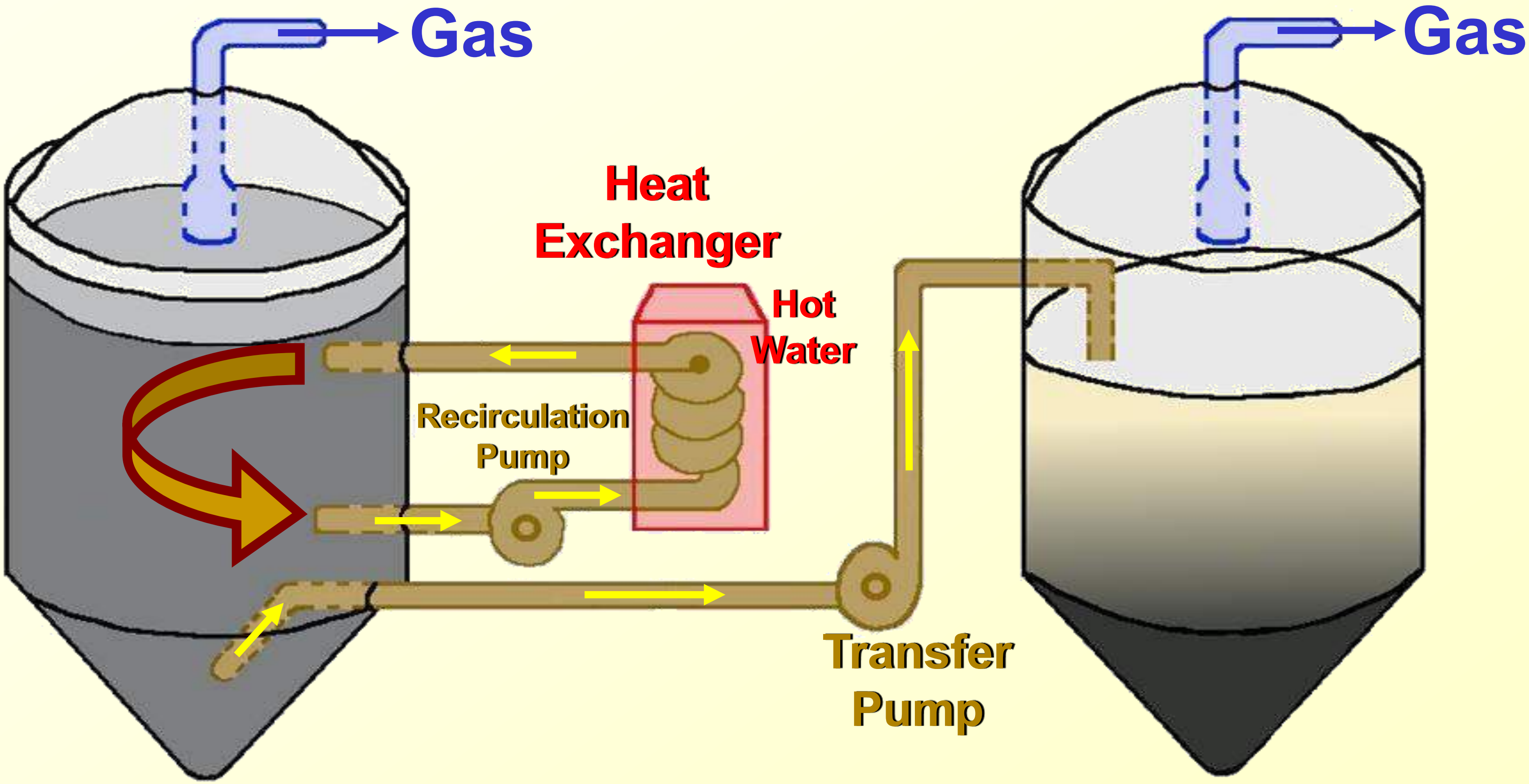
1. Less Solids
2. Lumpy Appearance
3. Black
4. Less Objectionable Odor
5. Volatile Content Reduced

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

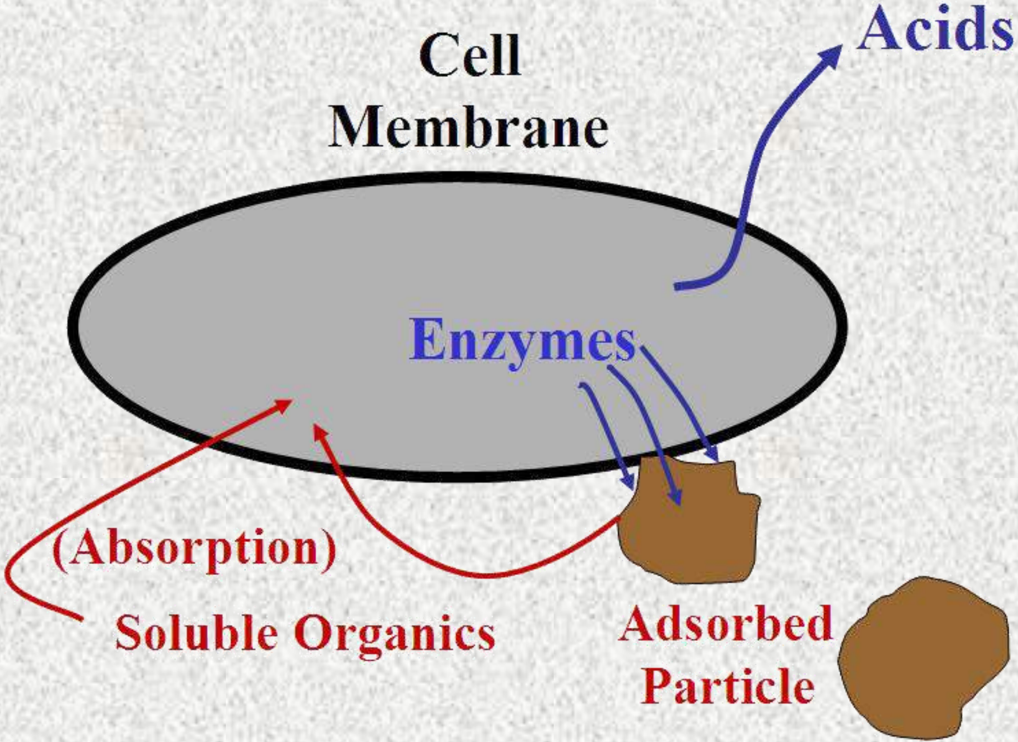
Naturally Occurring
Must Have Enough
Living Organisms
Two Different Types
BALANCE

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.

Most Anaerobic Digesters Are Operated in the Mesophilic Range

Mesophilic

68° F to 113° F

Best 85° F to 100° F

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. ANAERØBIC
   No Oxygen
2. TEMPERTURE
   Mesophilic - Constant
3. pH Best - 6.8 to 7.2

Sudden Changes
Toxic Materials
Start-up

Not Excessive

ACID Production INCREASED
OR
ALKALINITY DECREASED

5. BUFFERS (Alkalinity)
   Incoming Sludge and Created

4. VOLATILE ACIDS

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

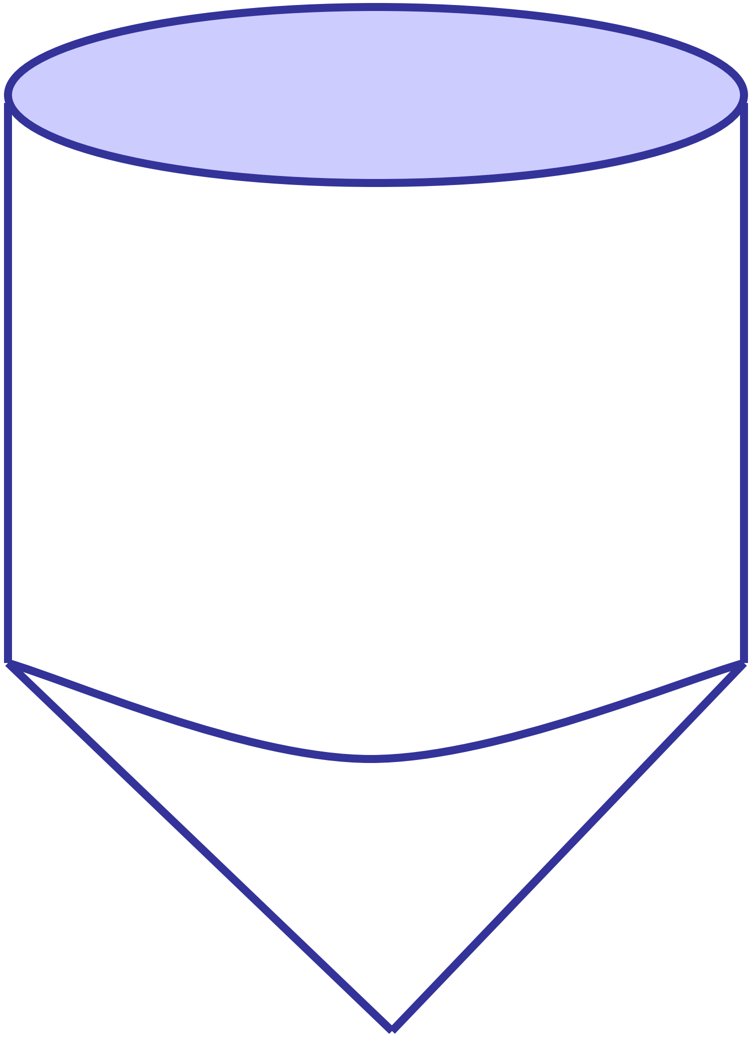
AMOUNT

Applied to the Treatment Process

Related to the SIZE of the System

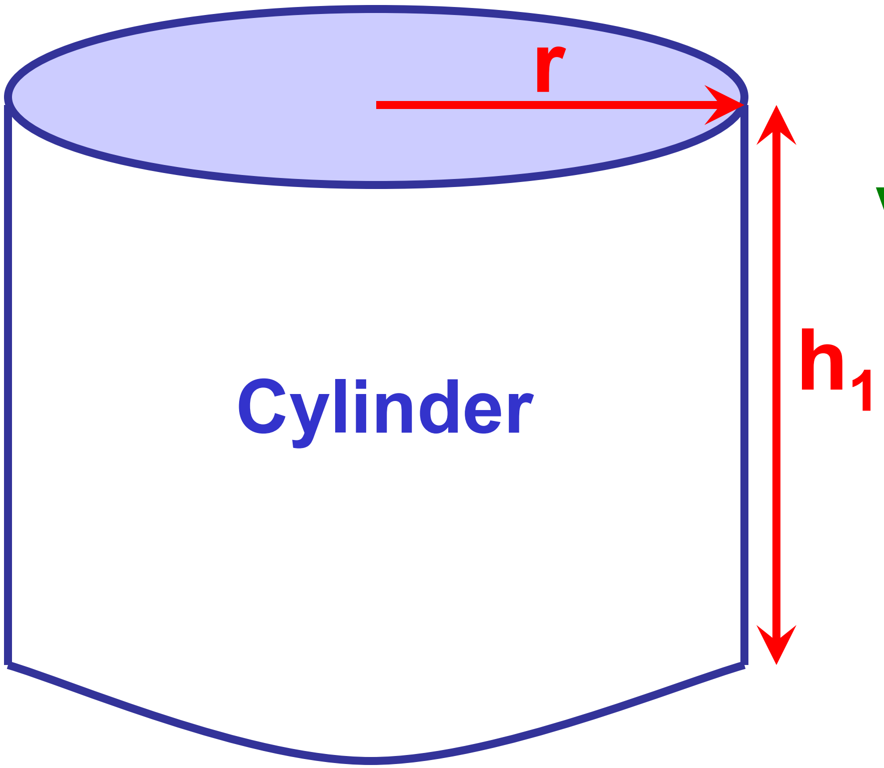
For An Anaerobic Digestion System – The SIZE Is The VOLUME Available for Digestion

(Volume - Cubic Feet OR Gallons)



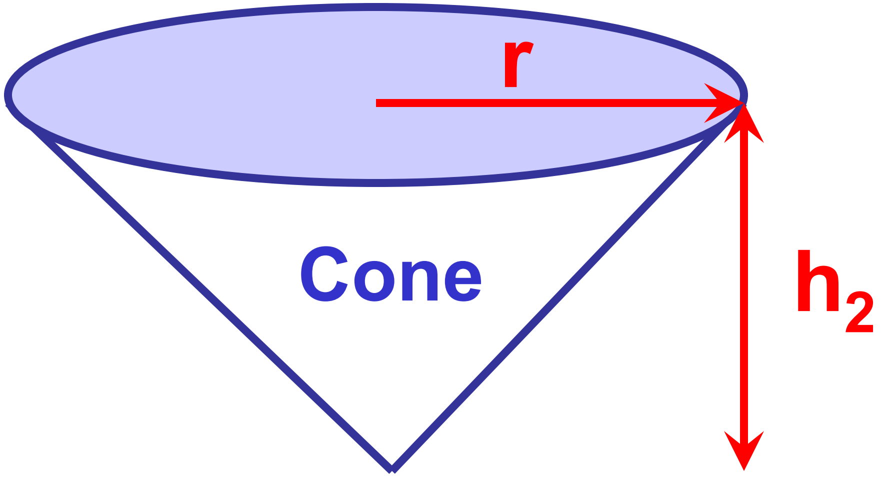
Calculation of Digester Volume

?



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

$\Pi\ r^2h_1$



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

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

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.

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

$$= 3.14 \text{ X } 27 \text{ ft X } 27 \text{ ft X } 22 \text{ ft}$$

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

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

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

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

Digester Volume Example Problem

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

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

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

Total Volume (gallons) =

cubic feet X 7.48 gal/ft^3

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

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

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.

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

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

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

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

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

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

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.

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

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

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

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

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

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

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.

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

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

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

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

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

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

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.

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

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

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

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

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

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

“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

$$\text{DET. TIME (Days)} = \frac{\text{Gallons}}{\text{Gallons / Day)}}$$

EXAMPLE

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

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

$$= \text{35 Days}$$

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.**

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

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

$$\boxed{= \text{ 36.1 Days}}$$

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.

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

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

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

$$= 35.9 \text{ Days}$$

“LOADING”

Amount Applied to the Treatment Process

Related to the SIZE of the System

Hydraulic Loading

Amount of Sludge Added
Volume (gallons)

Detention Time

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

“LOADING”

Amount Applied to the Treatment Process

Related to the SIZE of the System

Hydraulic Loading

Amount of Sludge Added
Volume (gallons)

Organic Loading

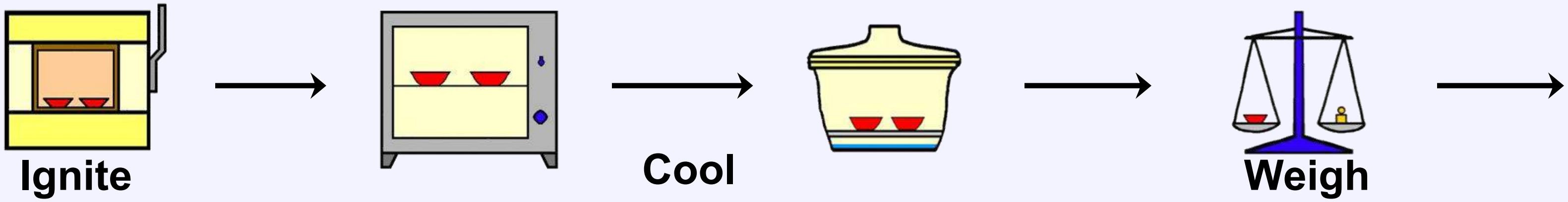
Amount of VOLATILE Solids added
Weight (pounds)

PERCENT TOTAL SOLIDS

Outline of Solids Analysis Procedure

SLUDGE SOLIDS PROCEDURE

Evaporating Dish Preparation

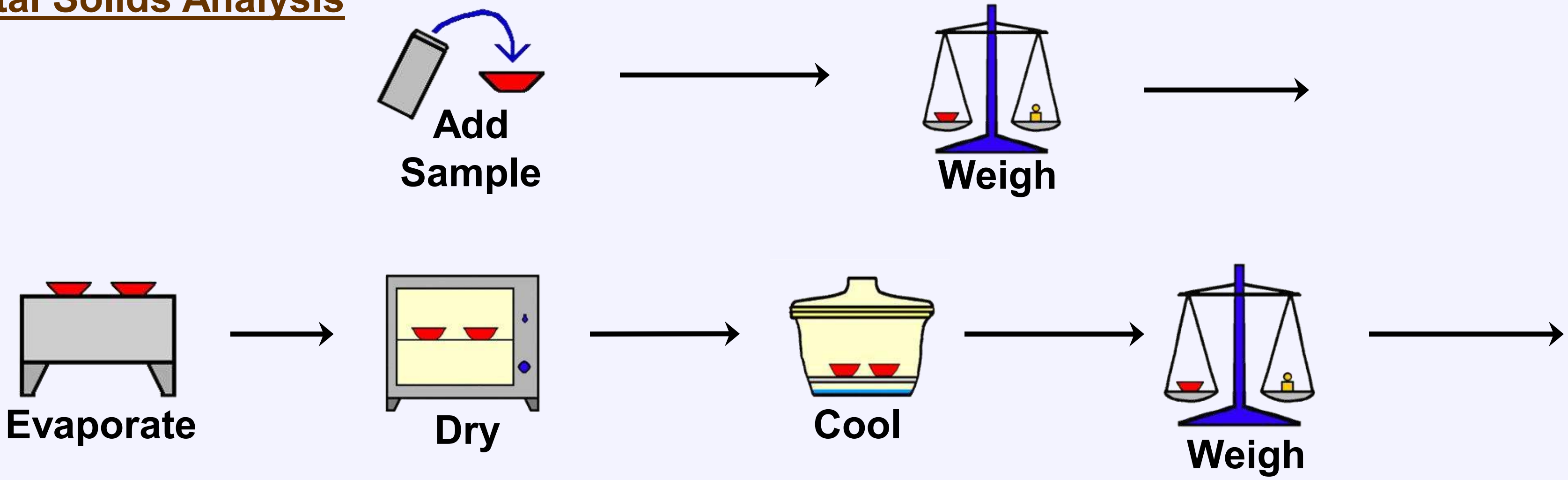


Ignite

Cool

Weigh

Total Solids Analysis



Add Sample

Weigh

Evaporate

Dry

Cool

Weigh

Percent Total Solids

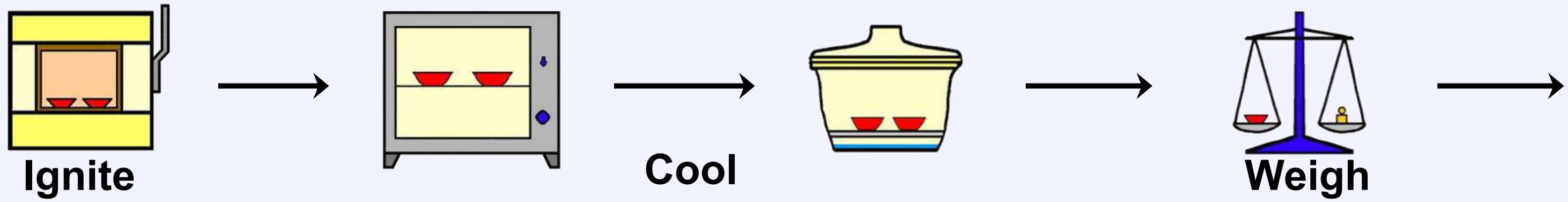
$$\% = \frac{\text{Amount in Question}}{\text{Total Amount Possible}} \times 100\%$$

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

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

SLUDGE SOLIDS PROCEDURE

Evaporating Dish Preparation

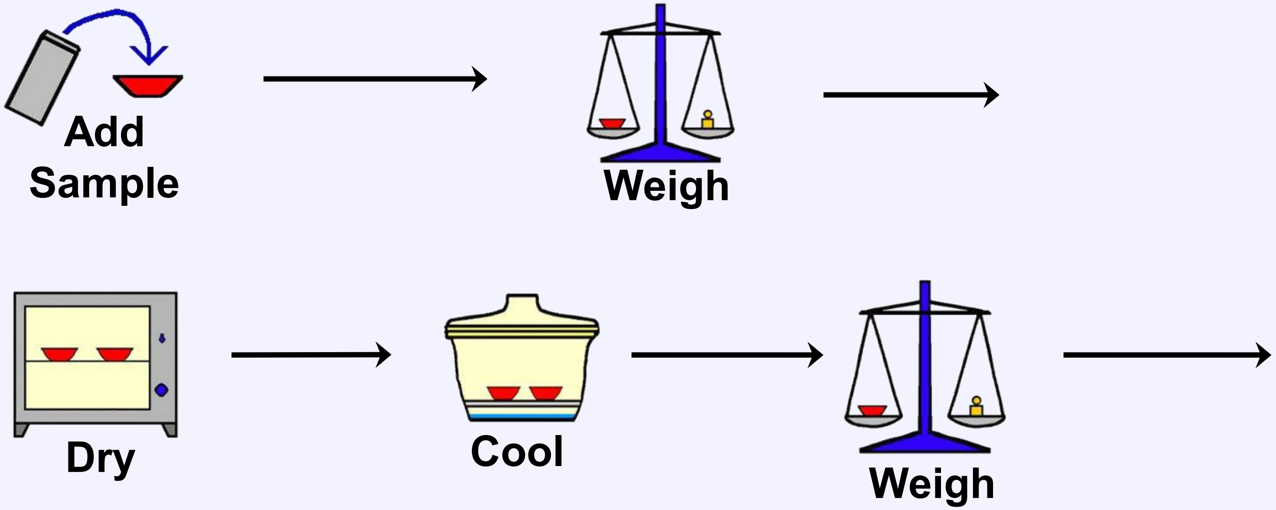


Ignite

Cool

Weigh

Total Solids Analysis



Add Sample

Weigh

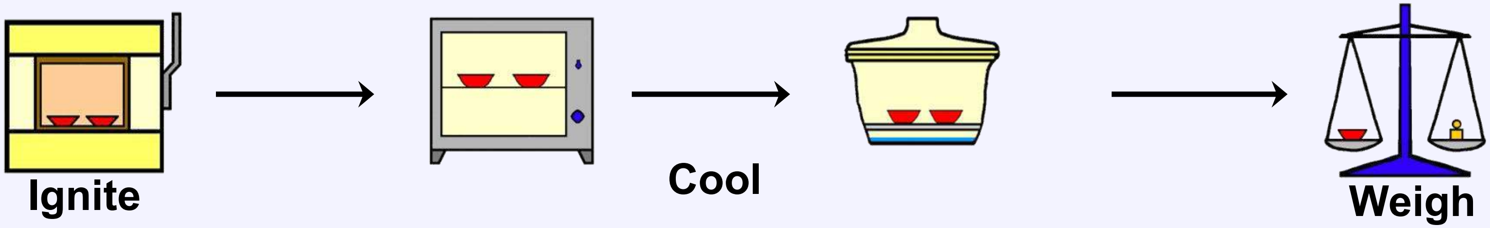
Evaporate

Dry

Cool

Weigh

Volatile Solids Analysis



Ignite

Cool

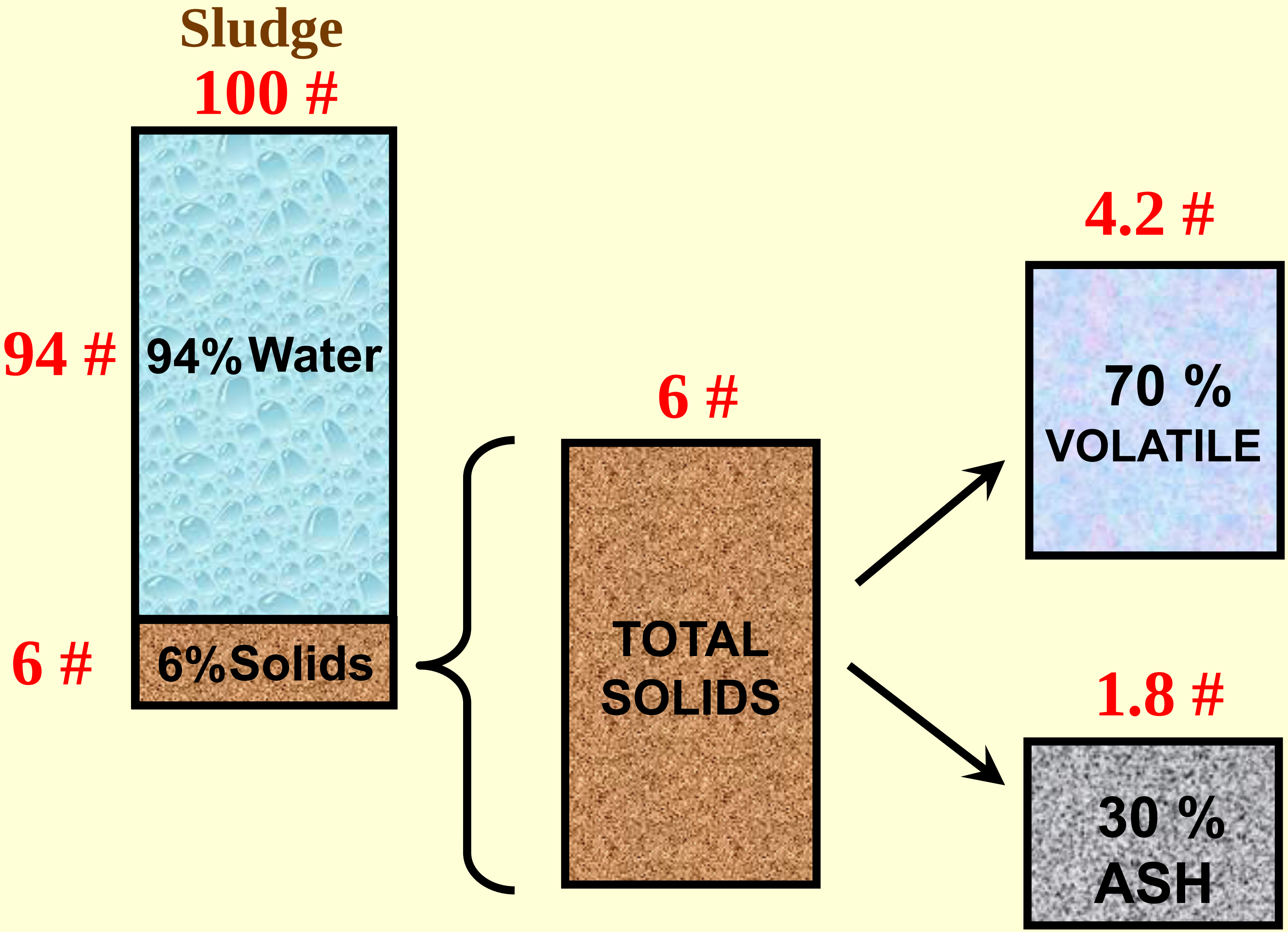
Weigh

Percent Volatile Solids

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

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

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



Sludge

100 #

94 #

94% Water

6 #

6% Solids

6 #

TOTAL SOLIDS

4.2 #

70 % VOLATILE

1.8 #

30 % ASH

SLUDGE SOLIDS DIAGRAM

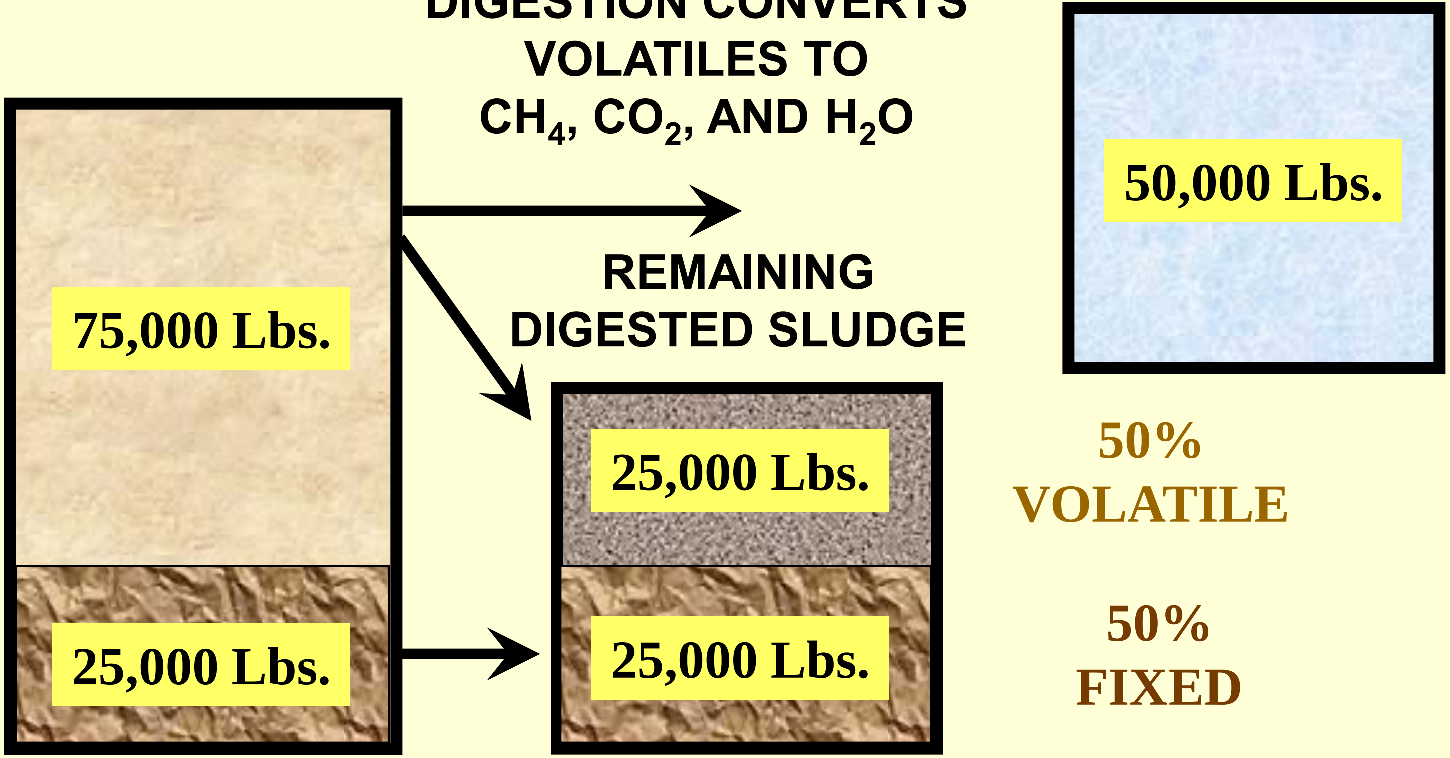
BEFORE DIGESTION

100,000 Lbs. RAW SLUDGE

(Dry Weight)

AFTER DIGESTION

CH_4, CO_2, H_2O



DIGESTION CONVERTS VOLATILES TO CH_4, CO_2, AND H_2O

REMAINING DIGESTED SLUDGE

75% VOLATILE

75,000 Lbs.

25% FIXED

25,000 Lbs.

50,000 Lbs.

25,000 Lbs.

25,000 Lbs.

50% VOLATILE

50% FIXED

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%**

LBS DRY SOLIDS =

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

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

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

= 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%

LBS VOLATILE SOLIDS =

LBS DRY SOLIDS X % VOLATILE SOLIDS

= 2,802 LBS DRY SOLIDS X $\frac{82}{100}$

= 2,802 X 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

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

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

$$= \underline{1{,}095.7 \text{ POUNDS VOLATILE SOLIDS}}$$

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.

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

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

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

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

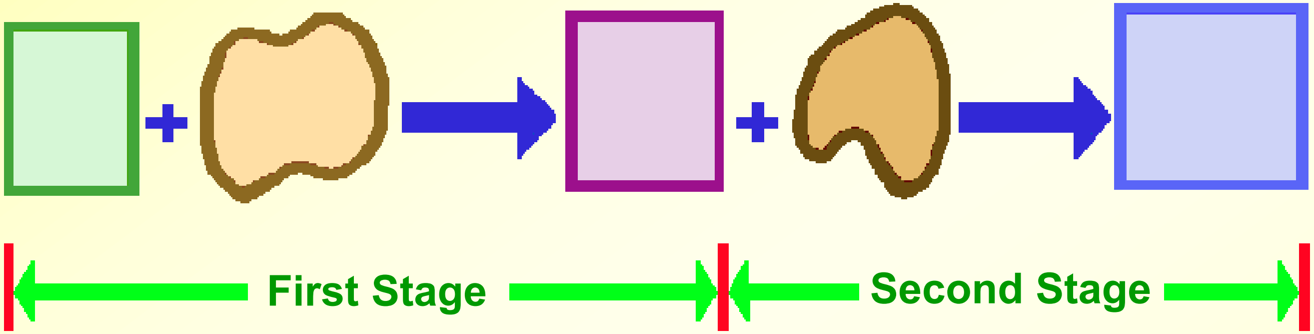
90 to 95^0 F

Methane Formers Very Sensitive to **Changes**

Good Mixing Essential

SUMMARY

Balance



Poor Mixing

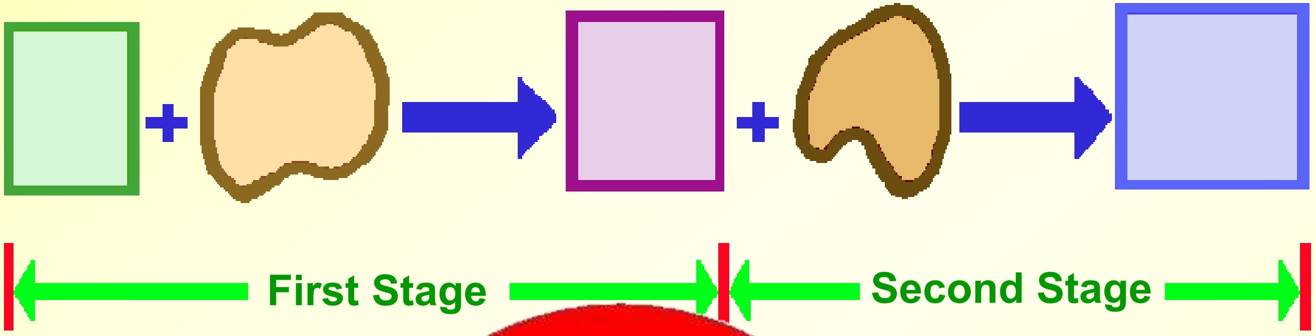
Over Loading

Excess Water

Temperature

SUMMARY

Balance



Poor Mixing

Over Loading

Excess Water

Temperature

OPERATION AND CONTROL

ENVIRONMENT

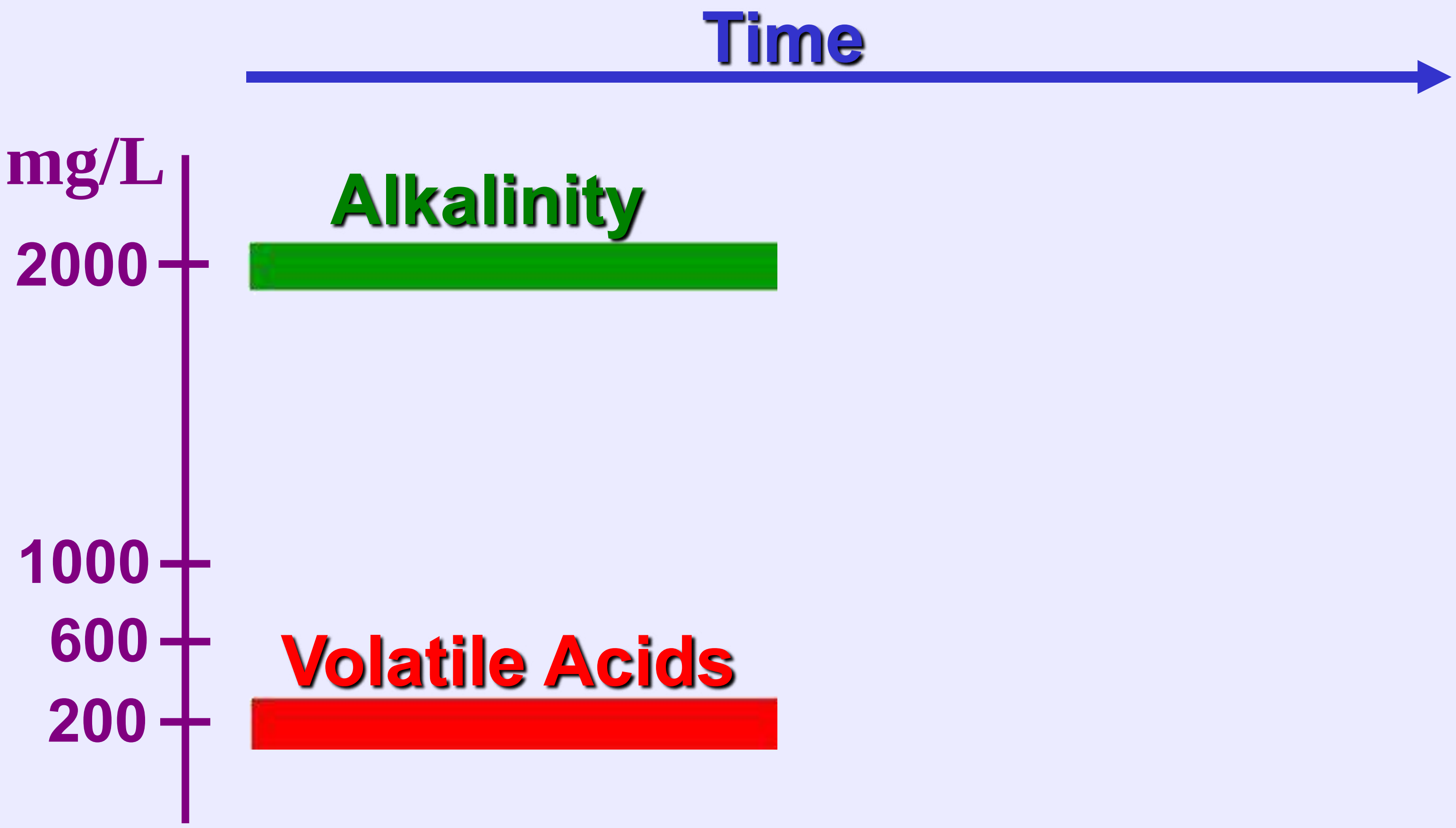
Volatile Acid/Alkalinity Relationship

Ratio

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

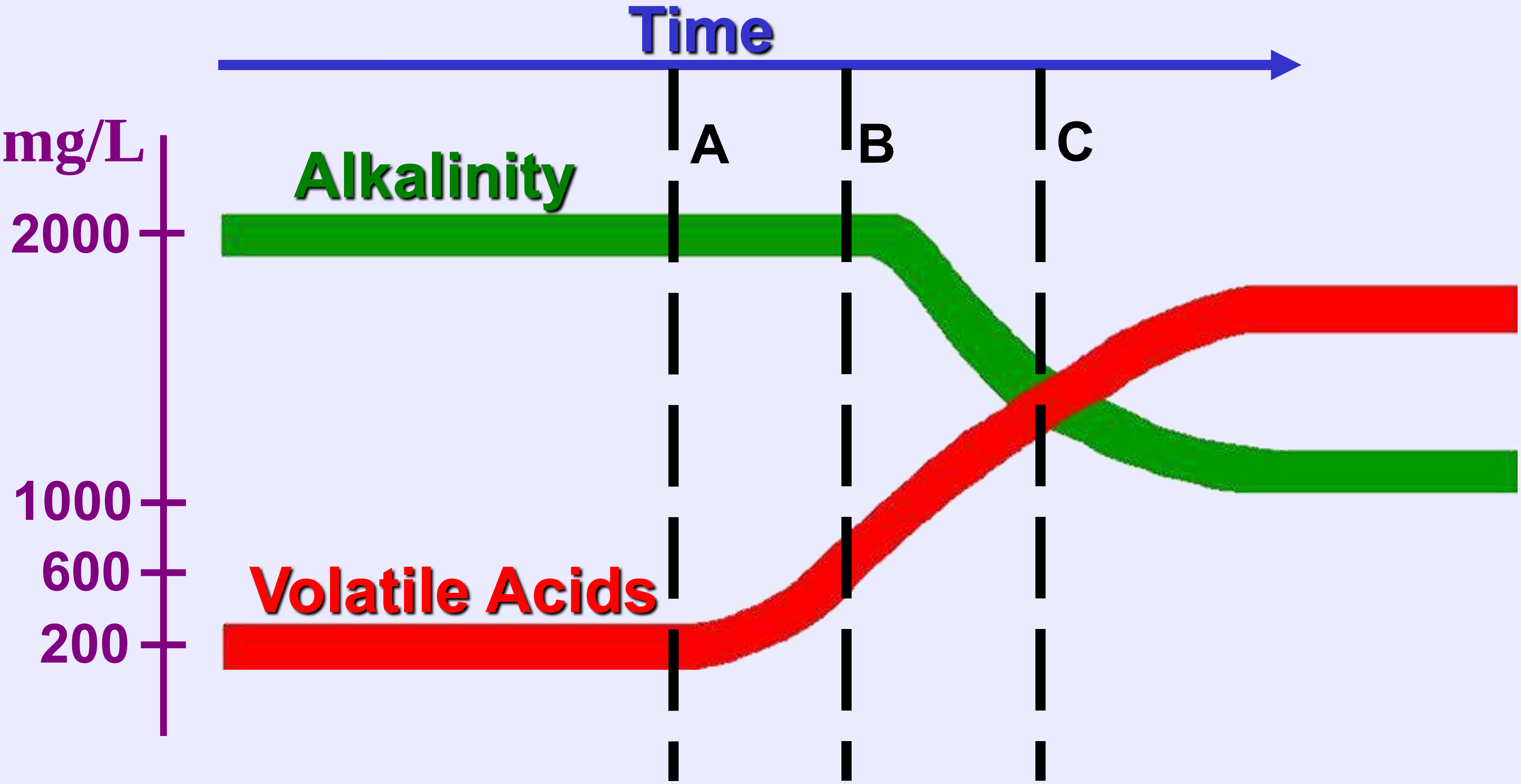
$$\frac{140\text{ mg/L}}{2{,}800\text{ mg/L}} = 0.05$$

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

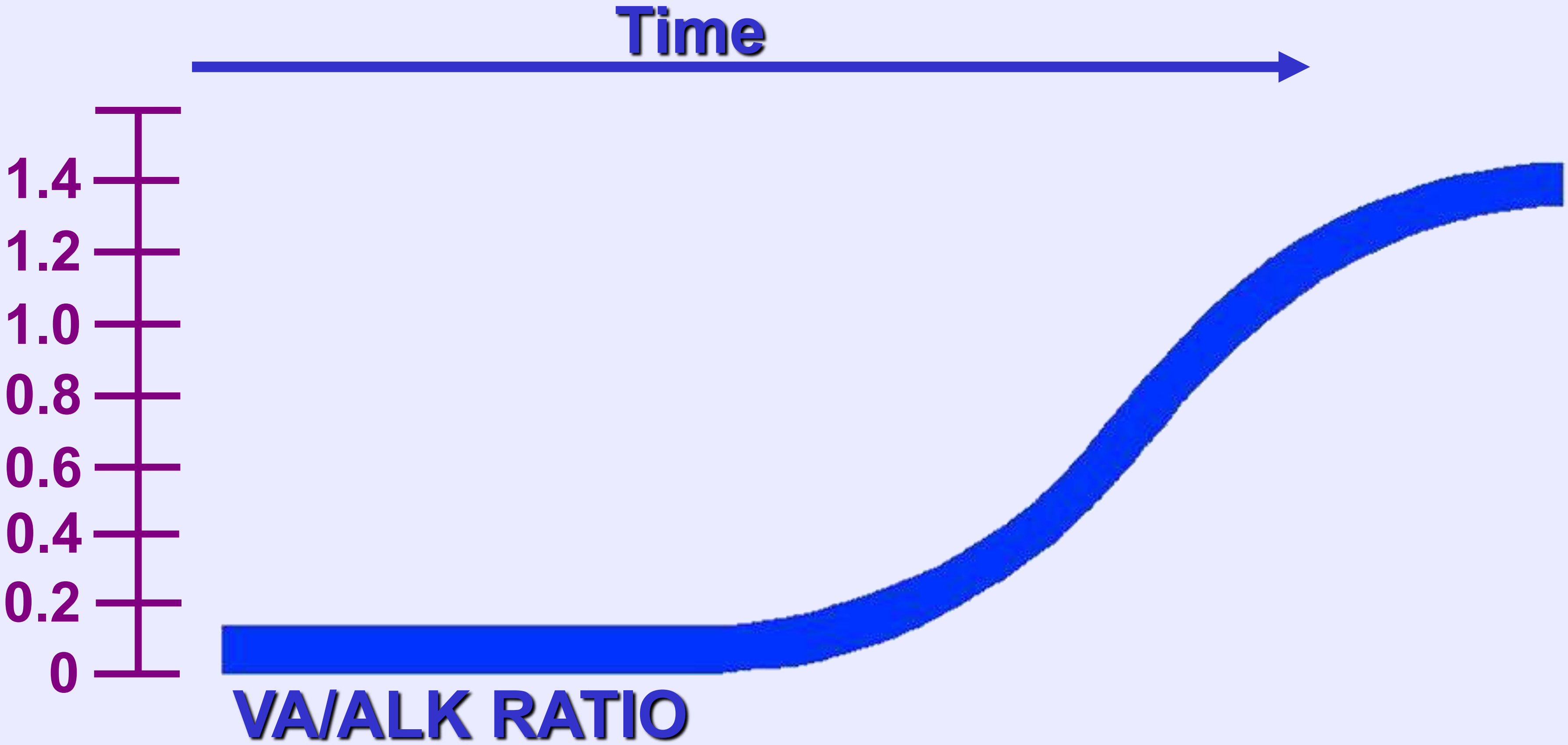


At Time A Something has Happened to Cause the Volatile Acids to Increase

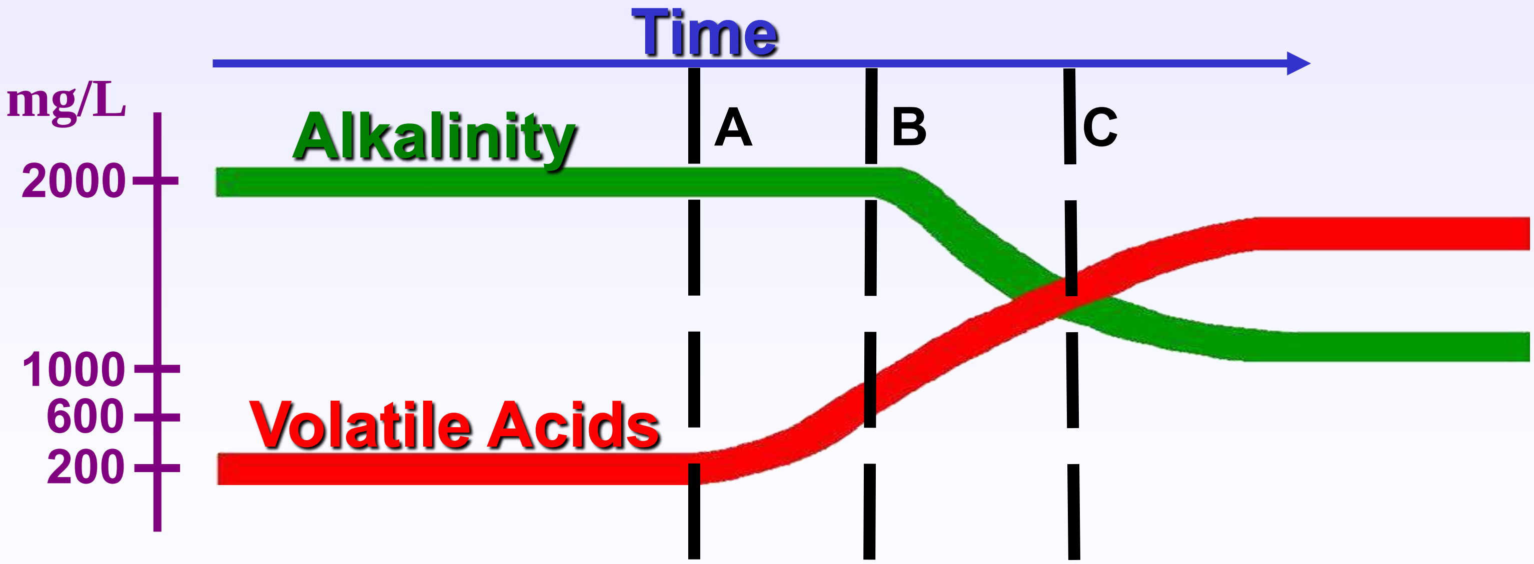
Followed by a Decrease in Alkalinity at Time B

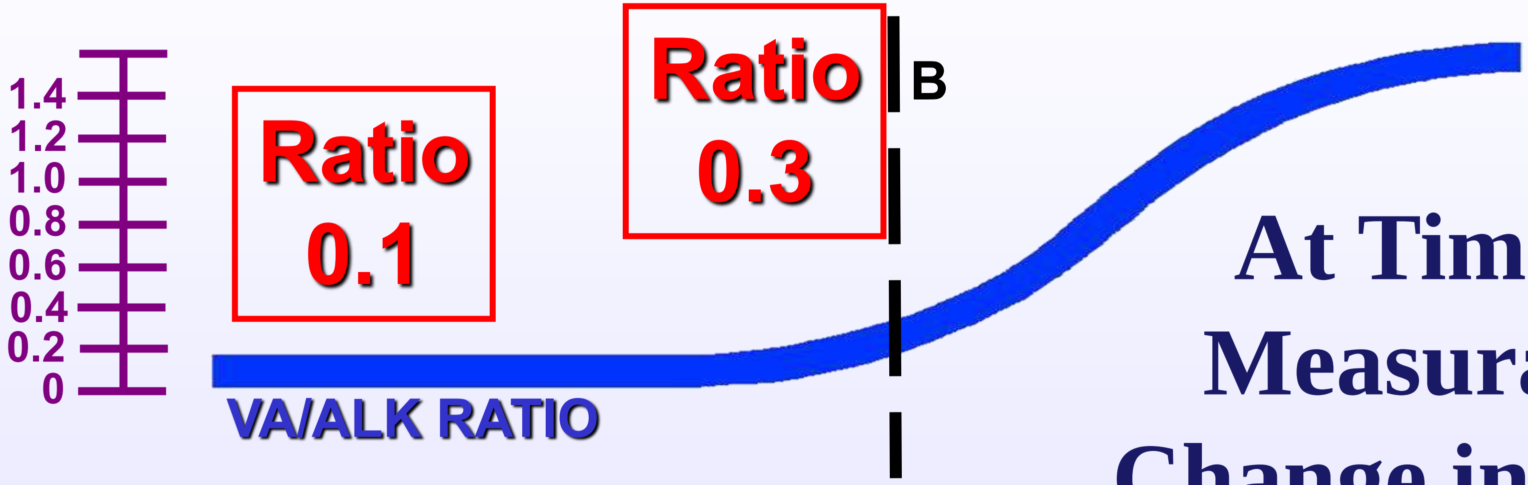
At Time C the Digester has Become Sour

II. Volatile Acids / Alkalinity Ratio



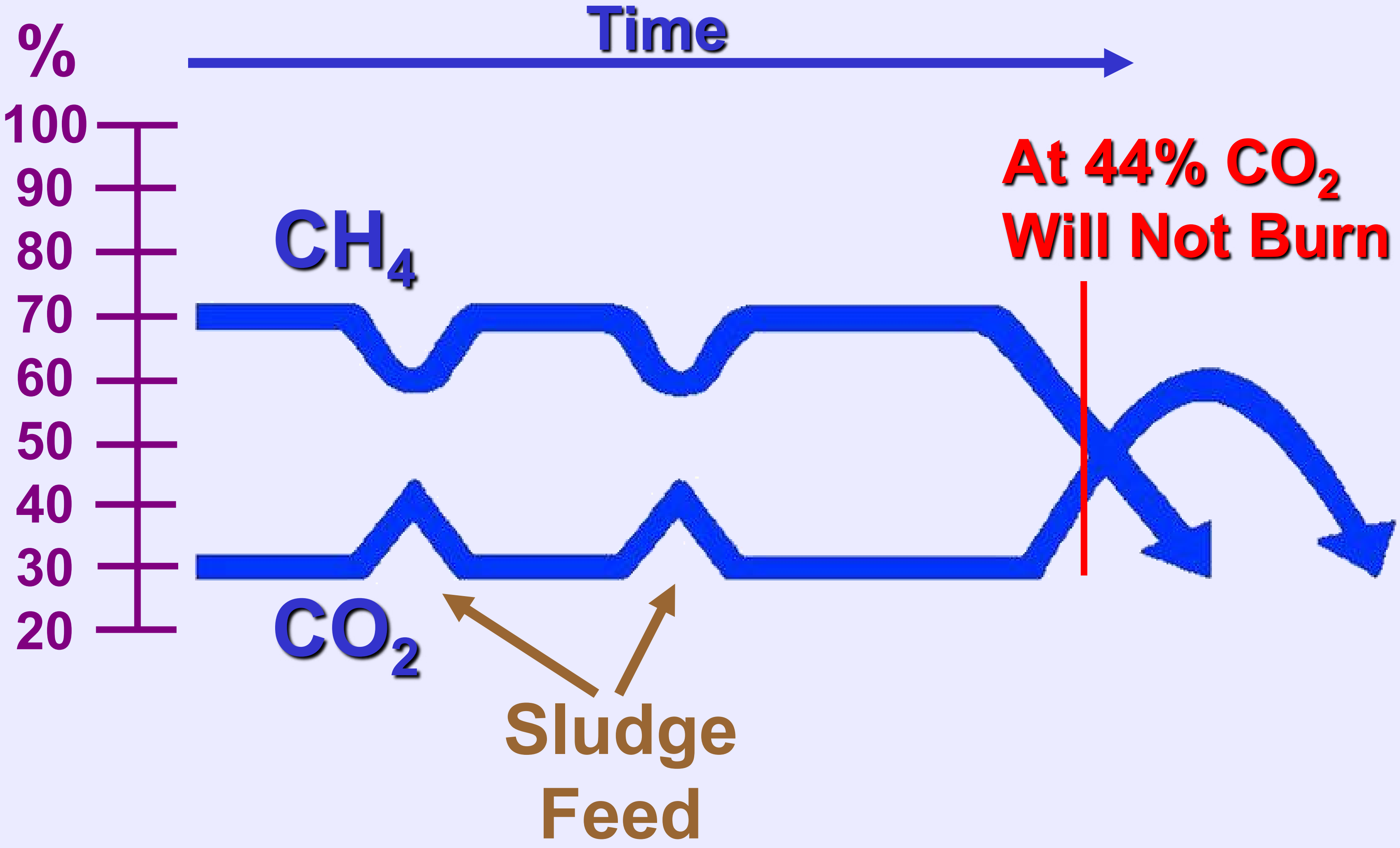
Comparing Graph I to Graph II



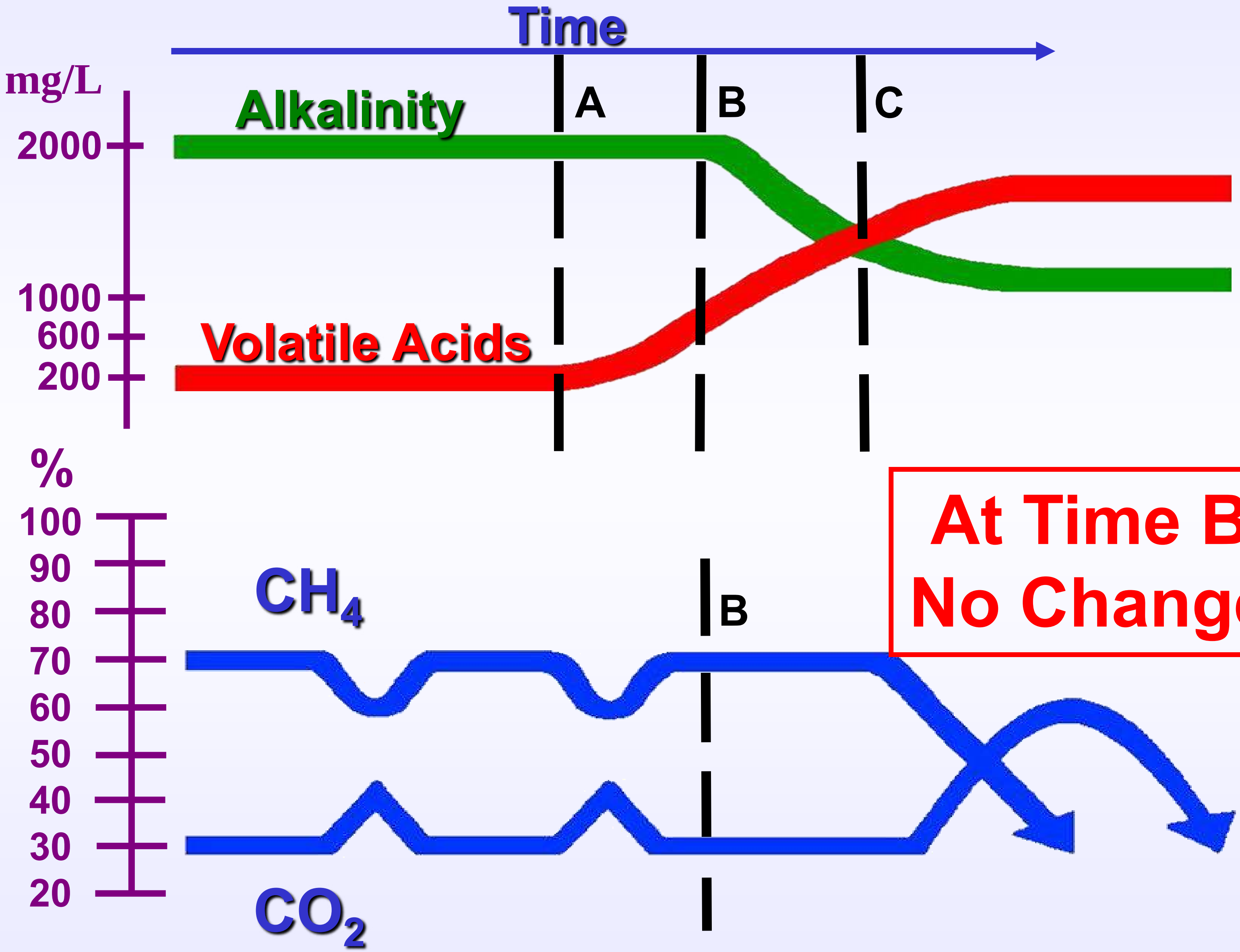


At Time B
Measurable
Change in Ratio

III. Relationship of Methane and Carbon Dioxide

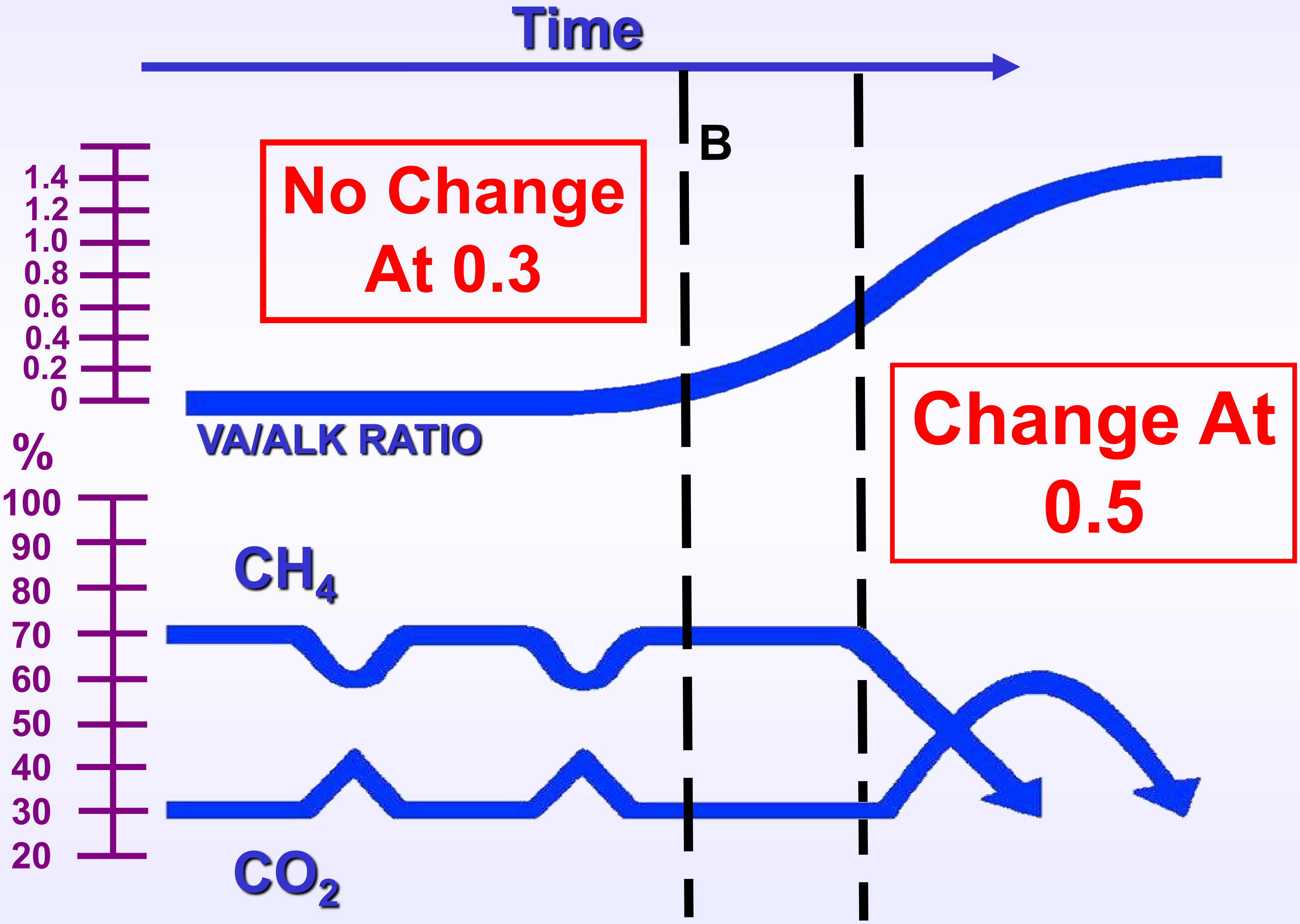


Comparing Graph I to Graph III



At Time B
No Change

Comparing Graph II to Graph III

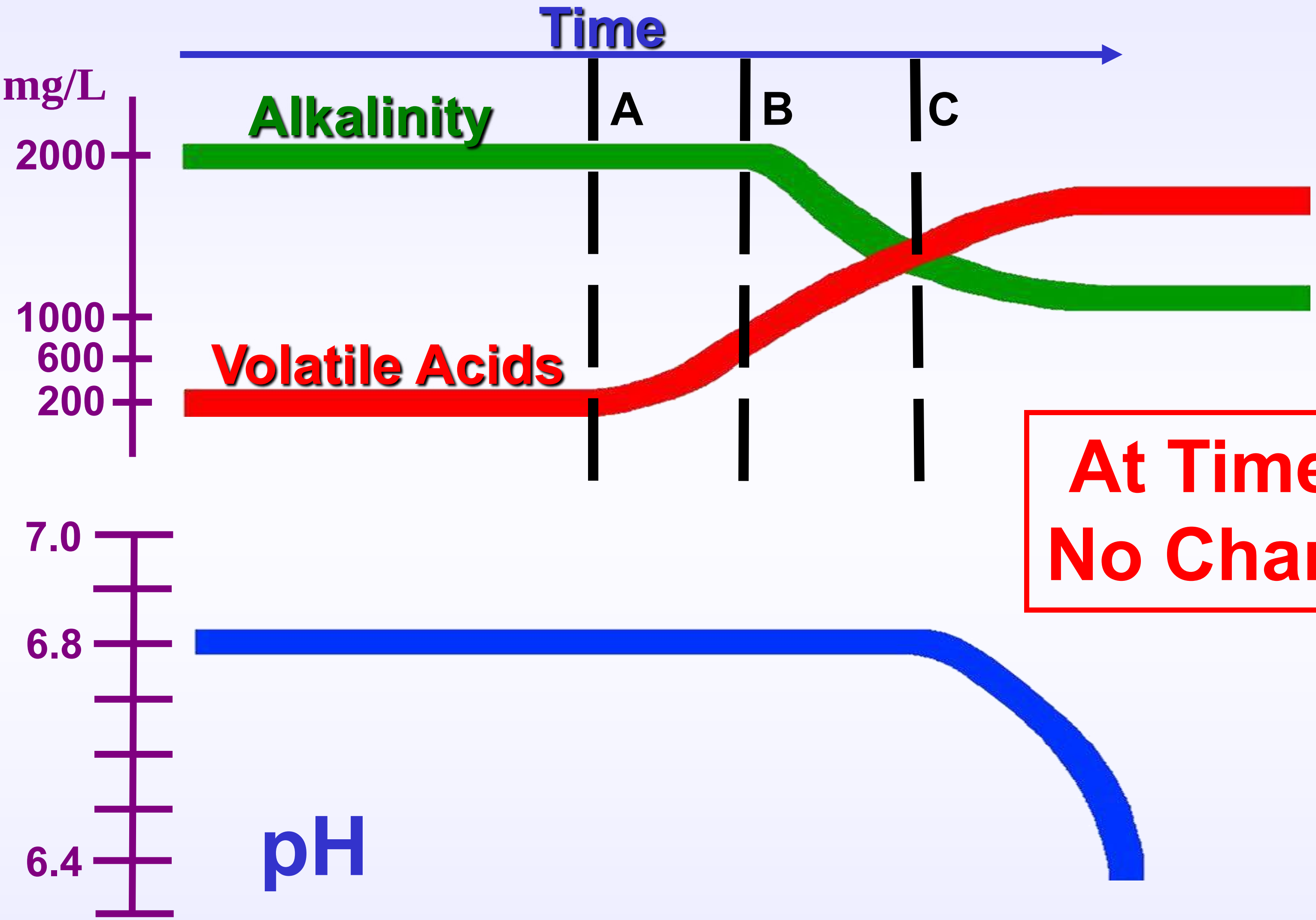


No Change At 0.3

Change At 0.5

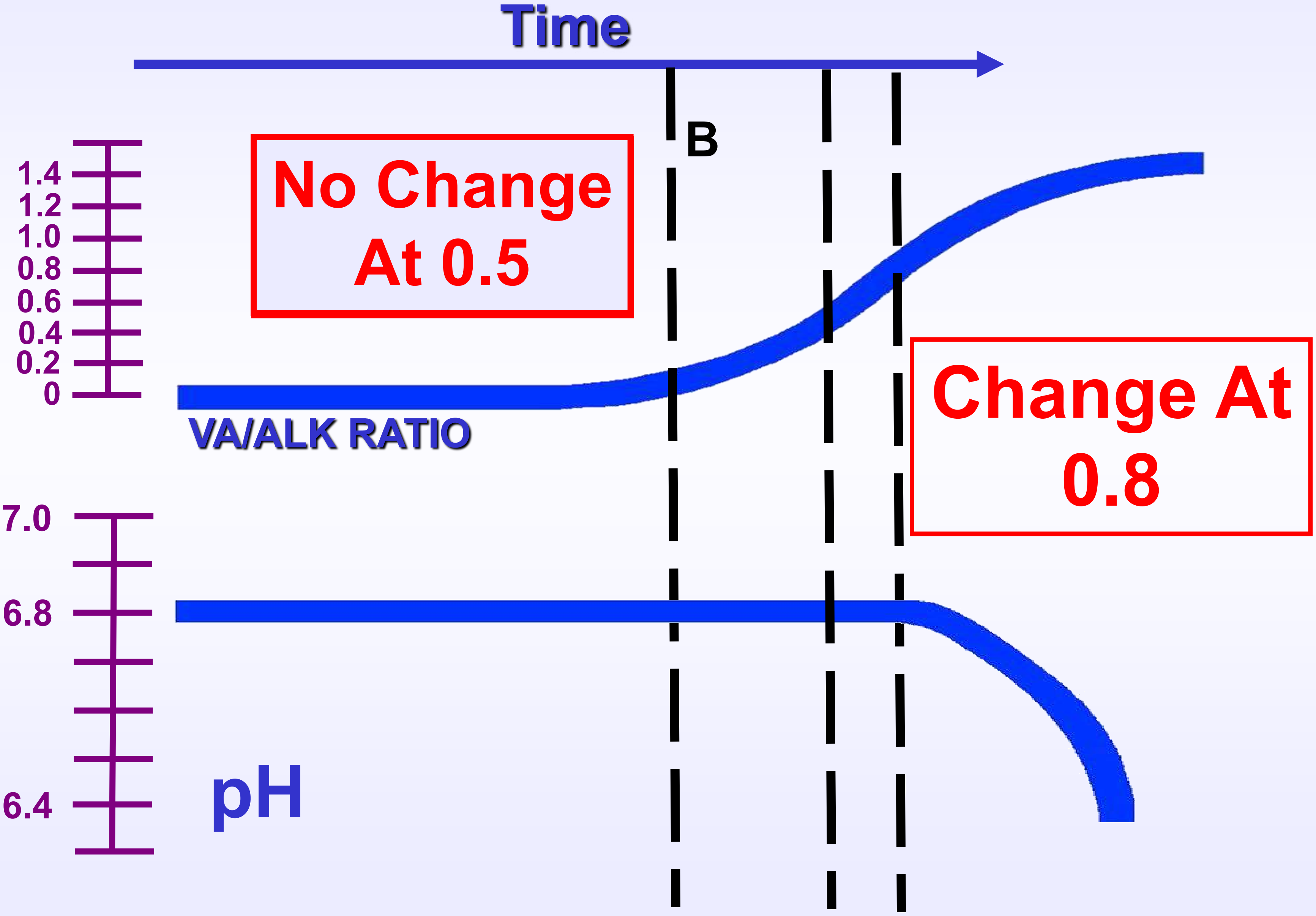
IV. Relationship of pH Change

Comparing Graph I to Graph IV



At Time B
No Change

Comparing Graph II to Graph IV



No Change At 0.5

Change At 0.8

OPERATION AND CONTROL

ENVIRONMENT

Order of Measurable Changes When A Digester is BECOMING 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)**

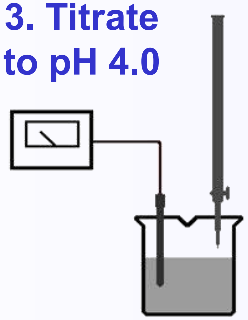
VOLATILE ACIDS AND TOTAL ALKALINITY

Outline of Procedure

1. Separate Solids

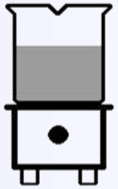
2. Measure 50 mL

3. Titrate to pH 4.0



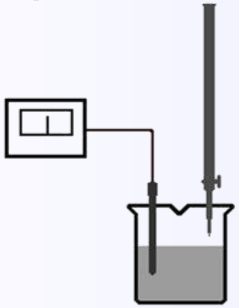
4. Record mL used, Then Titrate to pH 3.3

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 =

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

% Reduction of Volatile Solids =

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

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 =

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

$$= \frac{.73 - .51}{.73 - (\ .73 \times .51)} \times 100\ \%$$

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

$$= \frac{.22}{.358} \times 100\ \% \qquad \boxed{= 61.5\ \%}$$

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 =

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

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

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

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

= 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 =

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

= 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 =

$$\frac{\text{Cubic Feet Gas}}{\text{\% Vol. Slds. Destroyed (decimal) X Lbs. Vol. Slds. In}}$$

Lbs. Vol. Solids Destroyed

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

Lbs. Vol. Solids In

$$= \frac{7{,}850\ \text{ft}^3}{852.9\ \text{\# Vol. Slds. Destroyed}} \boxed{=\ 9.2\ \text{ft}^3\text{/Lb. Vol. Slds. Destroyed}}$$

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?

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

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

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

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 !

Biosolids Treatment and Disposal

TEJASREE.VEMURI
ASST.PROFESSOR
SMGG

Types of Biosolids

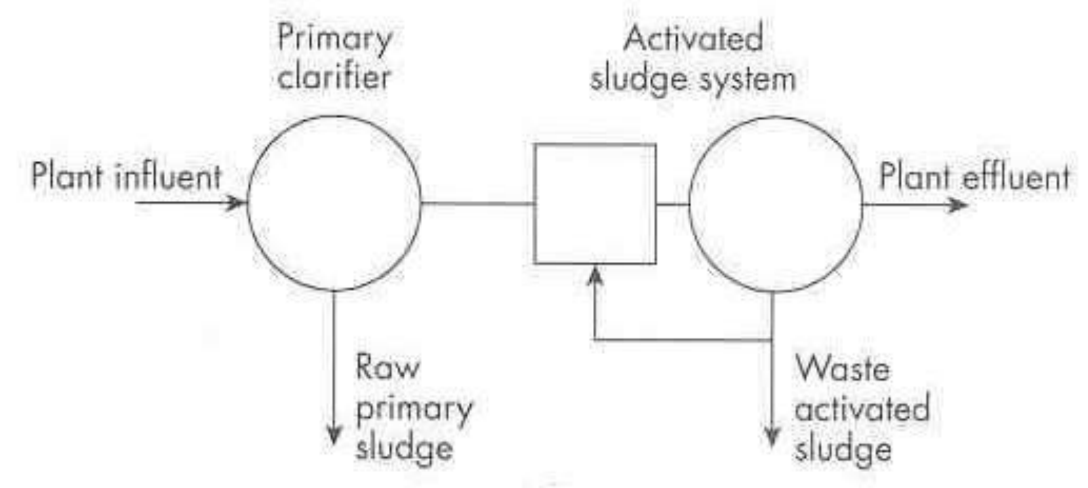
- Primary sludge
  - Solids that settle out in the primary settling basin
- Biological or Secondary Sludge
  - Solids that have grown in a secondary treatment process (fixed film or suspended growth)

Biosolids Quantities

Determined by mass balance, knowing kinetic parameters

Example

A wastewater treatment plant treats 6 mgd that has an influent BOD of 200 mg/L and suspended solids of 180 mg/L. The primary clarifier removes 60% of the solids and 30% of the BOD. The aeration basin of the activated sludge process removes 95% of the BOD it receives, produces an effluent with a suspended solids concentration of 20 mg/L, and a yield of 0.5 lb solids per lb of BOD removed. How much primary and secondary sludge is produced by the system?



Influent Solids: $X_0 = 180 \text{ x } 6 \text{ x } 8.34 = 9007$ lb/day

Primary solids: $X_p = 0.6 \text{ x } 9007 = 5404$ lb/day

Solids into activated sludge: $9007 – 5404 = 3603$ lb/day

Effluent Solids: $X_e = 20 \text{ x } 6 \text{ x } 8.34 = 1001$ lb/day

Biological Solids produced as BOD is used up.

BOD entering activated sludge system:

S_i = 0.7 x 200 x 6 x 8.34 = 7006 lb/day

BOD destroyed in aeration basin:

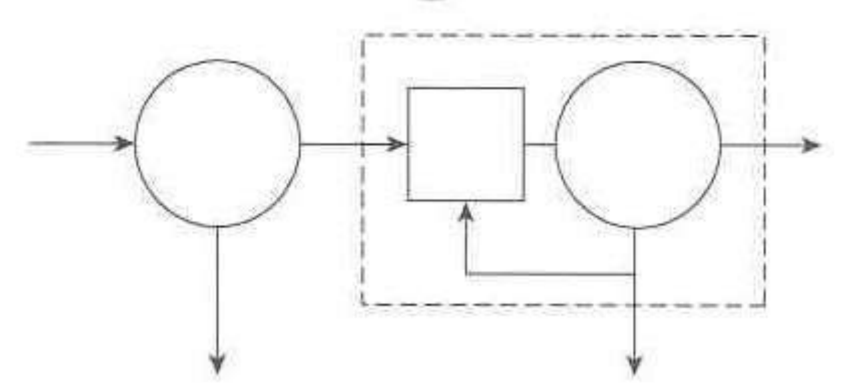
0.95 x 7006 = 6655 lb/day

Solids produced:

Y x BOD removed = 0.5 x 6655 = 3328 lb/day

Solids wasted determined by mass balance

At S.S. :



0 = solids into aeration basin – solids wasted – solids in effluent + solids created

$$0 = 3603 - 1001 - X_w + 3328$$

$$X_w = 5930 \text{ lb/day}$$

Solids Treatment Train

- Stabilization
  - Reduce problems: odor, pathogens
- Conditioning (Dewatering)
  - Produce physical characteristics to allow disposal
- Disposal

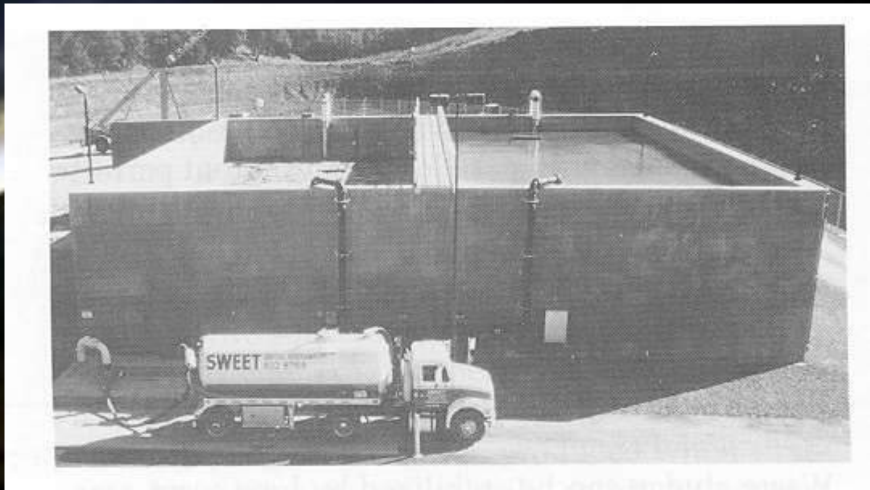
Sludge Stabilization

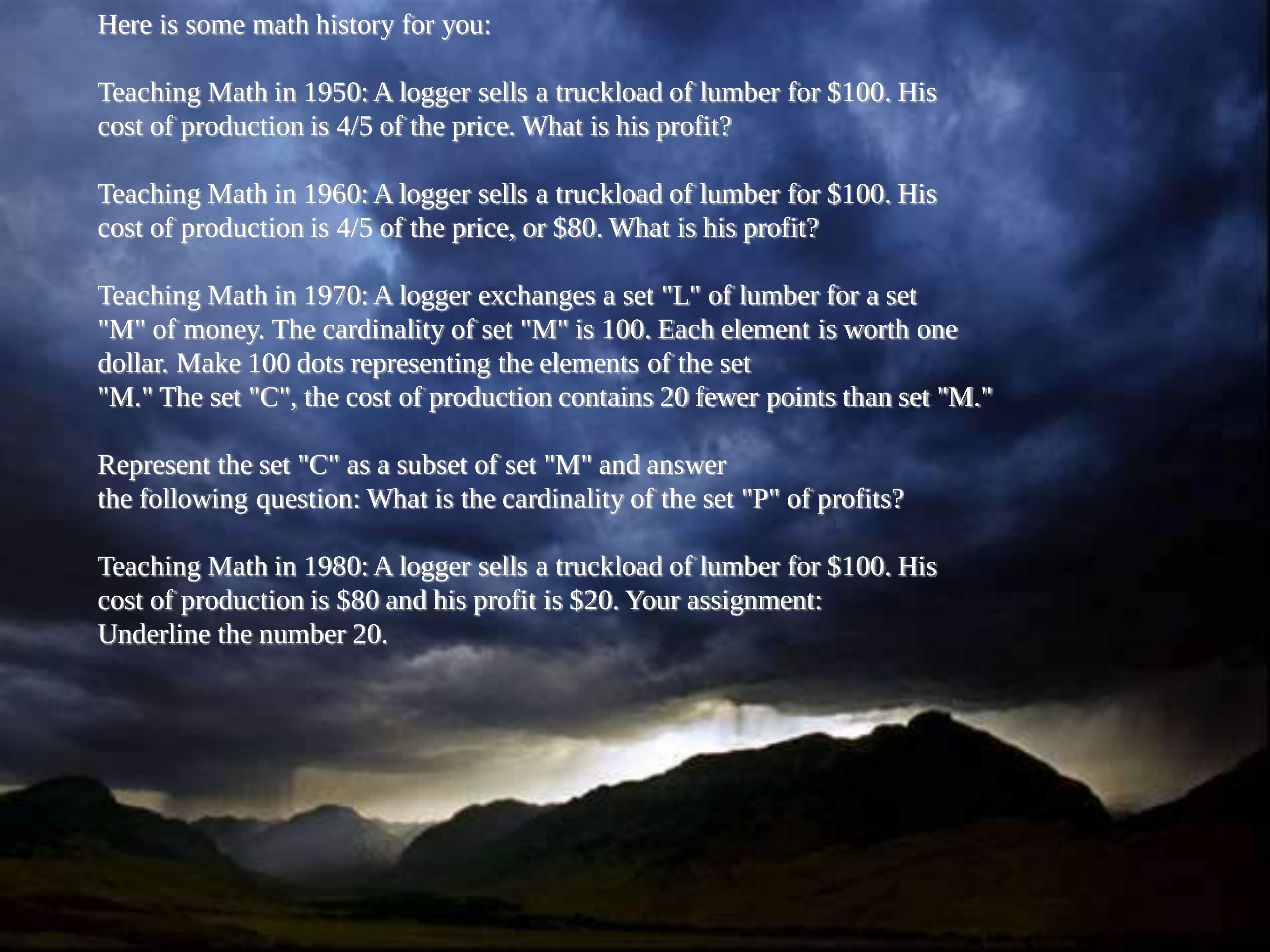
Lime Stabilization

Lime ($Ca(OH_2)$ raises the pH and causes high temperature to kill pathogens and restrict growth of other microorganisms

Aerobic Digestion

Waste activated sludge placed in aeration tank and aerated. Organisms die and are used as food by other organisms. Result is reduction in solids.





Here is some math history for you:

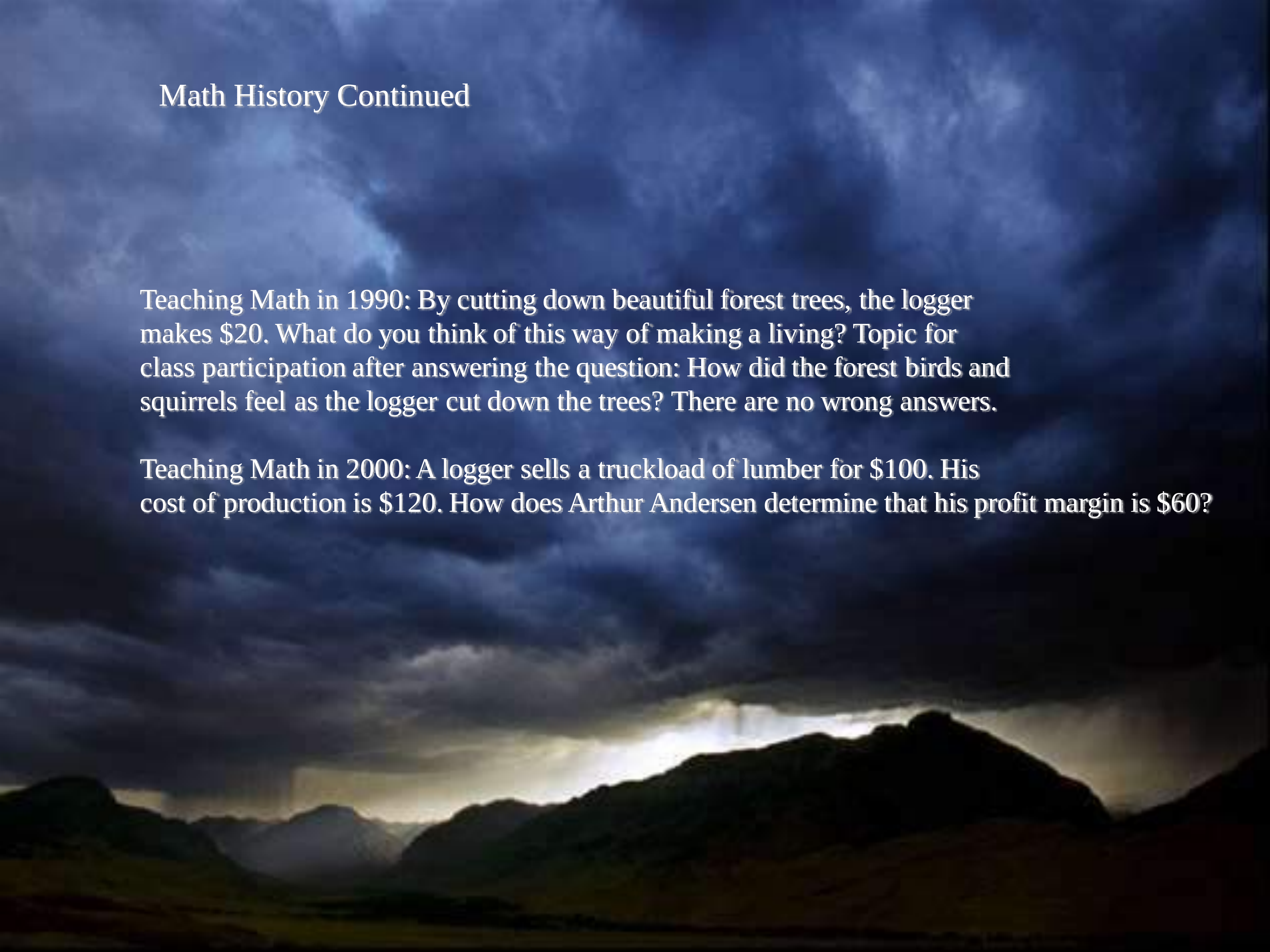
Teaching Math in 1950: A logger sells a truckload of lumber for $100. His cost of production is 4/5 of the price. What is his profit?

Teaching Math in 1960: A logger sells a truckload of lumber for $100. His cost of production is 4/5 of the price, or $80. What is his profit?

Teaching Math in 1970: A logger exchanges a set "L" of lumber for a set "M" of money. The cardinality of set "M" is 100. Each element is worth one dollar. Make 100 dots representing the elements of the set "M." The set "C", the cost of production contains 20 fewer points than set "M."

Represent the set "C" as a subset of set "M" and answer the following question: What is the cardinality of the set "P" of profits?

Teaching Math in 1980: A logger sells a truckload of lumber for $100. His cost of production is $80 and his profit is $20. Your assignment: Underline the number 20.

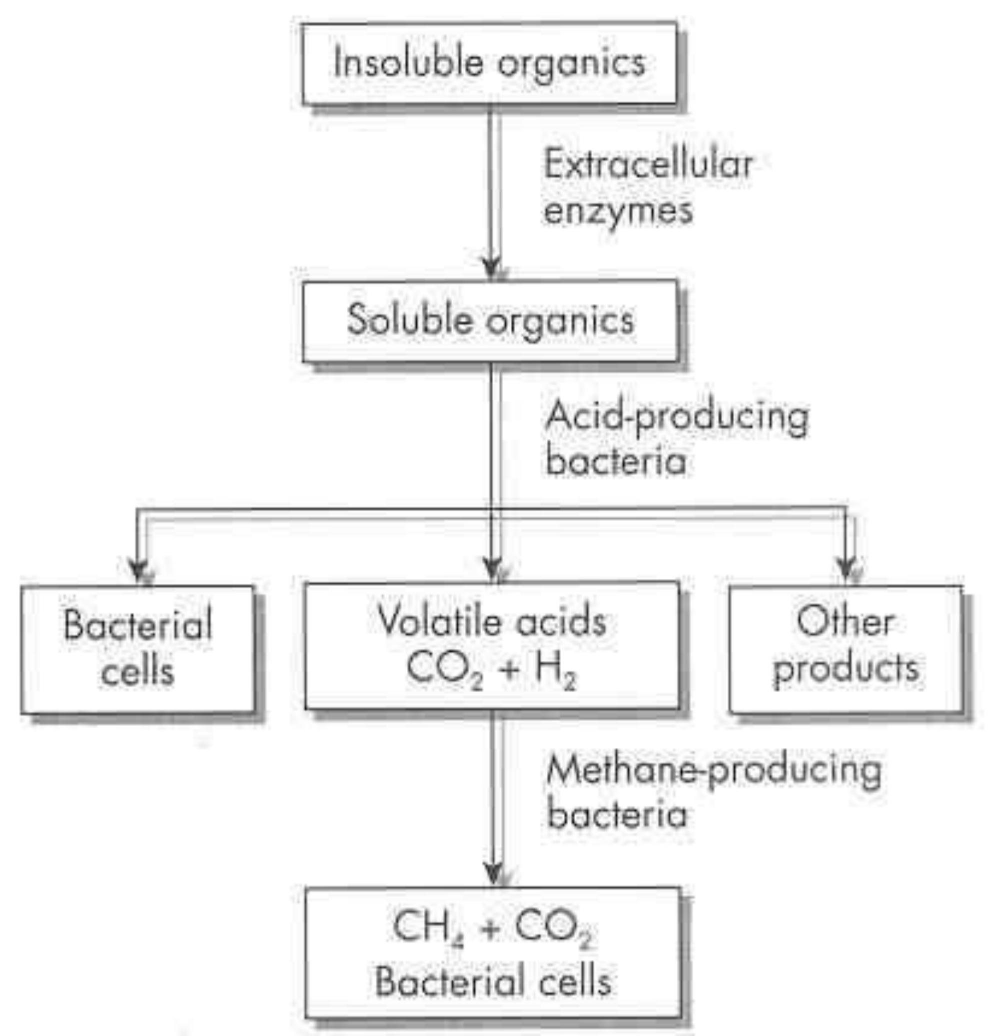


Math History Continued

Teaching Math in 1990: By cutting down beautiful forest trees, the logger makes $20. What do you think of this way of making a living? Topic for class participation after answering the question: How did the forest birds and squirrels feel as the logger cut down the trees? There are no wrong answers.

Teaching Math in 2000: A logger sells a truckload of lumber for $100. His cost of production is $120. How does Arthur Andersen determine that his profit margin is $60?

Anaerobic Digestion



Insoluble organics

Extracellular enzymes

Soluble organics

Acid-producing bacteria

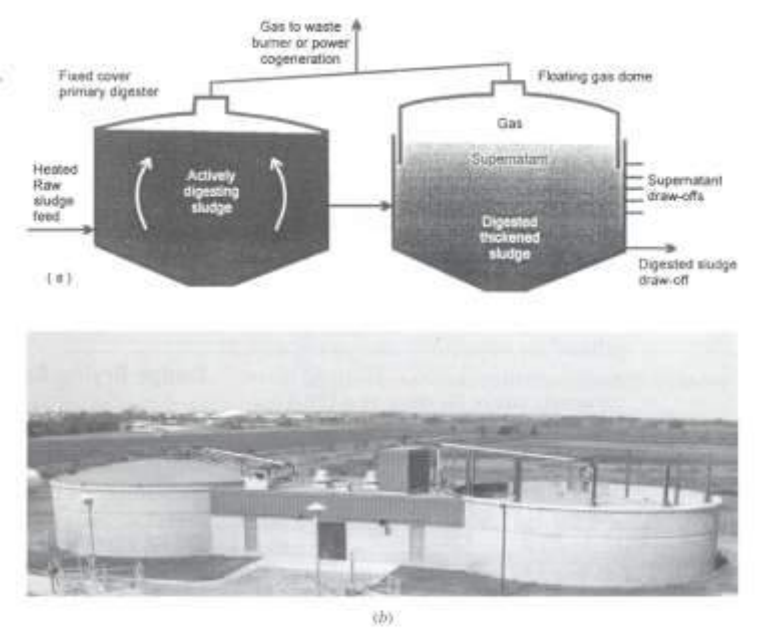
Bacterial cells

Volatile acids $CO_2 + H_2$

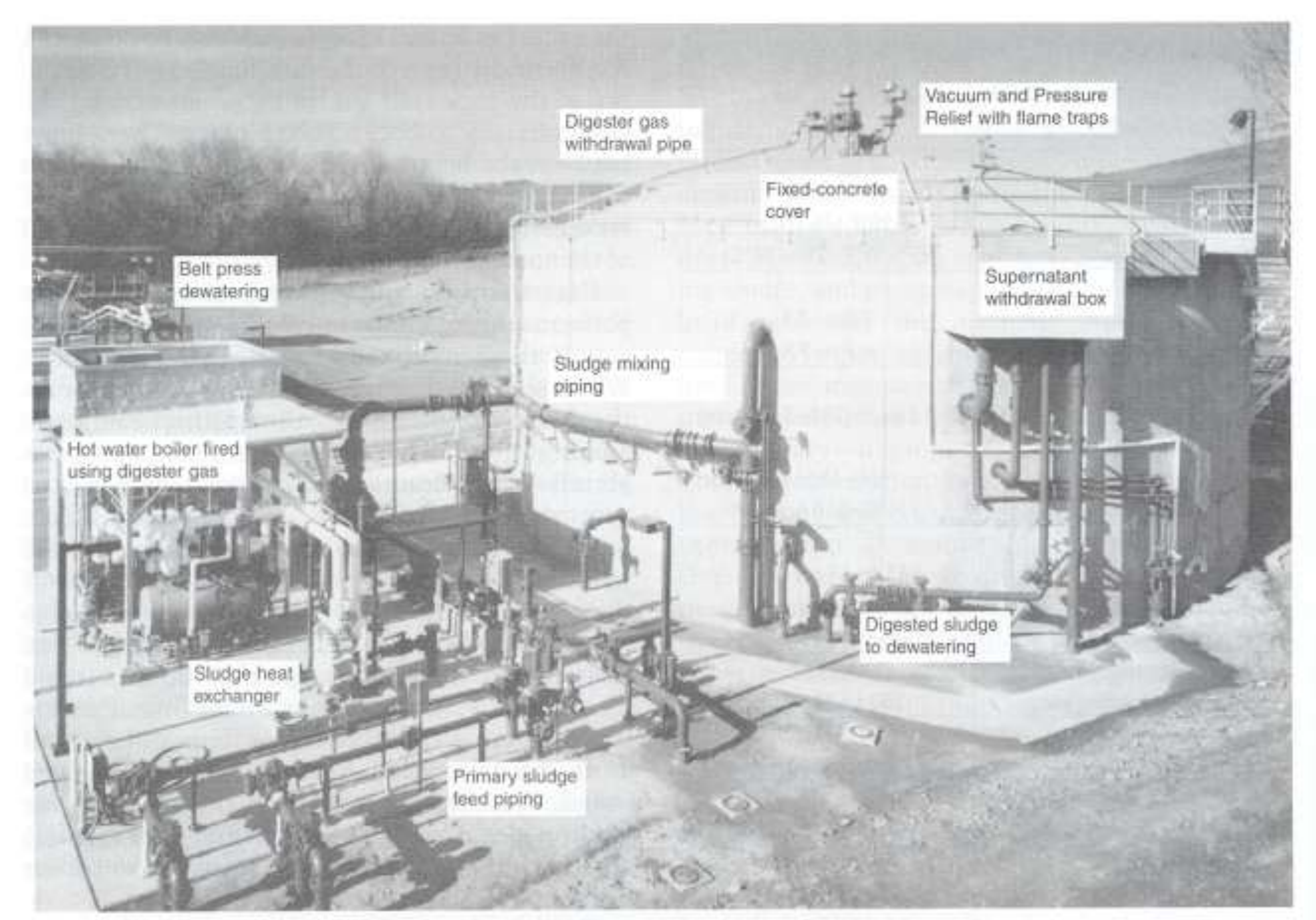
Other products

Methane-producing bacteria

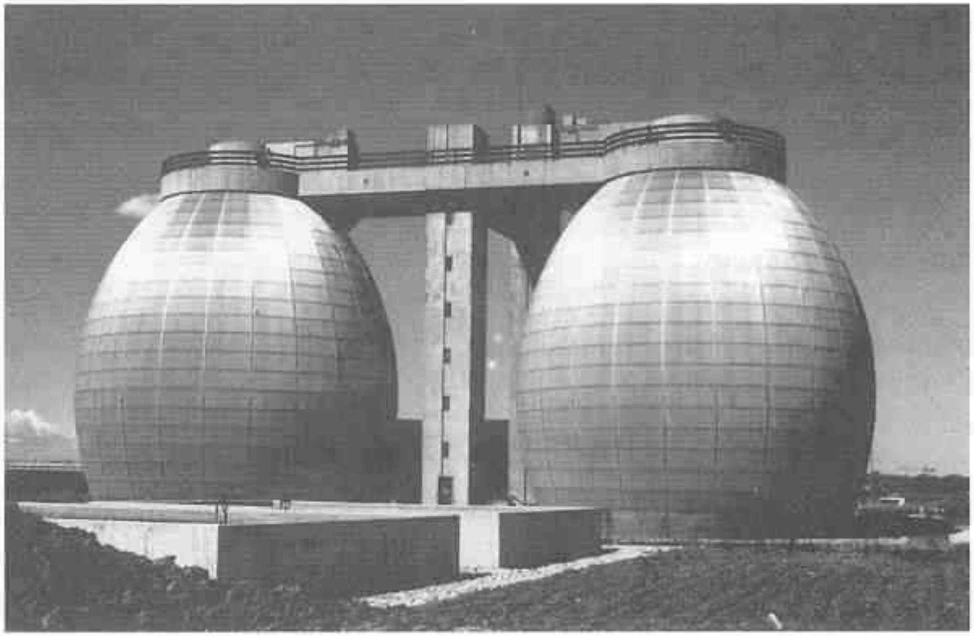
$CH_4 + CO_2$ Bacterial cells

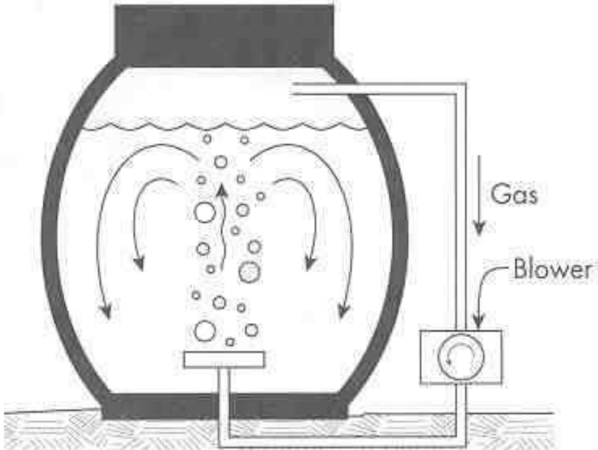


Anaerobic Digester Mechanical Plant



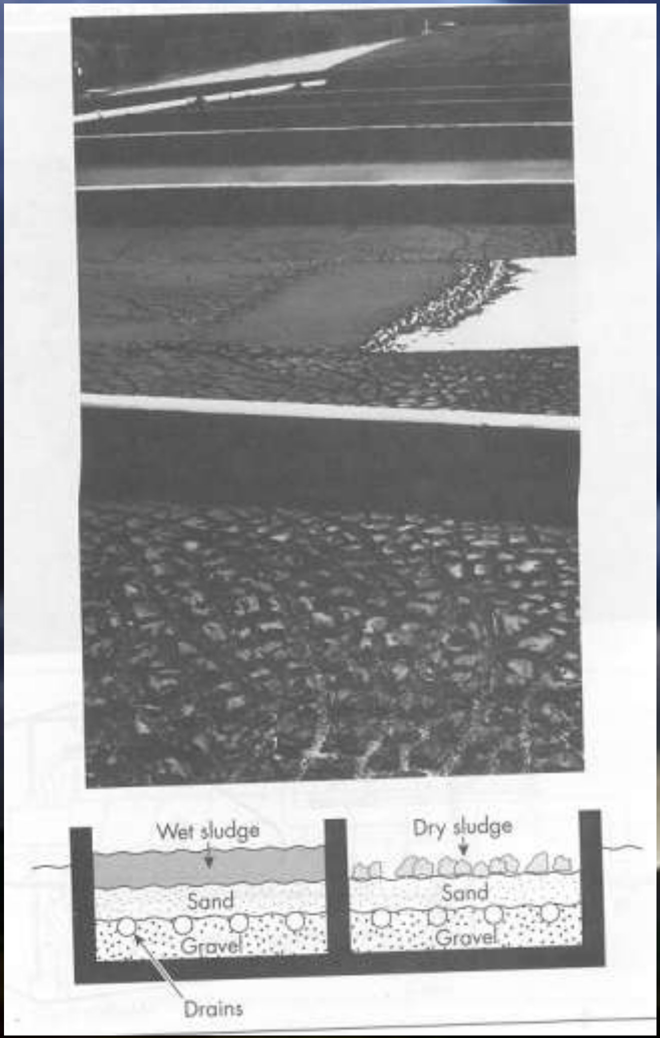
Egg Shaped Digesters

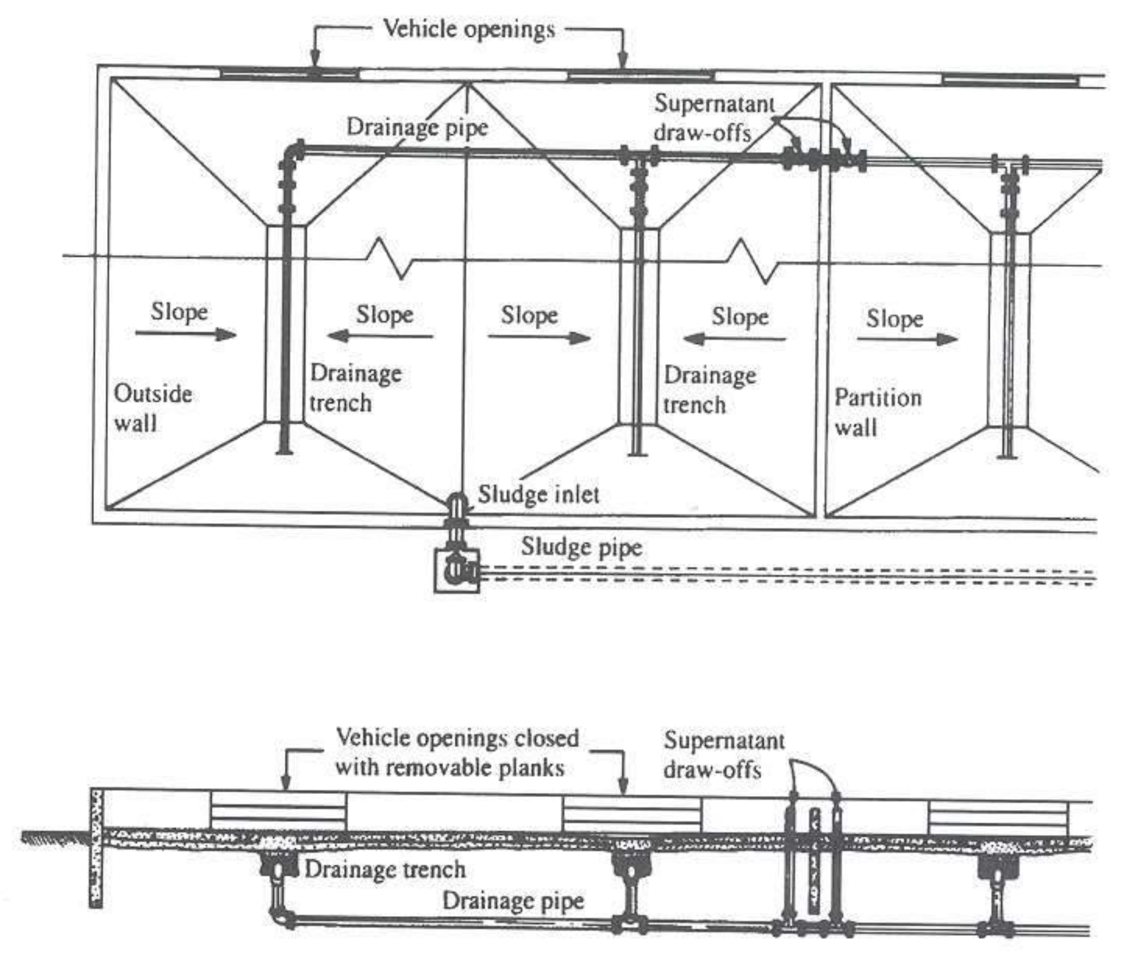




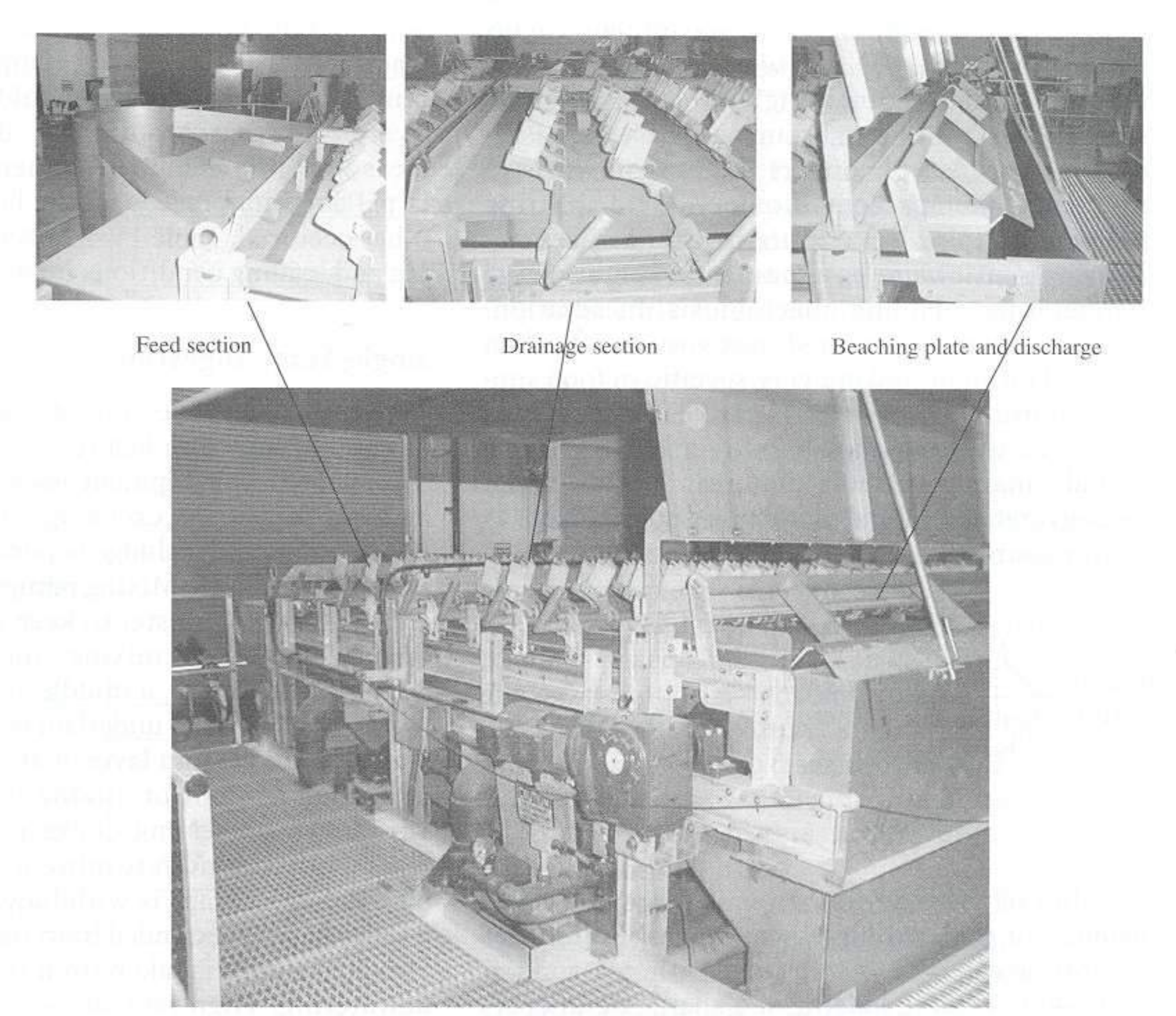
Conditioning

Drying Beds

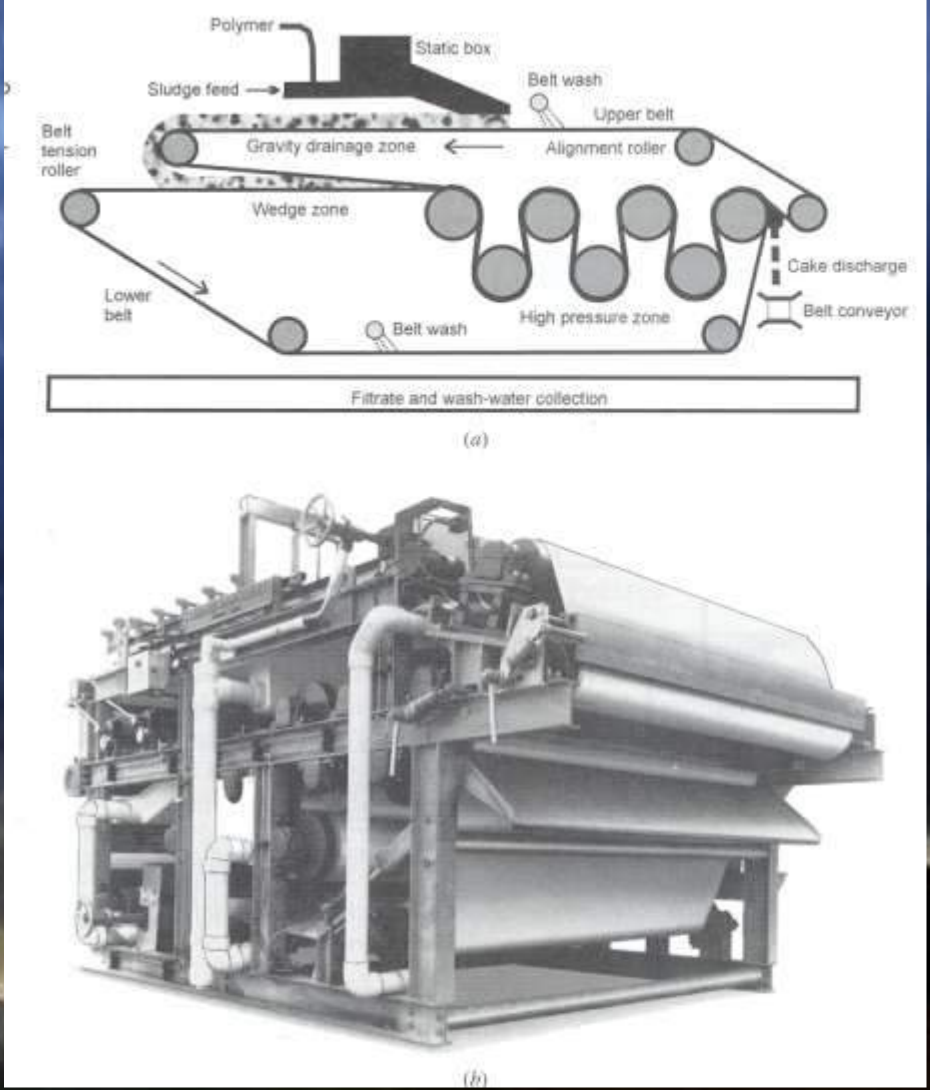




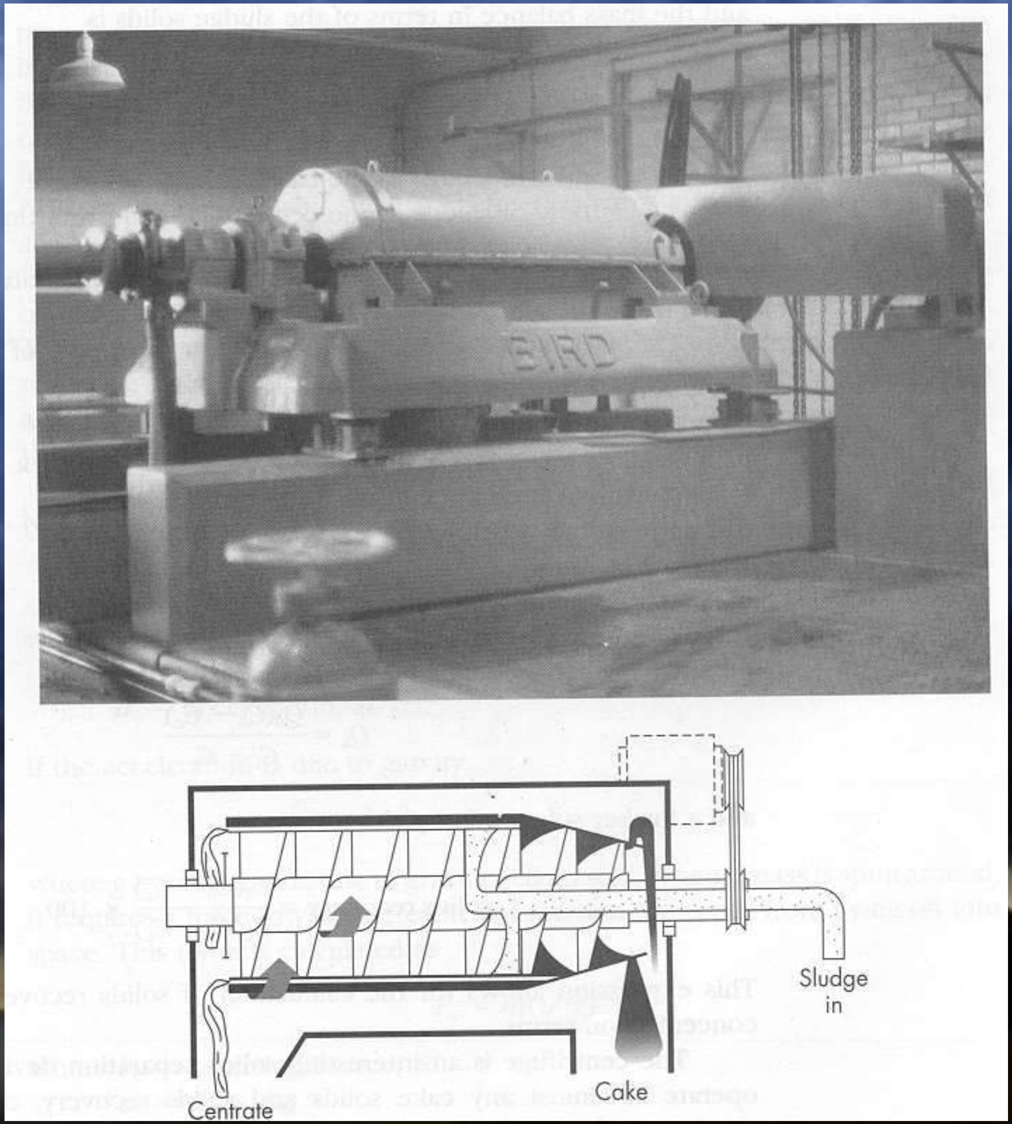
Gravity Belt Thickening



Belt Filter Press



Centrifuge



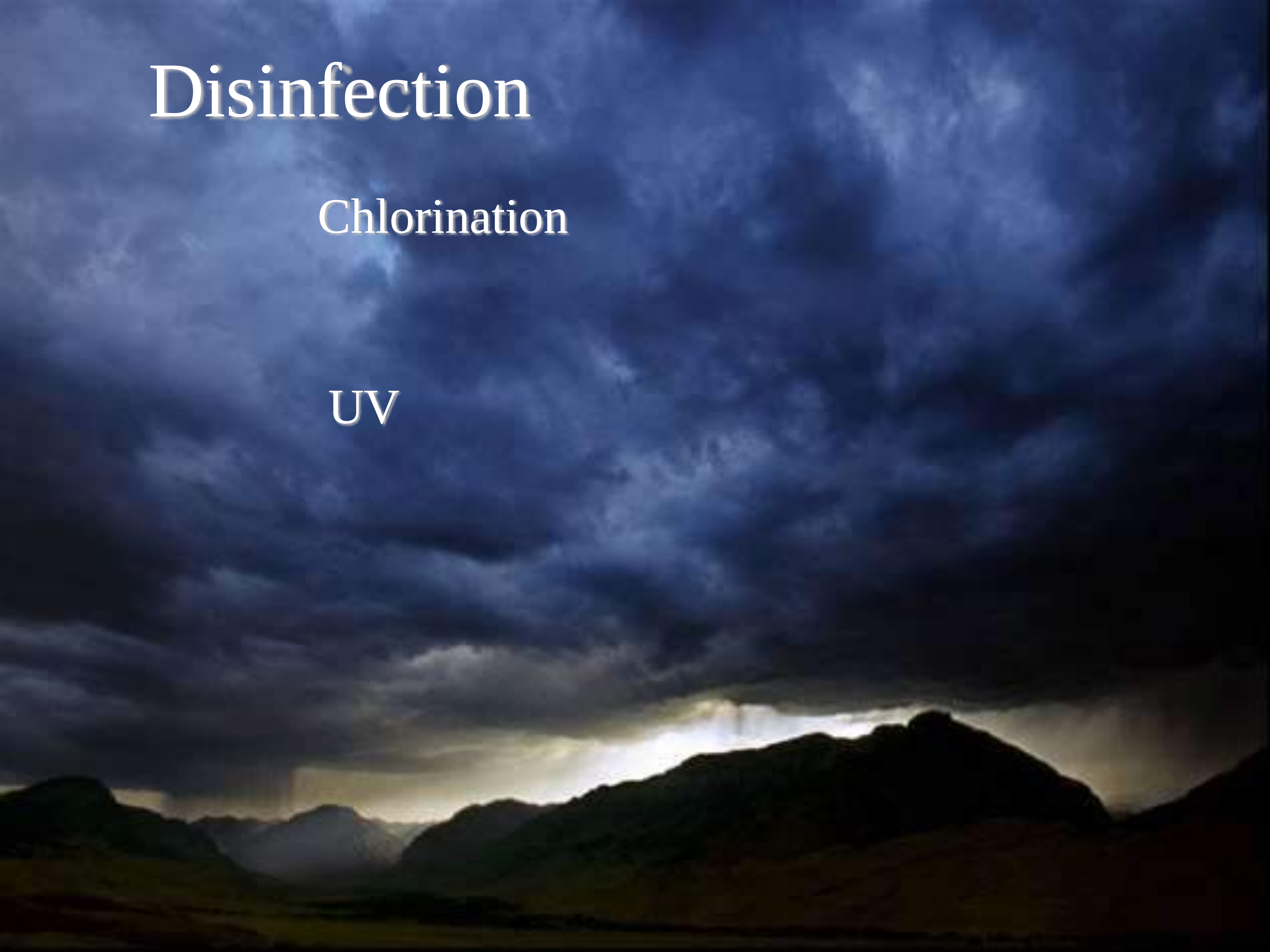
Composting

Ultimate Disposal

Landfill

Land Application

Incineration



Disinfection

Chlorination

UV

DISPOSAL OF SEWAGE INTO WATER BODIES

6.3 Wastewater disposal by Dilution process and essential conditions for dilution

Disposal into water bodies

- Purification of wastewater by self-purification of natural water

Essential Conditions :

A. Sewage
  - ✓ Fresh Sewage
  - ✓ No floating & suspended solids
  - ✓ No toxic substances

B. Water Bodies
  - ✓ High DO content
  - ✓ Not being used for water supply & navigation
  - ✓ Volume of water >> Volume of sewage
  - ✓ Thorough mixing capacity

Causes of water pollution

1) Improper disposal of sewage (continued)

- Industrial waste contains large amounts of toxic chemicals. Heavy water pollution occurs when untreated industrial waste is irresponsibly discharged into water bodies.
- Sewage is treated at sewage treatment plants to remove its waste products before it is released into water bodies.

Sewage treatment process

Some substances in detergents, sprays and even body lotions and shampoo are non-biodegradable and cannot be removed by sewage treatment processes.

Disposal of Sewage

- Disposal of sewage by
- Natural method – Dilution, on Land
- Artificial Method
- Screening & detritus removal
- Sedimentation with or without chemical
- Biological Treatment
- **Types of receiving water body**
- Ocean or Sea – More dilution factor, high TDS
- Lakes – Stagnant water
- Perennial river- Flowing water
- Estuaries

SEWAGE DISPOSAL

The disposal of treated effluent into land or water body is sewage disposal. This can be of two methods,

(i) Dilution – disposal in water bodies.
(ii) Effluent irrigation – disposal on land.

DILUTION:

The disposal of effluent by discharging it into water courses such as streams, rivers or large body of water such as lake, sea is called dilution.

EFFLUENT IRRIGATION:

When the effluent is evenly spread on the surface of land it is effluent irrigation. The water of sewage percolates on the ground and the suspended solids remain at the surface of the ground. The remaining organic suspended solids are partly acted upon by the bacteria and are partly oxidized by exposure to atmospheric actions of heat, light and air.

While considering the characteristics of Vellore Corporation it is preferred that *Effluent Irrigation* i.e. land disposal for the following reasons.

(i) Vellore Corporation is not a coastal city i.e. sea is out of reach. Vellore does not have any perennial river makes impossible for dilution.
(ii) The nearby river stream Pallar has very small amount of dry weather flow. In summer season it runs dry.
(iii) The Sewage Treatment Plant is designed according to Indian Standards which produces effluent having lesser hazardous characteristics than the standards of land disposing.
(iv) It is an alternative source of water for irrigation and it contains the manure and some amount of NPK compounds.

6.5. Factors affecting self purification

1. **Dilution**
   - Ratio of volume of water bodies to sewage
   - Higher the Dilution ratio, not appreciably reduction in DO

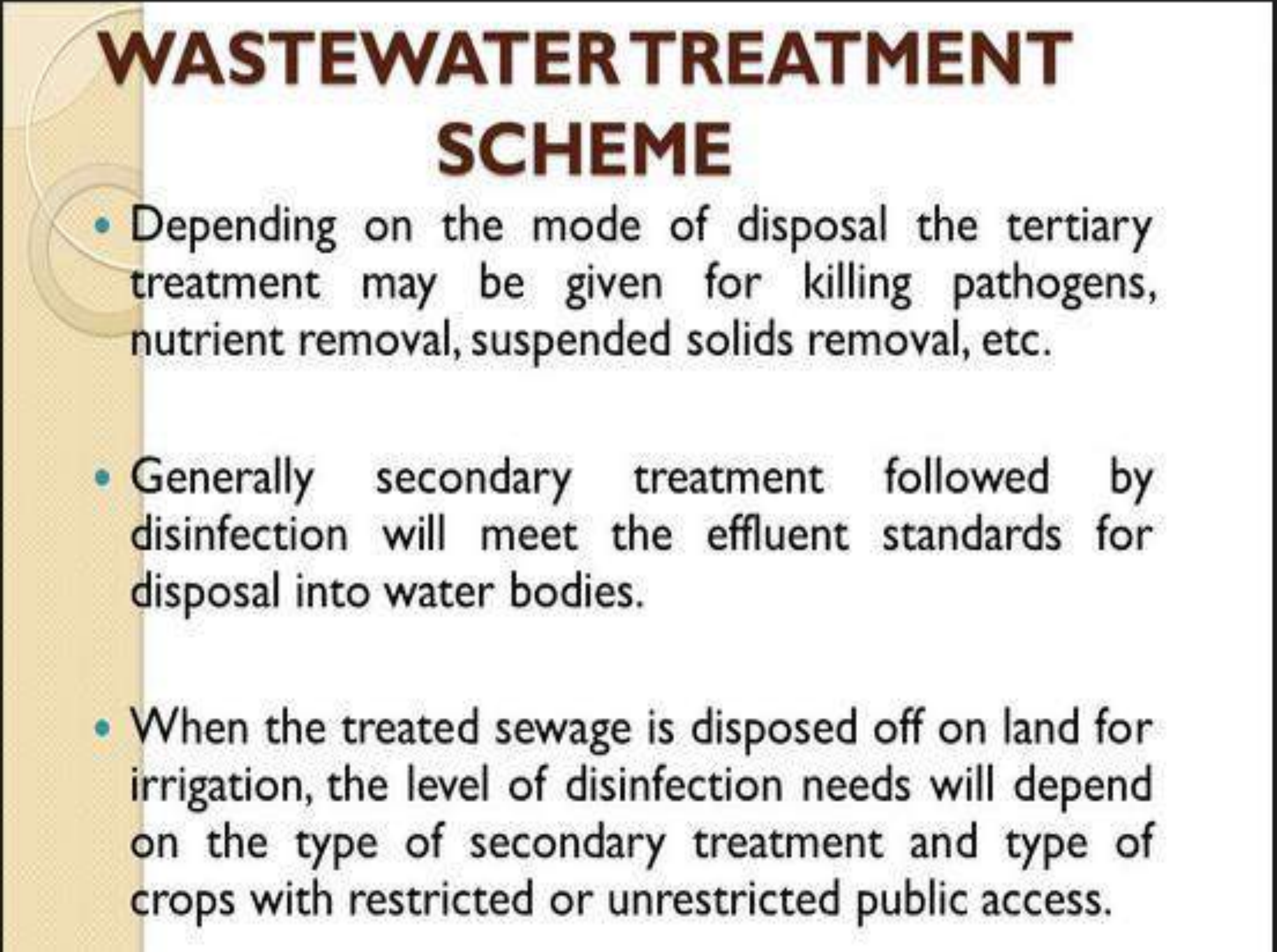
$$C=(Cs*Qs+Cr*Qr)/(Qs+Qr)$$

where,

C= resulting concentration of mixture

Cs, Cr = concentration of organic content BOD,suspended solids in sewage & river resp.

Qs, Qr =Discharges of sewage & river



WASTEWATER TREATMENT SCHEME

- Depending on the mode of disposal the tertiary treatment may be given for killing pathogens, nutrient removal, suspended solids removal, etc.

- Generally secondary treatment followed by disinfection will meet the effluent standards for disposal into water bodies.

- When the treated sewage is disposed off on land for irrigation, the level of disinfection needs will depend on the type of secondary treatment and type of crops with restricted or unrestricted public access.


Thank You!!!

DISPOSAL OF SEWAGE ON LAND

- The process in which wastewater is evenly distributed over the ground surface which acts as a low rate filter.
- Suspended particles are strained out colloids and organic matter are absorbed by the soil particles.
- Nutrients are utilized by vegetation and more complex organic materials are decomposed to simpler inorganic compounds by soil bacteria.

QUALITY STANDARDS FOR WASTE WATER EFFLUENTS TO BE DISCHARGED ON LAND FOR IRRIGATION

- The bureau of Indian standards previously known as Indian standard institution, has vide his code no. 3307-1965 laid down the tolerance limits for various polluting characteristics of Waste water effluents for their discharge on land irrigation.

- In order to make them legally enforceable , GOI has notified the standards polluted effluents For discharge on land under environment rules 1986.

- These standards are based upon the quality of irrigation water required by the crops, thus limit the concentration of pollutants contained in sewage.

THESE PRESCRIBE BIS STANDARDS ARE SHOWN IN TABLE

SL. NO.	POLLUTANT OF WASTE WATER	RULES (1986)
1.	COLOUR AND ODOUR	REMOVE COLOUR AND ODOUR AS FAR AS PARTICABLE
2.	BOD	100mg/l
3.	SUSPENDED SOLIDS	200mg/l
4.	pH value	5.5 to 9
5.	OIL AND GREASE	10mg/l
6.	ARSENIC	0.2mg/l
7.	CYANIDE	0.2mg/l
8.	RADIOACTIVE MATERIALS	
	alpha emitters	10^{-8}µc/ml

FACTS ABOUT LAND DISPOSAL METHOD FOR DISPOSAL OF SEWAGE

- For land disposal, large area of land, preferably with sandy soils.

- This method is generally found to be better choice in hot climatic areas.

- Land disposal saves the inland rivers from getting polluted by sewage

THE DISPOSAL OF SEWAGE ON LAND CAN BE ADOPTED UNDER FOLLOWING CONDITION

- WHEN SOME NATURAL RIVERS OR WATER COURSES ARE NOT LOCATED IN THE VICINITY

- WHEN IRRIGATION WATER IS SCARCELY AVAILABLE.

- LOW RAINFALL AREA.

THE VARIOUS TECHNIQUES THAT ARE EMPLOYED FOR IRRIGATING CROPS ARE :

1. SURFACE IRRIGATION CALLED BROAD IRRIGATION

In this method, sewage is applied in different ways, on to the surface of the land, like free flooding.

2. SUB-SURFACE IRRIGATION

In this method sewage is supplied directly to the root zone of crops.

3. SPRINKLER OR SPRAY IRRIGATION

In this method, sewage is spread over the soil through nozzles.

SEWAGE SICKNEES

- When sewage is applied continuously on a piece of land, the soil pores or voids may get Filled up and clogged with sewage matter retained in them.

- This phenomenon of soil getting clogged is known as sewage sickness of land.

IN ORDER TO PREVENT THE SEWAGE SICKNESSOF A LAND,THE FOLLOWING PREVENTIVE MEASURES MAY BE ADOPTED

- Primary treatment of sewage
- Choice of land
- Giving rest to the land
- Rotation of crop

Sewage Discharges and Oxygen Depletion in Natural Waters

Outline of Topics

- Introduction
  - overview of problems due to human and animal waste pollution
  - combined sewer overflows
  - pathogens
- Oxygen Depletion
  - saturated DO
  - oxygen demand (BOD, COD)
  - sources of BOD waste
  - oxygen sag curves
- Sewage Treatment
  - primary and secondary treatment
  - tertiary treatment
  - disinfection
  - sewage sludge

Pollution due to Human & Animal Waste

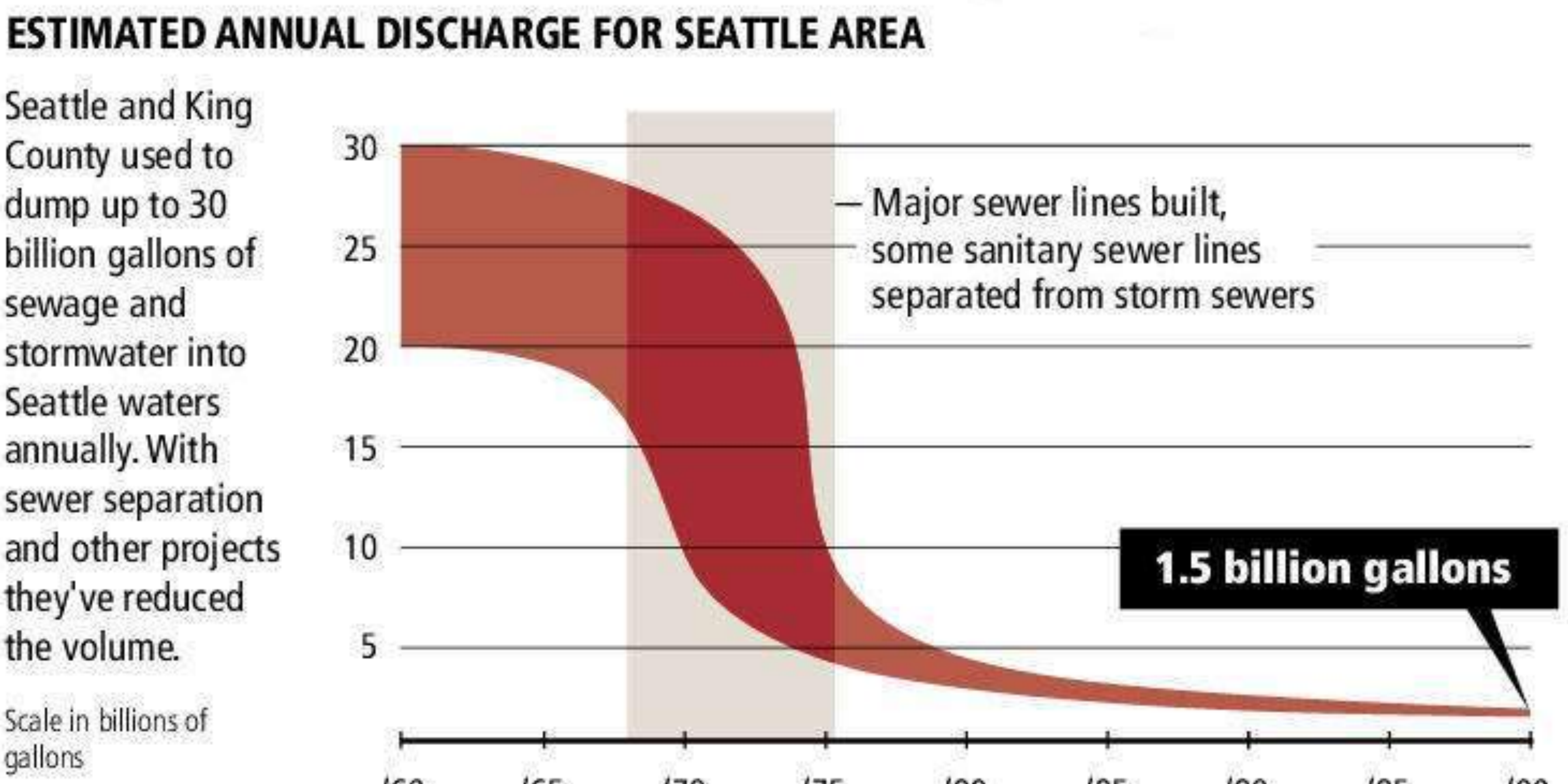
- Sources?
  - Municipal wastewater (ie, sewage)
    - Especially from combined sewer overflows (CSOs)
    - Treated sewage discharge from POTW (publicly owned treatment works)
  - Septic tanks
    - Subsurface disposal/treatment system for each home
      - When sewer lines are not available (eg, sparsely populated areas)
    - Consists of a buried septic tank and either a leaching field or seepage pit
      - From EB: “Solids are decomposed by the anaerobic bacterial action of the sludge. After several years the accumulation of sludge interferes with the action, and a scavenger unit must pump the sludge out of the tank for disposal elsewhere.”
  - Livestock waste
    - Any agricultural operation that includes livestock
    - Animal feeding operation (AFOs)
      - Confined livestock
      - No crops
    - Large AFOs are a particular concern
      - ***Concentrated animal feedlot operations*** (CAFOs) are defined by the number of animals in the AFO
      - As of 2003, regulated as point sources under the NPDES portion of the Clean Water Act

The Nature of Sewage Discharges

- *Lecture Question*
  - What pollutants are present in raw sewage discharges? What are the resulting effects on ecosystem and human health?
  - Pathogens
    - Coliform count is usually 10^5 – 10^6 /mL in raw sewage
    - Cause various waster-borne diseases (see later slide). The most serious water pollution problem in developing countries.
  - Degradable Organic Pollution
    - "High BOD waste." BOD of raw sewage: 100-400 mg/L (typically 200 mg/L)
    - Causes oxygen depletion
  - Nutrients
    - Nitrogen, phosphorus in inorganic and organic forms
    - Associated with eutrophication and related problems.
  - Suspended Solids
    - Increases turbidity and siltation in receiving water body
  - Toxic Chemicals
    - Toxic organics
      - Disinfection byproducts (DBPs) in treated sewage
      - Pharmaceuticals and personal-care products (PPCPs)
      - Surfactants (especially linear alkyl sulfonates, LASs)
    - Anything else poured down the drain (toxic metals, etc)
    - Sometimes combined with industrial waste
    - Stormwater runoff (in combined systems)

Combined Sewer Overflows

- Case Study: Seattle
  - 1212 overflow events in 2001
  - Over 500 million gallons storm water + sewage flowed into Puget Sound

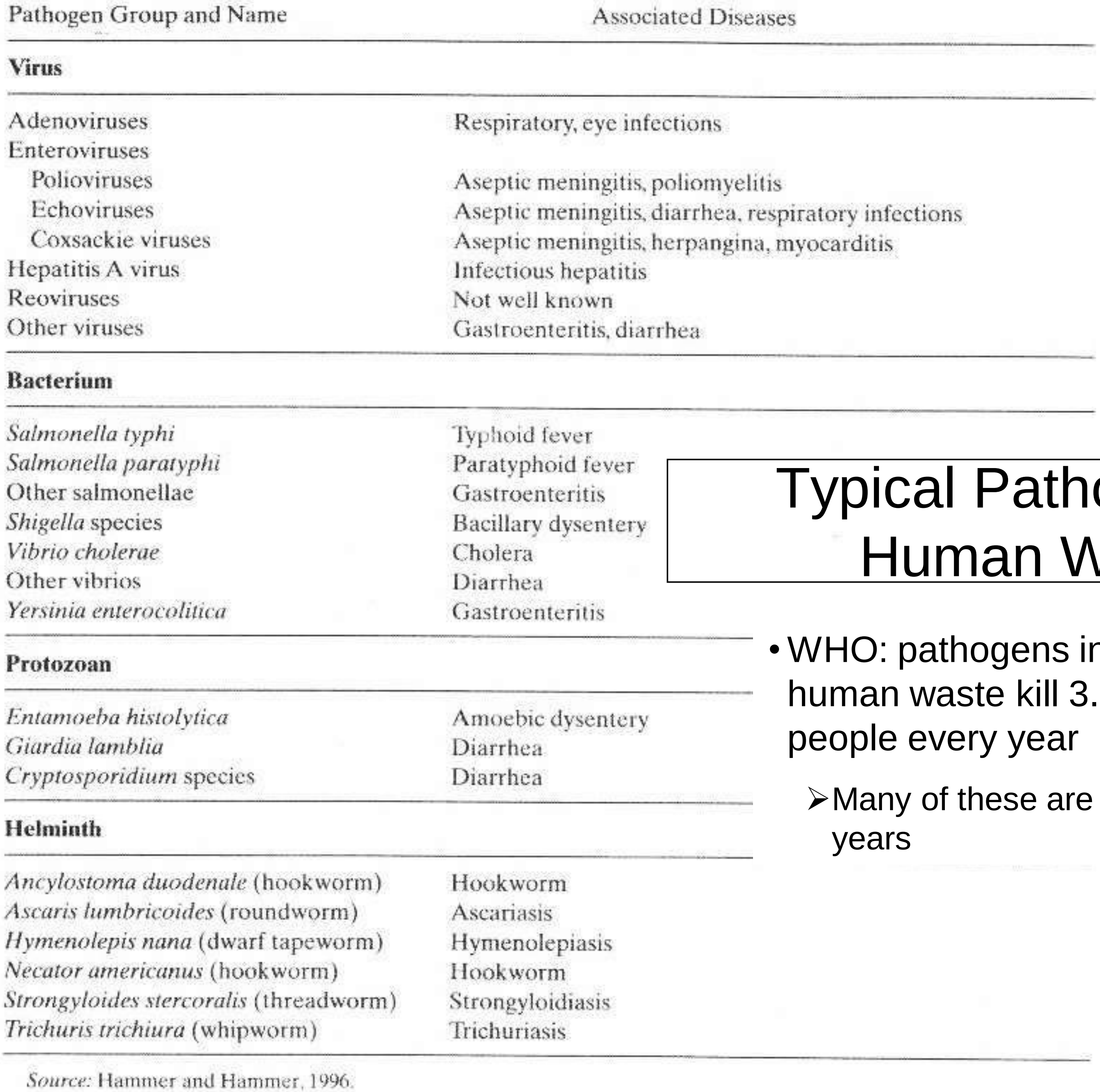


ESTIMATED ANNUAL DISCHARGE FOR SEATTLE AREA

Seattle and King County used to dump up to 30 billion gallons of sewage and stormwater into Seattle waters annually. With sewer separation and other projects they've reduced the volume.

Scale in billions of gallons

Typical Pathogens in Human Waste



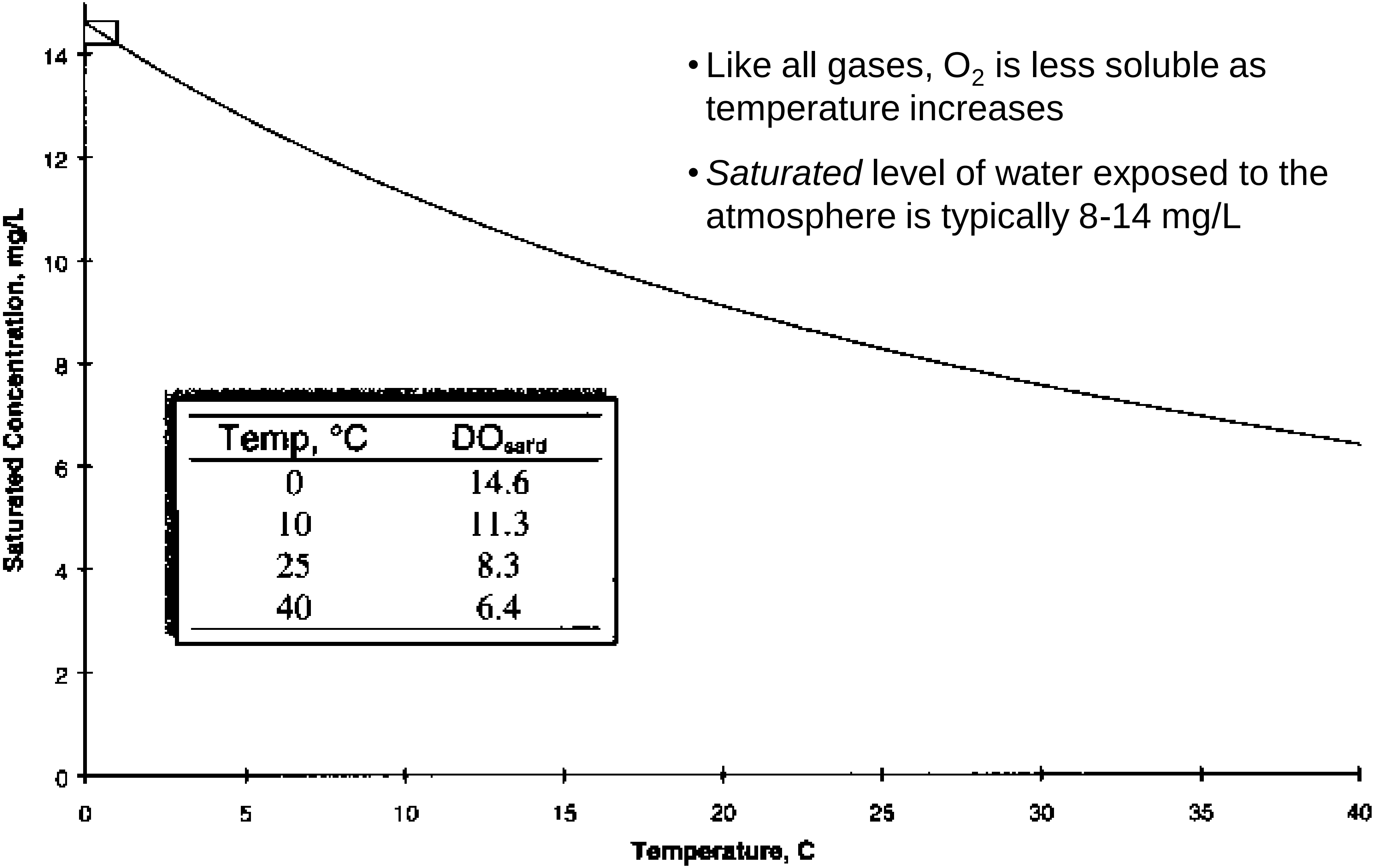
Pathogen Group and Name	Associated Diseases
Virus	
Adenoviruses	Respiratory, eye infections
Enteroviruses	
Polioviruses	Aseptic meningitis, poliomyelitis
Echoviruses	Aseptic meningitis, diarrhea, respiratory infections
Coxsackie viruses	Aseptic meningitis, herpangina, myocarditis
Hepatitis A virus	Infectious hepatitis
Reoviruses	Not well known
Other viruses	Gastroenteritis, diarrhea
Bacterium	
Salmonella typhi	Typhoid fever
Salmonella paratyphi	Paratyphoid fever
Other salmonellae	Gastroenteritis
Shigella species	Bacillary dysentery
Vibrio cholerae	Cholera
Other vibrios	Diarrhea
Yersinia enterocolitica	Gastroenteritis
Protozoan	
Entamoeba histolytica	Amoebic dysentery
Giardia lamblia	Diarrhea
Cryptosporidium species	Diarrhea
Helminth	
Ancylostoma duodenale (hookworm)	Hookworm
Ascaris lumbricoides (roundworm)	Ascariasis
Hymenolepis nana (dwarf tapeworm)	Hymenolepiasis
Necator americanus (hookworm)	Hookworm
Strongyloides stercoralis (threadworm)	Strongyloidiasis
Trichuris trichiura (whipworm)	Trichuriasis

Source: Hammer and Hammer, 1996.

- WHO: pathogens in water from human waste kill 3.4 million people every year
  - ➢Many of these are children under 5 years

Saturated Oxygen Levels in Fresh Water

- Like all gases, O_2 is less soluble as temperature increases
- *Saturated* level of water exposed to the atmosphere is typically 8-14 mg/L



Temp, °C	DO$_{sat'd}$
0	14.6
10	11.3
25	8.3
40	6.4

Effects of Oxygen Depletion

DO level (mg/L)	**Qualitative effect**
6 – 15	OK
4 – 6	Stressed
2 – 4	Choking
1 –2	Dying
0 – 1	Dead

- Effects of low DO on ecosystem communities and populations
  - How much DO is enough?
  - Rapid decrease in DO can cause massive ***fish kills***
  - So-called ***dead zones*** form if DO level falls enough

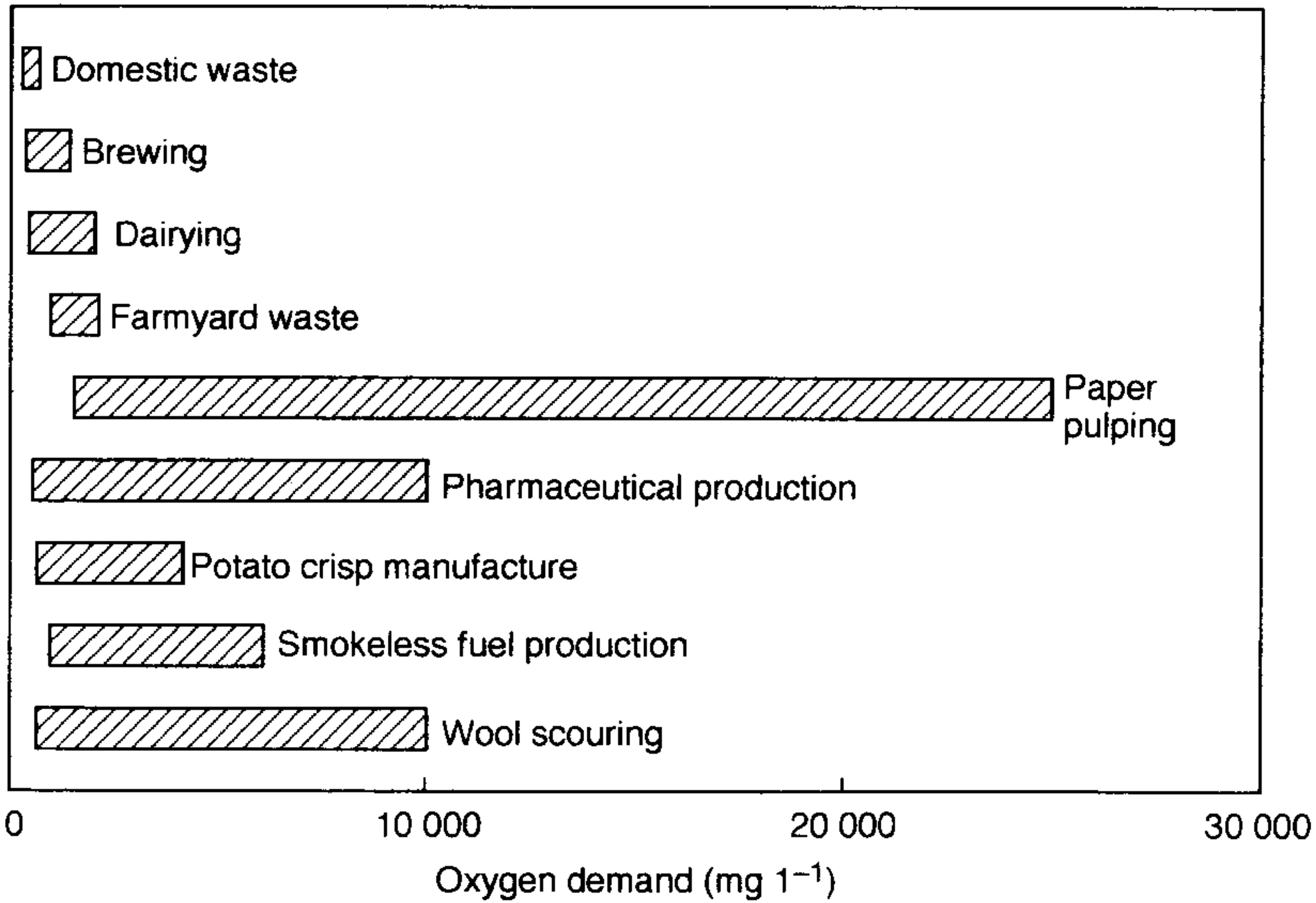
- Effects of low DO on chemical composition
  - Converts chemicals to their to *reduced* state
    - Methane (CH_4), hydrogen sulfide (H_2S), and ammonia (NH_3) instead of carbon dioxide (CO_2), sulfate (SO_4^{2-}) or nitrate (NO_3^-)
  - Reduced forms of metals frequently more soluble
    - Metals can become more mobile
    - Increases exposure of humans and animals to toxic metals

BOD Waste Water

- *Question*
  - What is “high-BOD” waste water?
  - What are the major sources of high-BOD waste water?

  - BOD = biochemical (or biological) oxygen demand
    - When organic material is decomposed (mostly microbial aerobic respiration) it “demands” oxygen
  - ***Oxygen demand*** represents a potential loss of DO in a water body
    - Important factor: relative rates of oxygen loss and replenishment
    - If the rate of oxygen loss due to decomposition exceeds the rate of oxygen replenishment (eg due to dissolution of gaseous O_2), then ***the DO level falls***
  - Oxygen demand can be quantified by measurement of BOD, COD (or TOC)
    - *BOD measurement*: (i) collect a sample of known volume; (ii) measure the DO level; (iii) seal and incubate at constant temperature for 5 or 7 days; (iv) measure the DO level again.
    - The BOD is the difference between the two DO measurements.
    - BOD is determined by the amount of degradable material present in the water. Usually, it is mostly due to organic material (“CBOD”) but can also be due to other chemicals in their reduced state (eg, ammonium).

Common Sources of High-BOD Wastewater

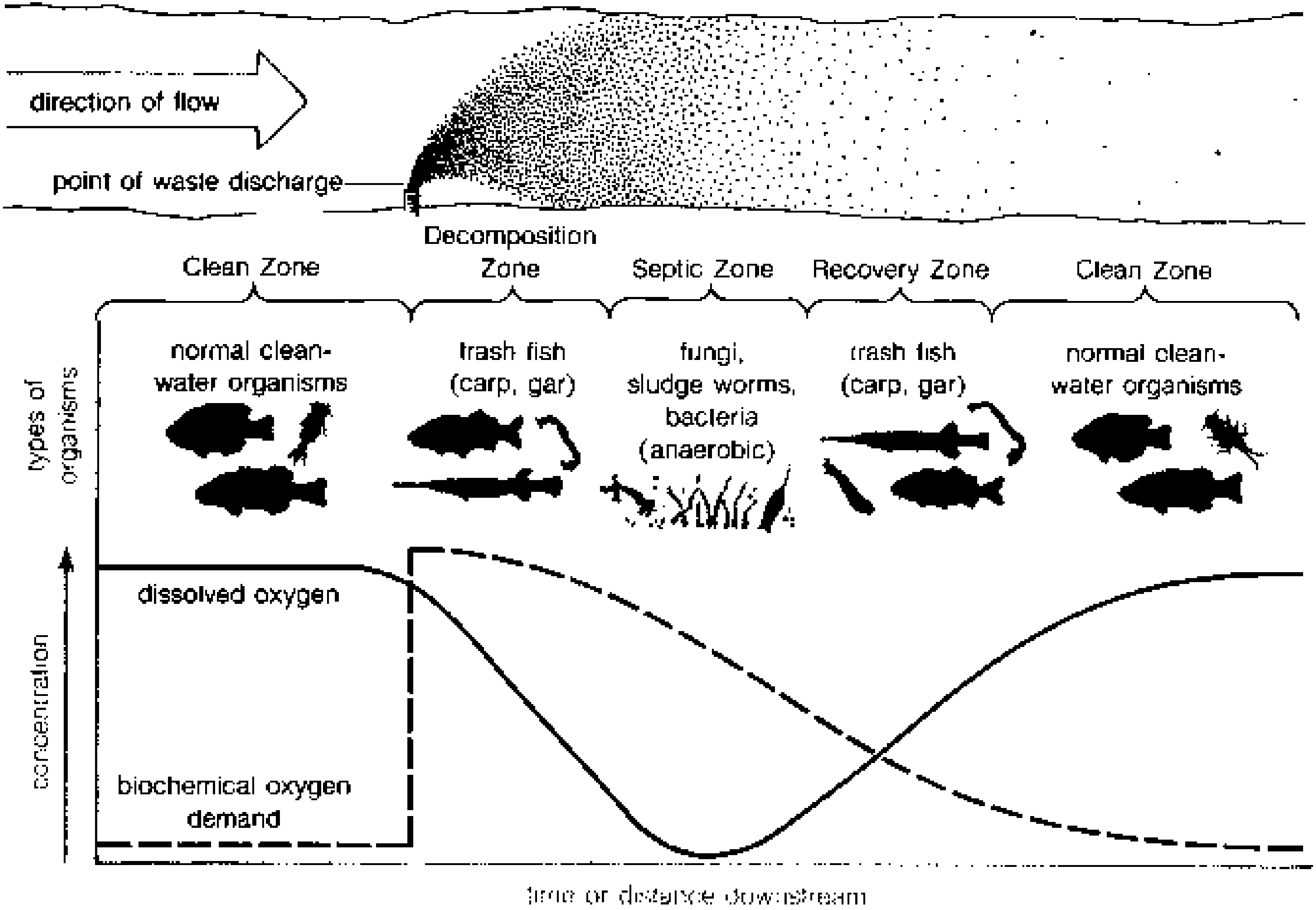


Oxygen-Sag Curves

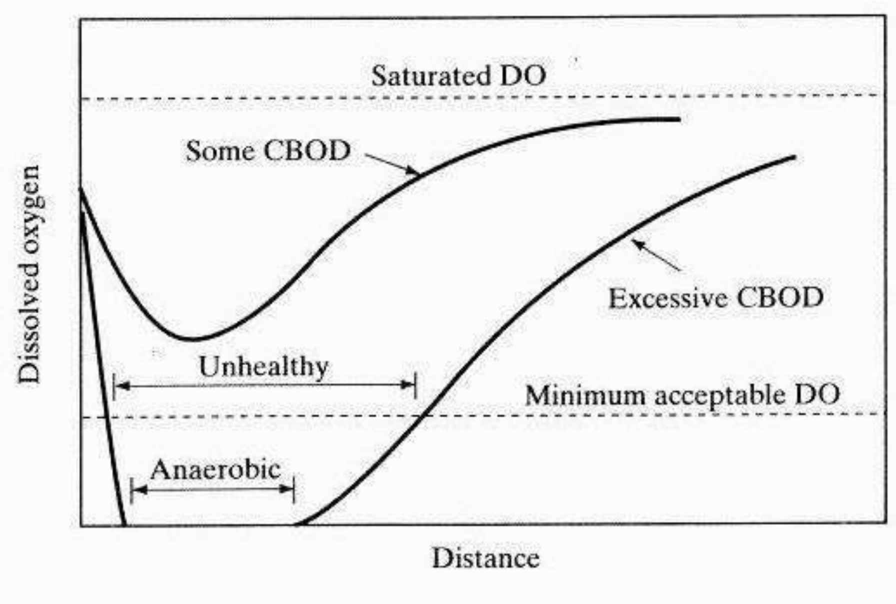
- *Question*
  - What is an *oxygen sag curve*?

  - An oxygen sag curve is the dip in dissolved oxygen observed when BOD waste water is discharged continuously into a river.
    - The extent of the sag is determined by BOD level in the wastewater stream, by the rate of discharge, and by other factors such as temperature and river characteristics (flow rate, turbulence, etc).
  - An oxygen sag curve is also observed due to a one-time discharge of BOD waste into a lake
    - In that case, the DO drop is with *time* instead of *distance* downriver.
    - Continuous discharge of BOD waste into a lake results in a decrease in steady-state DO level (not a “sag” followed by a recovery).

Oxygen-Sag Curves

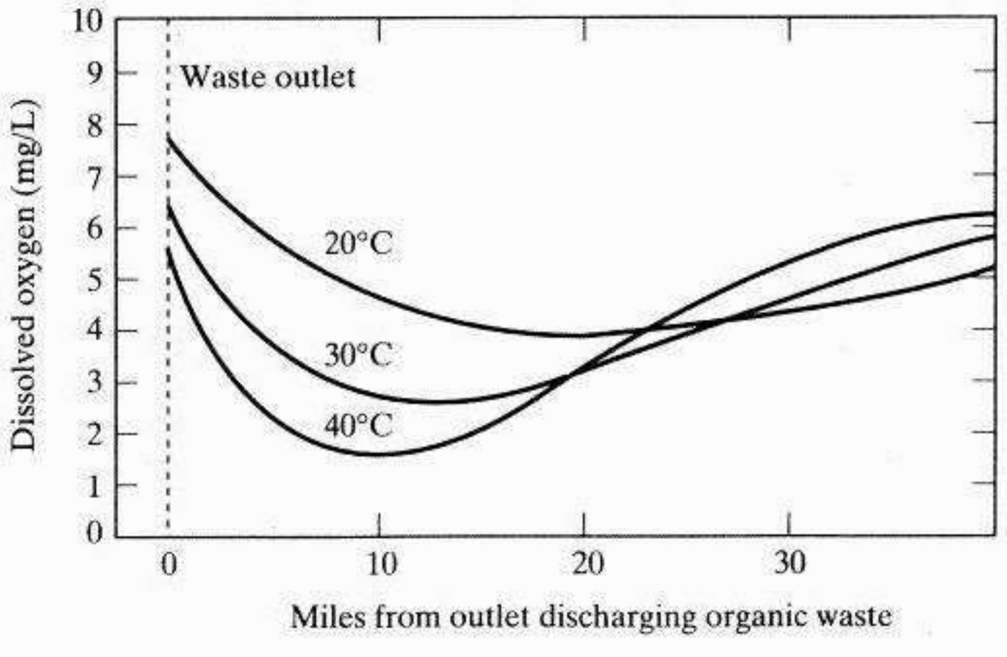


More Oxygen Sag Curves



Effect of BOD Level:
- sag becomes more severe
- longer distance (or time) at unhealthy DO levels

Effect of temperature:
- sag deepens and shortens
- may cause a portion of river to have unhealthy DO levels



Dynamics of Oxygen Depletion & Dissolution

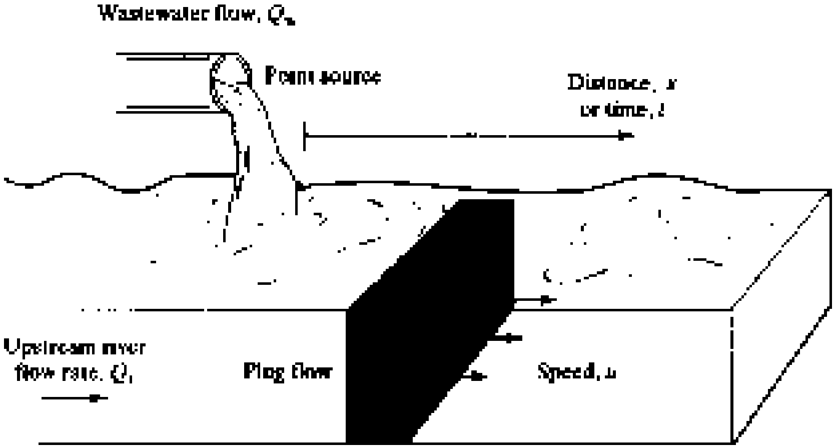


FIGURE 5.14 The point-source, plug flow model for dissolved-oxygen calculations.

Figure on left shows a model framework to calculate:

- DO as a function of distance downstream from a point source discharge; or
- DO as a function of time after a single “spike” discharge of BOD wastewater

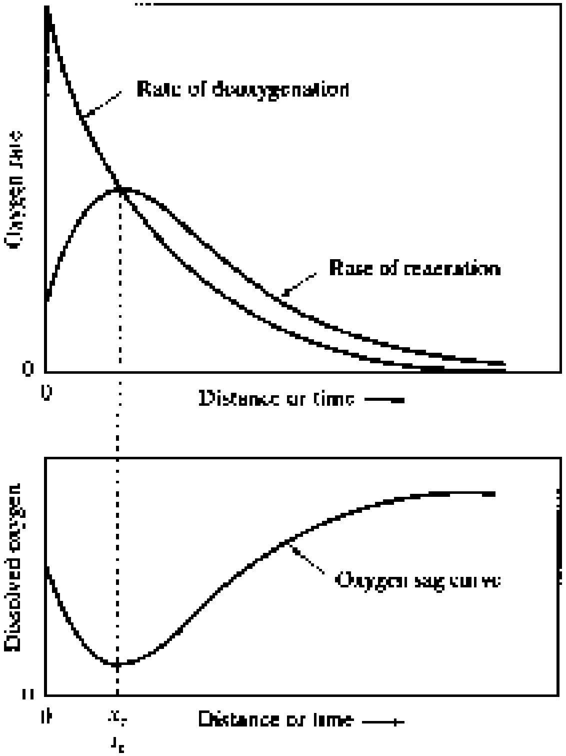


FIGURE 5.16 While the rate of deoxygenation exceeds the rate of reaeration the DO in the river drops. At the critical point those rates are equal. Beyond the critical point, reaeration exceeds decomposition, the DO curve climbs toward saturation, and the river recovers.

- DO falls when decomposition rate > dissolution rate and DO rises when decomposition rate < dissolution rate
- Rate of decomposition (deoxygenation)
  - Linearly proportional to BOD level
  - BOD falls exponentially with time
- Rate of oxygen dissolution (reaeration)
  - Linearly proportional to the *oxygen deficit*: DO_{sat} - DO_{actual}

Sewage Treatment

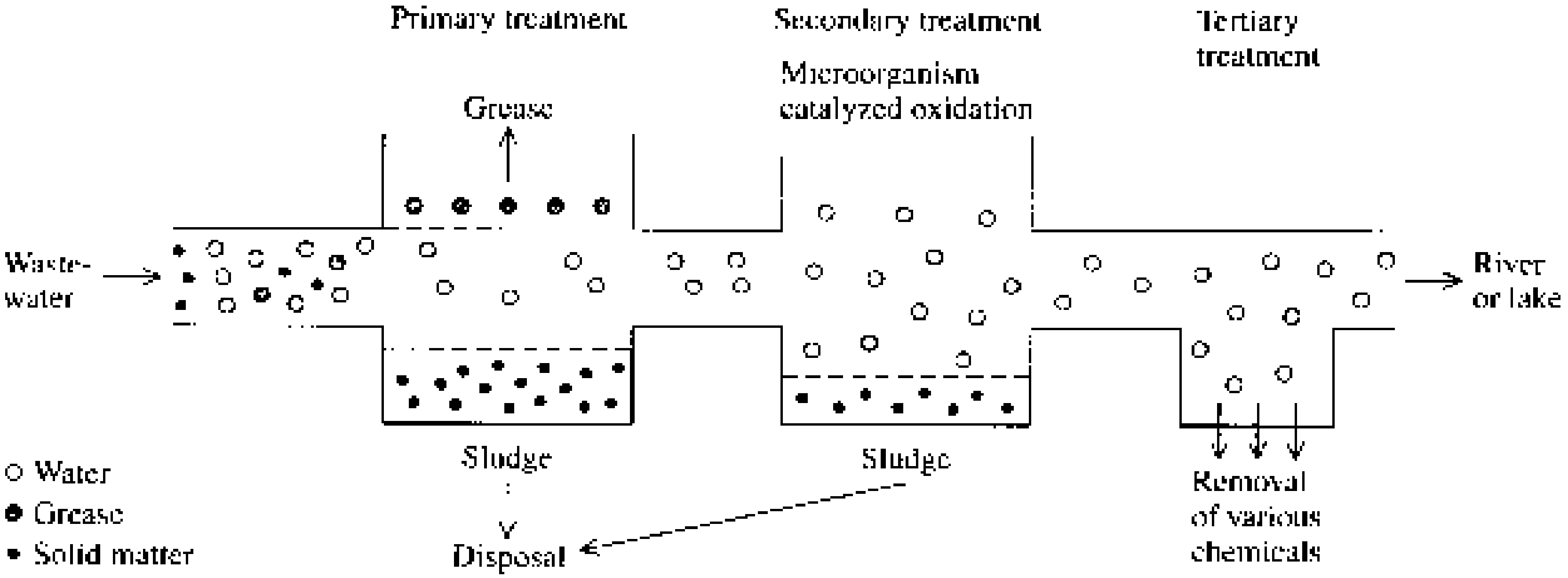
- *Lecture Question*
  - How does the Clean Water Act regulate sewage discharges?

  - CWA passed in 1972
    - Actually, they were comprehensive amendments to an existing statute
  - regulates sewage discharges (among other things) as point sources of pollution
    - A major problem at the time
    - Requires all Publicly-Owned Treatment Works (POTWs, ie "sewage treatment plants") to obtain discharge permits
    - Under the National Pollutant Discharge Elimination System (NPDES)
  - Requires that all POTWs meet a minimum of ***secondary treatment*** level of sewage
    - A big help in reducing BOD, but
    - Problems remain
      - BOD still a little high
      - Nutrient levels not reduced very much with only secondary treatment levels
      - And neither are toxics (metals, organics)

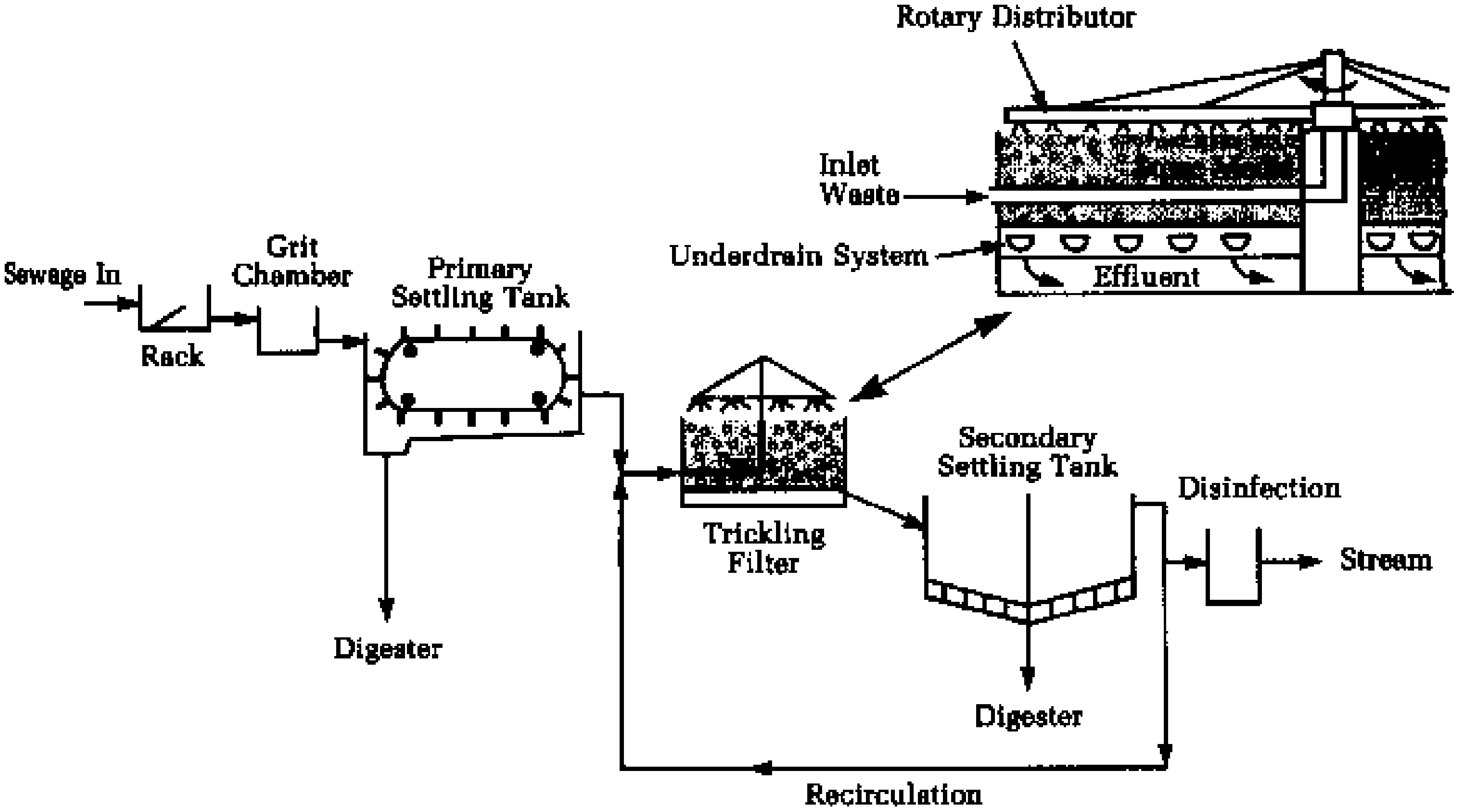
Sewage Treatment Plants (POTWs)

- *Lecture Question*
  - Describe in some detail the processes in the *primary* and *secondary* treatment of sewage.

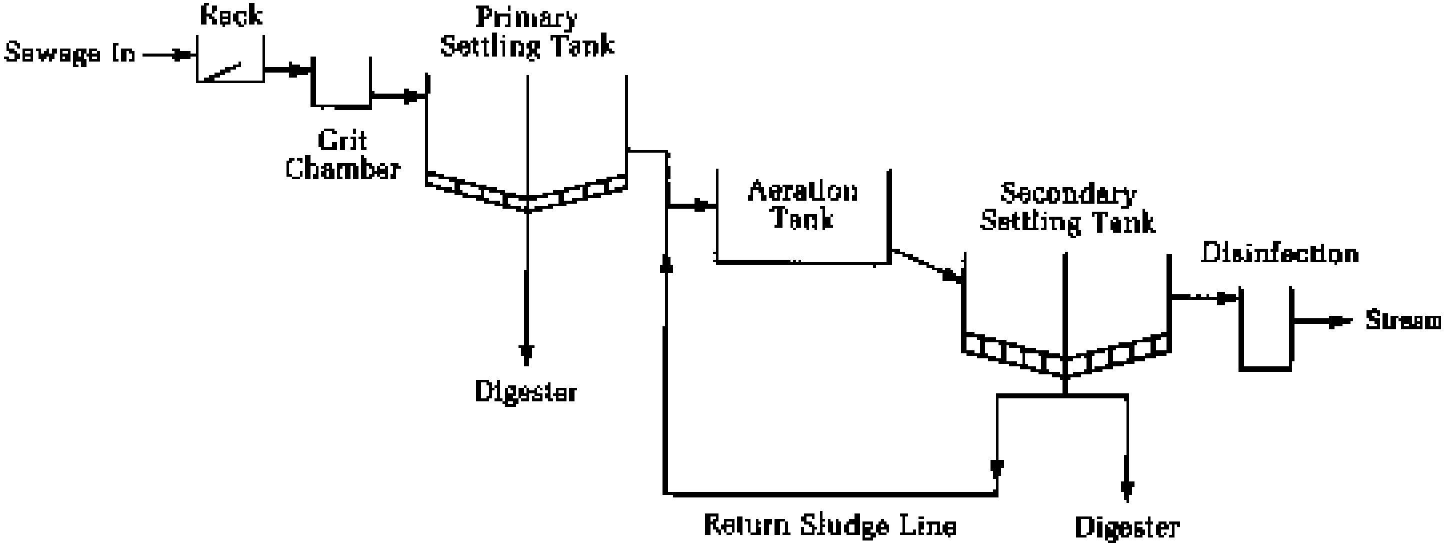
  - *Primary treatment*: physical separation for removal of bulky solids and oil/grease
  - *Secondary treatment*: bioreactor primarily intended to reduce BOD

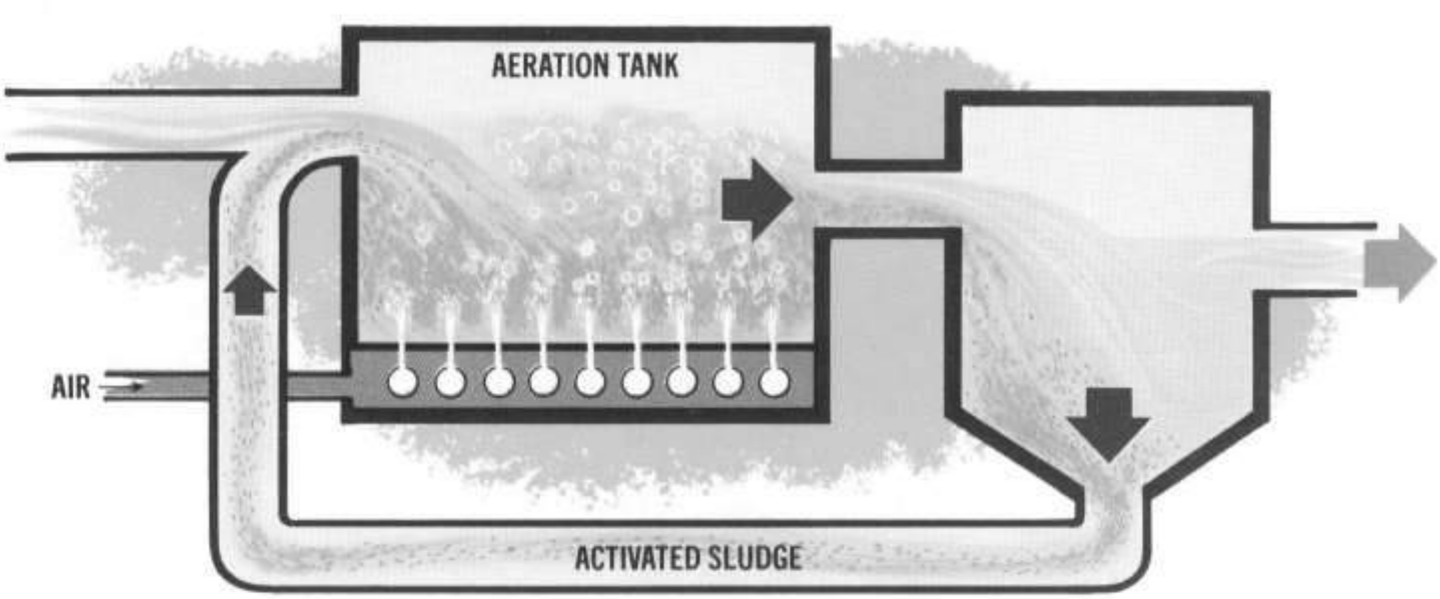


Secondary POTW: Trickling Filter Method

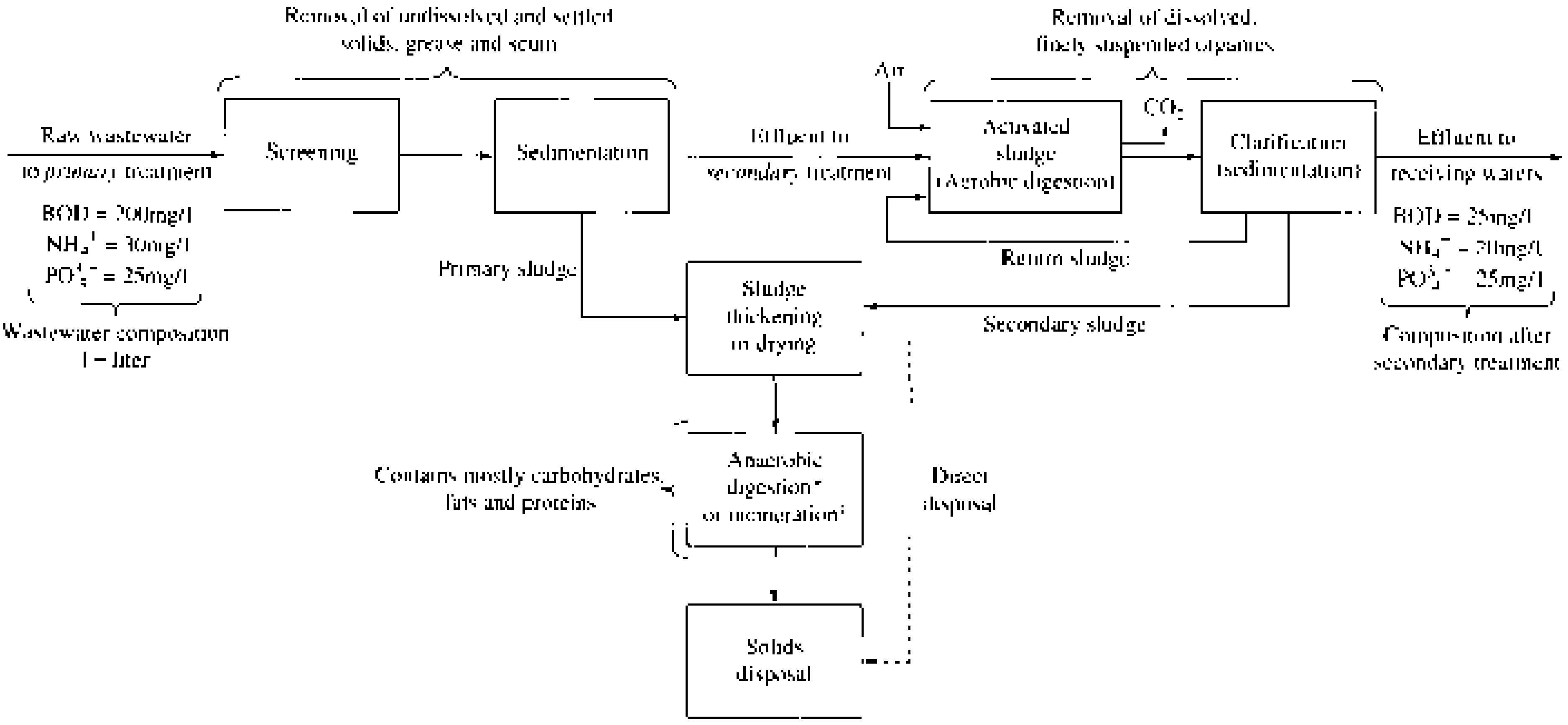


Secondary POTW: Activated Sludge Method





Effects of Primary and Secondary Treatment Levels



* Typically, 50% of the sludge can be digested anaerobically to produce methane gas.

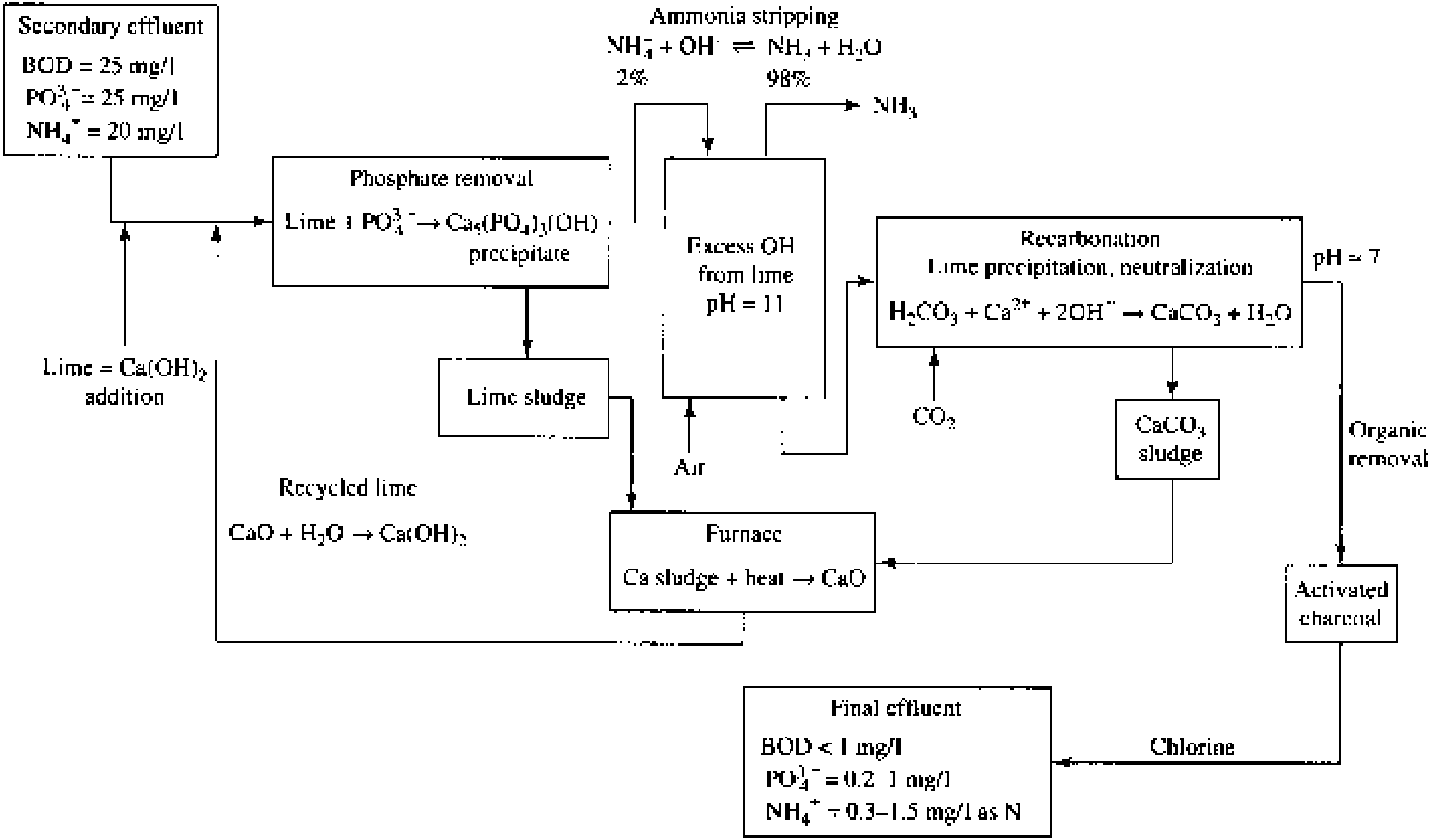
† Dried sludge can be burned as low-quality fuel with a heat value of about 13.5 kJ/g.

Advanced (Tertiary) Treatment

- *Lecture Question*
  - What are the methods used in *advanced* (tertiary) sewage treatment? How do they help safeguard water quality?

  - Advanced treatment consists largely of *chemical* treatment methods designed to do a number of things:
    - Remove nutrient pollution
      - Phosphate removed by treatment with lime, $Ca(OH)_2$
      - Ammonia removed by basification followed by sparging (accelerated outgassing)
    - Further reduce BOD
      - Coprecipitation, activated charcoal, further decomposition
    - Remove toxic organics
      - Activated charcoal filter
    - Remove toxic metals
      - Ion exchange resin filter

Effect of Tertiary Treatment Level



Secondary effluent

BOD = 25 mg/l

PO_4^{3-} = 25 mg/l

NH_4^+ = 20 mg/l

Phosphate removal

Lime + $PO_4^{3-} \rightarrow Ca_5(PO_4)_3(OH)$ precipitate

Lime = $Ca(OH)_2$ addition

Lime sludge

Recycled lime

$CaO + H_2O \rightarrow Ca(OH)_2$

Ammonia stripping

$NH_4^+ + OH^- \rightleftharpoons NH_3 + H_2O$

2% 98%

NH_3

Excess OH from lime pH = 11

Air

Furnace

Ca sludge + heat → CaO

Recarbonation

Lime precipitation, neutralization

$H_2CO_3 + Ca^{2+} + 2OH^- \rightarrow CaCO_3 + H_2O$

CO_2

$CaCO_3$ sludge

pH = 7

Organic removal

Activated charcoal

Chlorine

Final effluent

BOD < 1 mg/l

PO_4^{3-} = 0.2–1 mg/l

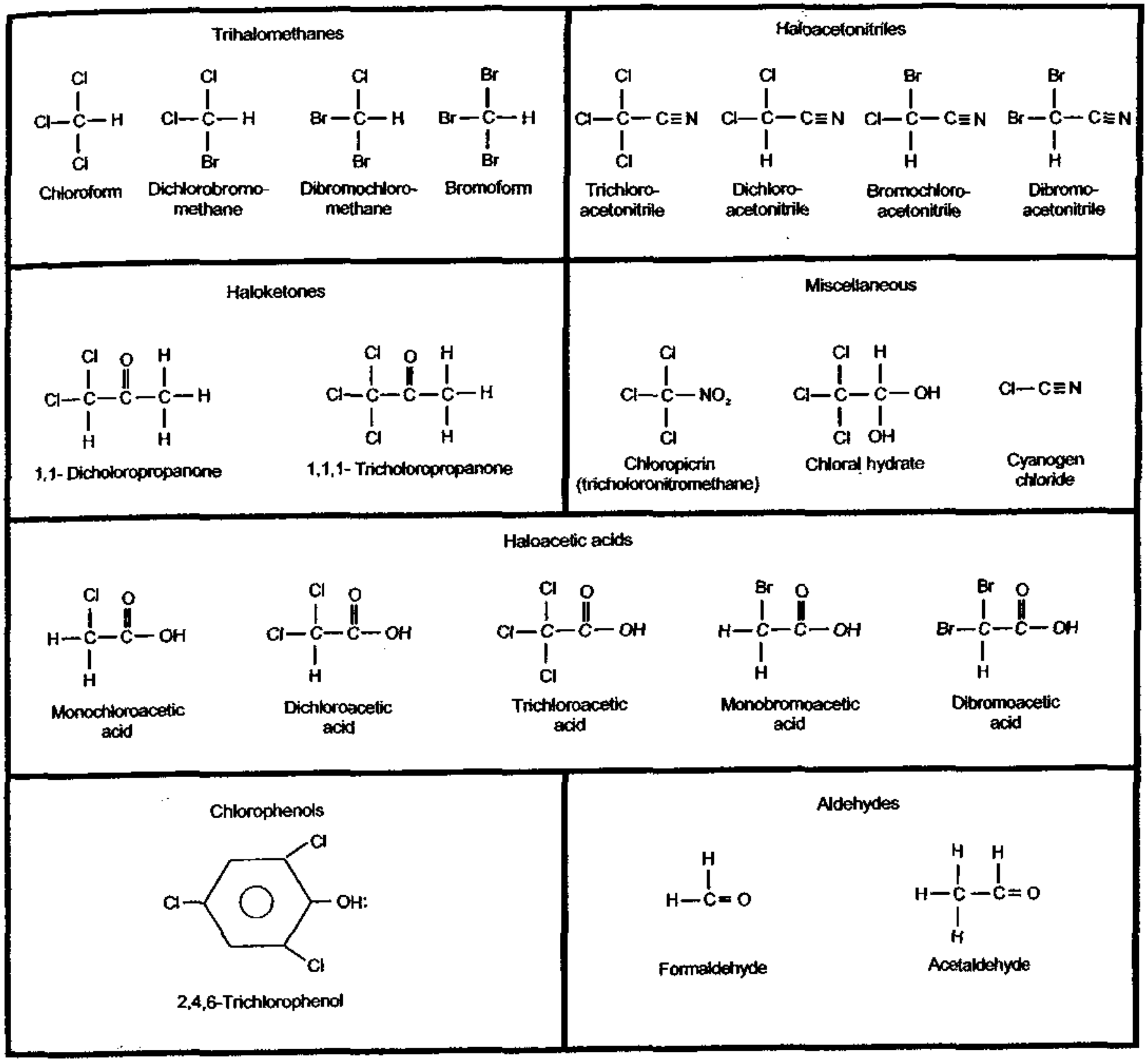
NH_4^+ = 0.3–1.5 mg/l as N

Disinfection

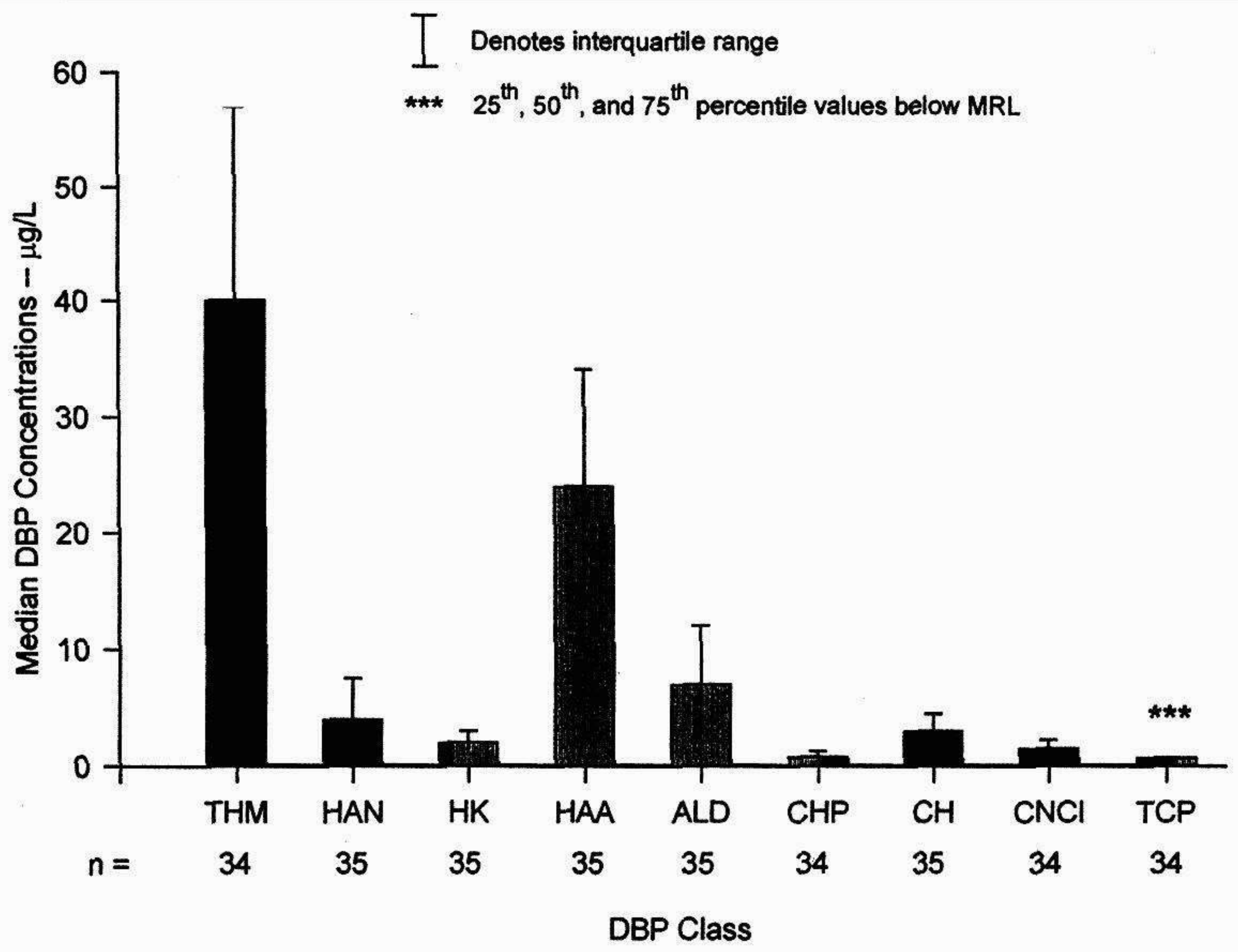
- *Lecture Question*
  - What are the main methods of disinfection used in sewage treatment?

  - Chlorination
    - Applied either as chlorine gas or as a hypochlorite (OCl^-) salt
      - pH control is important
    - Advantages
      - Cheap
      - Residual disinfection
    - Disadvantages
      - Many disinfection byproducts (DBPs): THMs, HAAs, chloramines
  - Alternatives
    - Ozonation
    - uv light
    - With alternative treatments, a lesser amounts of chlorine often also used for residual disinfection (or as a backup if coliform counts get too high).

DBPs Produced by Chlorination



Chlorinated DBPs in Teated Water



Sewage Sludge (Biosolids)

- *Lecture Question*
  - What is sewage sludge (‘biosolids’) and what is done with it?

  - Wastewater treatment generates large quantities of solid waste
    - Collectively this is called “sludge” or, more euphemistically, “biosolids”
    - Contains all solid material removed from the waste stream, including
      - Human waste, microorganisms, and toxic chemicals
    - Volume dwarfs that of municipal solid waste (ie, “trash”)
  - Sludge is very watery
    - Looks essentially like muddy water in original form
    - Only 1-10% solid
  - Usually ‘dewatered’ at the treatment plant
    - Texture of a wet sponge
    - 11-40% solid at this point

Disposal of Sewage Sludge

- Eventual Fate?
  - Land application/recycling (40-50%)
    - **67% of that used as fertilizer on crops**
      - Must be treated to remove pathogens
      - Continued uncertainty over health effects due to pathogens and pollutants in the sludge
    - 12% of that to public
      - Given or sold
    - 9% of that applied to damaged lands
      - Usually to revitalize closed mines
    - 3% of that sprayed onto forests
      - Slope cannot exceed 10-20%
  - Sanitary landfill (50%)
    - Direct
    - Incineration
      - Resulting ash is landfilled

A PRESENTATION
ON
SEWAGE DISPOSAL

Presented by

TEJASREE.VEMURI

Asst. PROFESSOR

SMGG

Objectives:

- At the end of this presentation you will have the idea about different methods of sewage disposal.
- You will certainly be familiar with dilution and land disposal methods of sewage disposal.
- You will know what sewage sickness means.

Outline

6.1 Necessity and objectives of wastewater disposal

6.2 Waste water disposal methods

6.3 Wastewater disposal by Dilution process and essential conditions for dilution

6.4 Self purification of rivers/streams

6.5 Factors affecting self purification

6.6 Oxygen sag curve

6.7 Streeter Phelps's equation

6.8 Numericals on self purification of rivers/streams

6.9 Wastewater disposal by land treatment

6.1 Necessity and objectives of wastewater disposal

Definition:

Sewage: liquid waste from community

Removing act of sewage :: *sewage disposal*

Necessity:

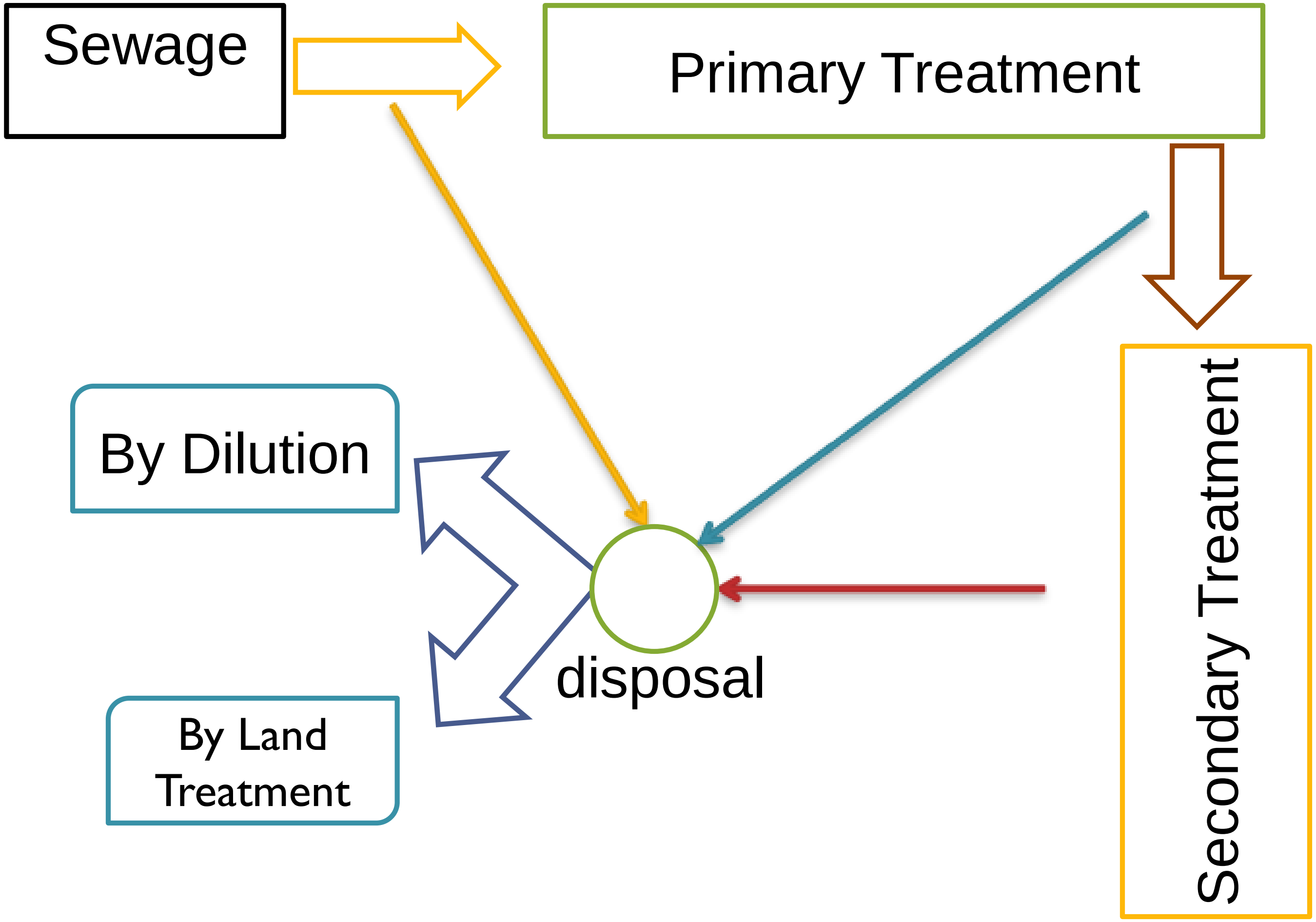
- Accumulation causes nuisance
- Selection of Pretreatment method
- Protection of groundwater

Objectives:

- To improve public health
- To use sewage in farm
- To protect aquatic life

6.2 Wastewater Disposal Method

Composition, Quality, Characteristic of Sewage



Sewage

Primary Treatment

Secondary Treatment

disposal

By Dilution

By Land Treatment

6.3 Wastewater disposal by Dilution process and essential conditions for dilution

Disposal into water bodies

- Purification of wastewater by self-purification of natural water

Essential Conditions :

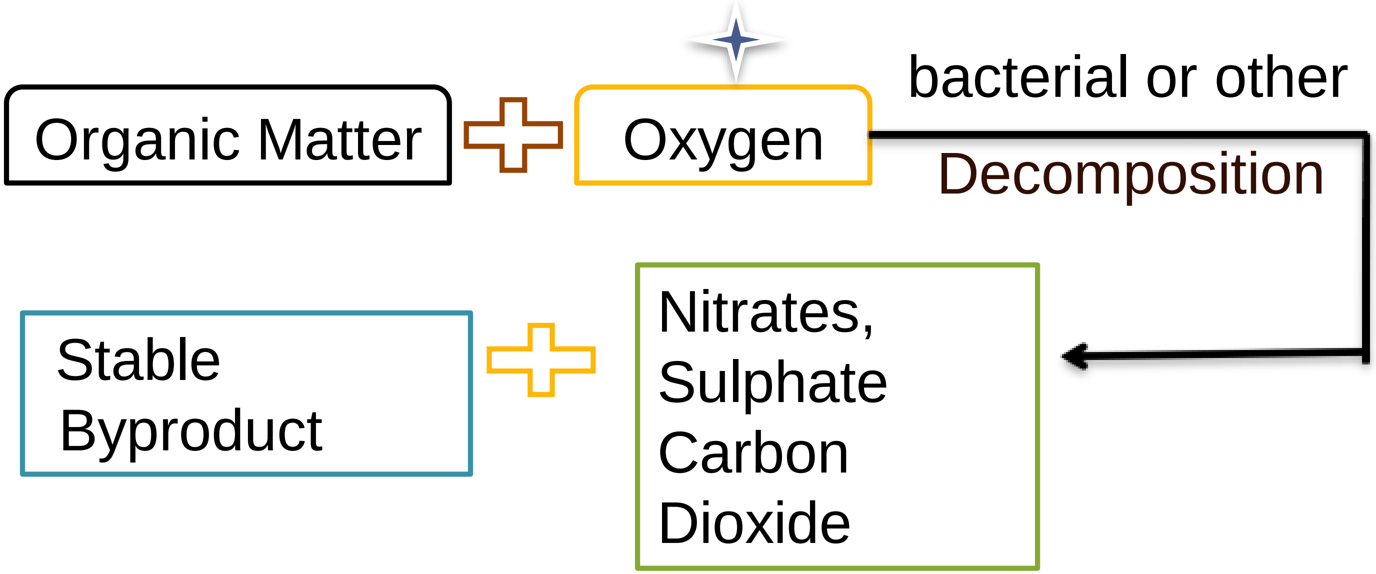
A. Sewage
   - ✓ Fresh Sewage
   - ✓ No floating & suspended solids
   - ✓ No toxic substances

B. Water Bodies
   - ✓ High DO content
   - ✓ Not being used for water supply & navigation
   - ✓ Volume of water >> Volume of sewage
   - ✓ Thorough mixing capacity

6.4. Self Purification of rivers/streams

Despite discharge of sewage,

Balancing its (river) DO content after few days.



Organic Matter + Oxygen

bacterial or other

Decomposition

Nitrates, Sulphate Carbon Dioxide + Stable Byproduct

- Due to decomposition, reduction in DO content.
- Deficit DO is replenished by aeration.

6.5. Factors affecting self purification

1. **Dilution**
   - ❖ Ratio of volume of water bodies to sewage
   - ❖ Higher the Dilution ratio, not appreciably reduction in DO

$$C=(Cs*Qs+Cr*Qr)/(Qs+Qr)$$

where,

C= resulting concentration of mixture

Cs, Cr = concentration of organic content BOD,suspended solids in sewage & river resp.

Qs, Qr =Discharges of sewage & river

2. Current

\# Disperse the wastewater

\# High velocity of current – reduction in time of recovery

But affected to long length of stream.

3.Sunlight

\# Enhance aquatic plants to produce oxygen

4. Sedimentation

\# Removal of suspended solids by settling

\# Anaerobic decomposition due to settled solids

5. Temperature

\# High temp. increases solubility of oxygen in water.

\# High temp. causes less self-purification time.

6. Oxidation

\# Capability of stream to absorb more oxygen

7. Reduction

\# Hydrolysis of organic matter

6.6 Oxygen Sag Curve

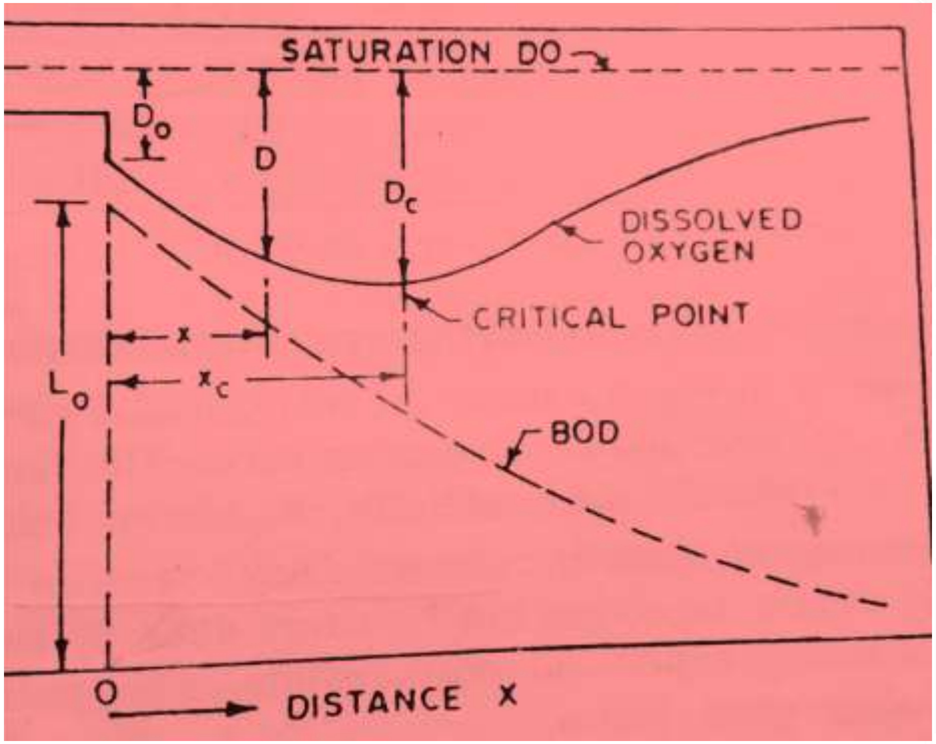


fig: OXYGEN SAG AND BOD REMOVAL IN STREAM

Variation of oxygen deficit with the distance along the stream or time of flow from the point of application

Oxygen deficit, D =
Saturation DO -
Actual DO

Normal saturation DO for freshwater :

14.62 mg/l @ 0 degree

7.63 mg/l @ 20 degree

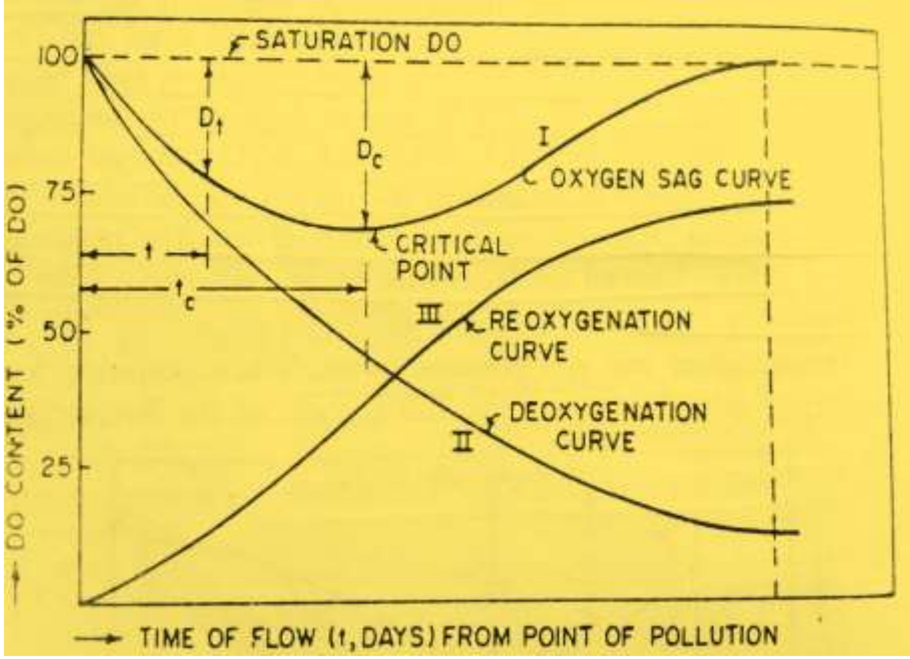


fig : DEOXYGENATION, REOXYGENATION AND OXYGEN SAG CURVES

Terminology:

-Initial oxygen deficit, D_0

-Critical deficit , Dc

-Re-oxygenation curve, III

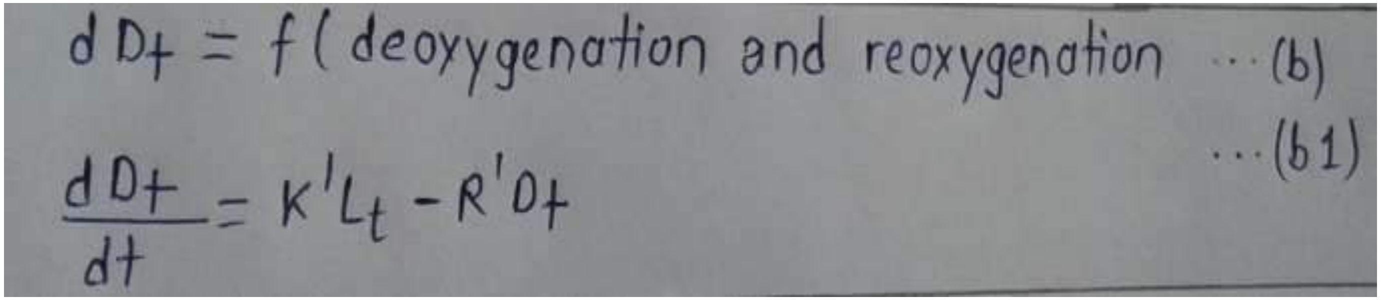
-De-oxygenation curve, II

-Dissolved Oxygen

6.7.Streeter-Phelps Equation

- Mathematical expression for oxygen sag curve
- Concept of superposition of rate of deoxygenation & reoxygenation

Some Formulas



$dD_t = f($deoxygenation and reoxygenation ...(b)

$$\frac{dD_t}{dt} = K'L_t - R'D_t \quad \ldots(b1)$$

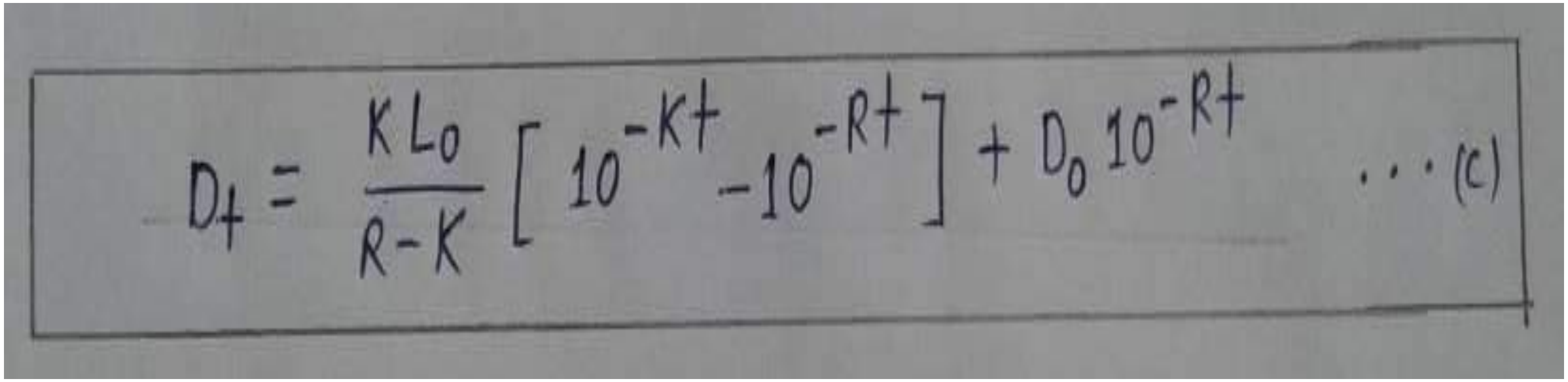
Where,

Dt = DO deficit at any time t.

Lt = amount of first stage BOD remaining in the sample at time t

K’ = BOD reaction constant (base e)

R’ = Re-Oxygenation constant (base e)



$$D_t = \frac{K L_0}{R-K}\left[10^{-Kt} - 10^{-Rt}\right] + D_0 10^{-Rt} \quad \cdots (c)$$

This eqn …(c) is Streeter-Phelps Equation.

Where,

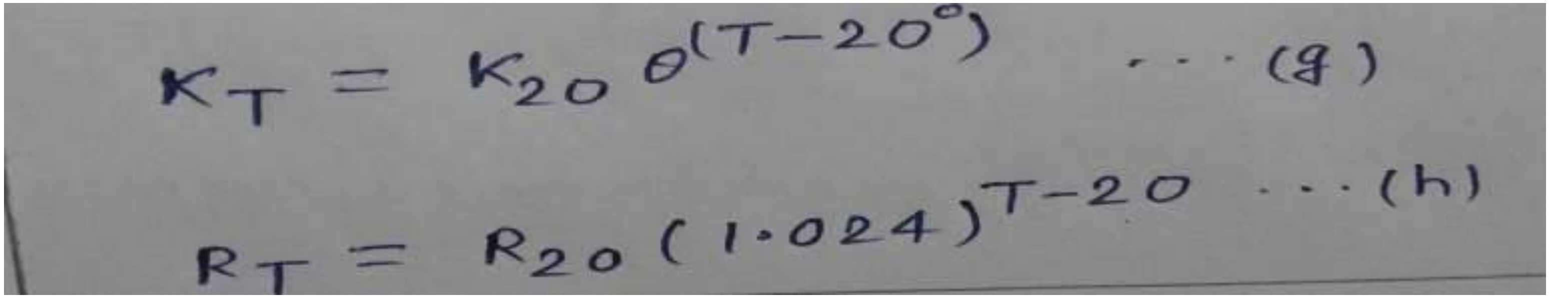
D_t = DO deficit at any time t.

L0 = Ultimate BOD

K= BOD reaction constant

R = Re-Oxygenation constant

D_0=Initial Do deficit @ t=0



$$K_T = K_{20}\,\theta^{(T-20^\circ)} \quad \cdots (g)$$

$$R_T = R_{20}(1\cdot 024)^{T-20} \quad \cdots (h)$$

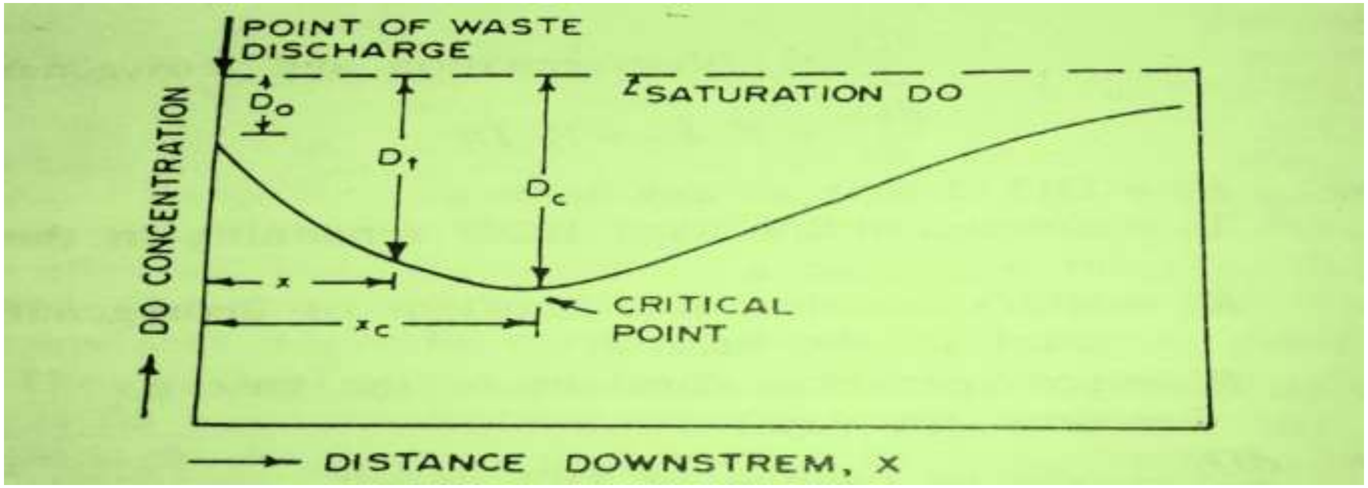
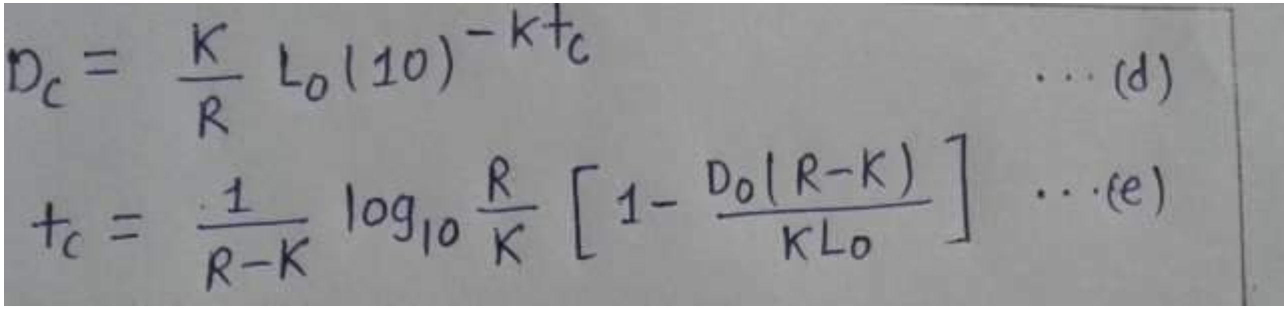


Fig : Characteristic Oxygen Sag Curve Obtained Using Streeter- Phelps Equation



$$D_c = \frac{K}{R} L_0 (10)^{-K t_c} \quad \cdots (d)$$

$$t_c = \frac{1}{R-K} \log_{10} \frac{R}{K} \left[1 - \frac{D_0 (R-K)}{K L_0} \right] \quad \cdots (e)$$

Where,

Dc= Critical DO deficit

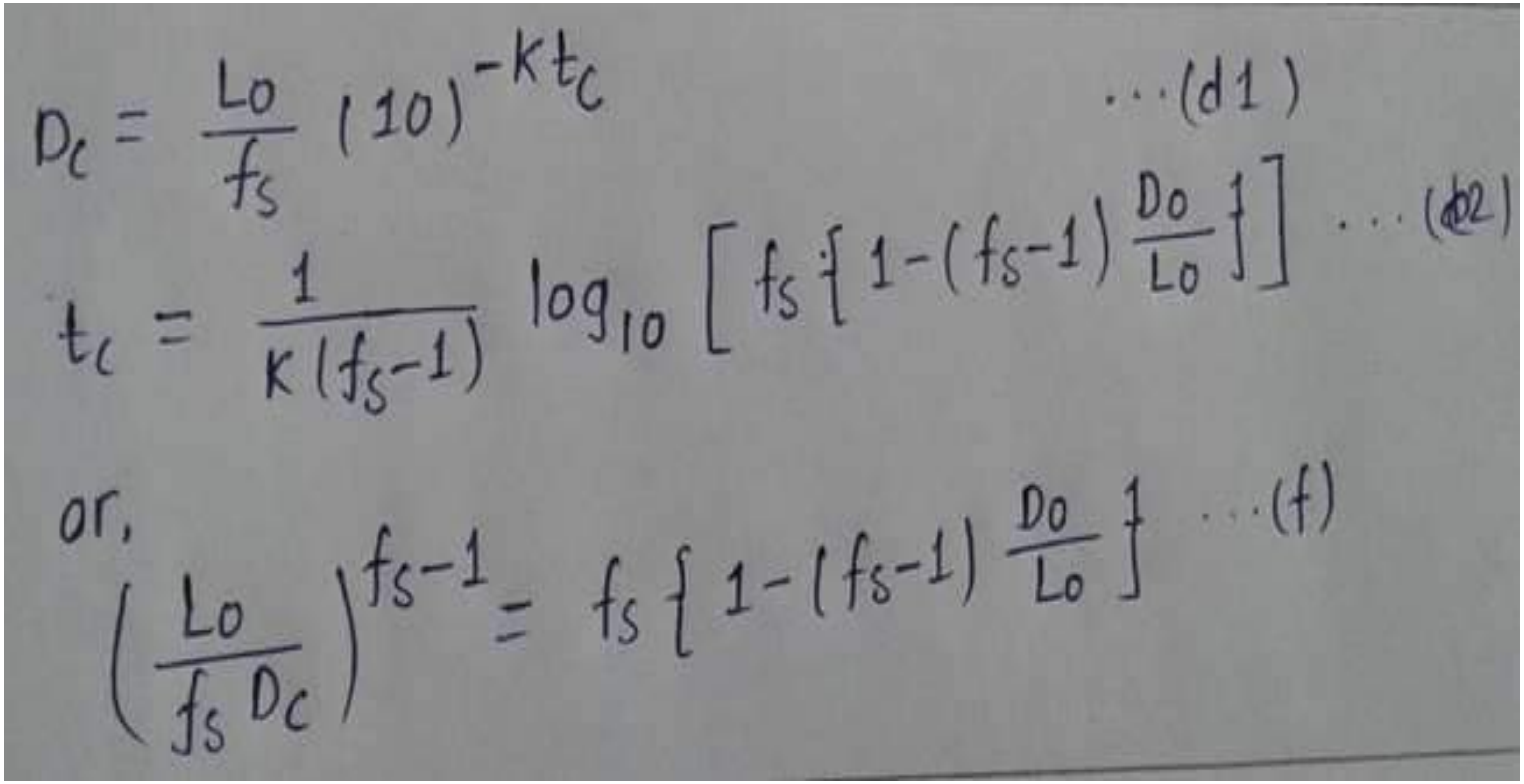
Tc= Time required to reach critical point

Xc= Tc * velocity of stream’v’

Put Fs = R/K (or R'/K'),

Fs is self- purification constant

Introducing 'Fs' in eqn (d), (e), we have



$$D_c = \frac{L_0}{f_s}(10)^{-Kt_c} \quad \cdots (d1)$$

$$t_c = \frac{1}{K(f_s-1)} \log_{10}\left[f_s \left\{ 1-(f_s-1)\frac{D_0}{L_0} \right\} \right] \quad \cdots (d2)$$

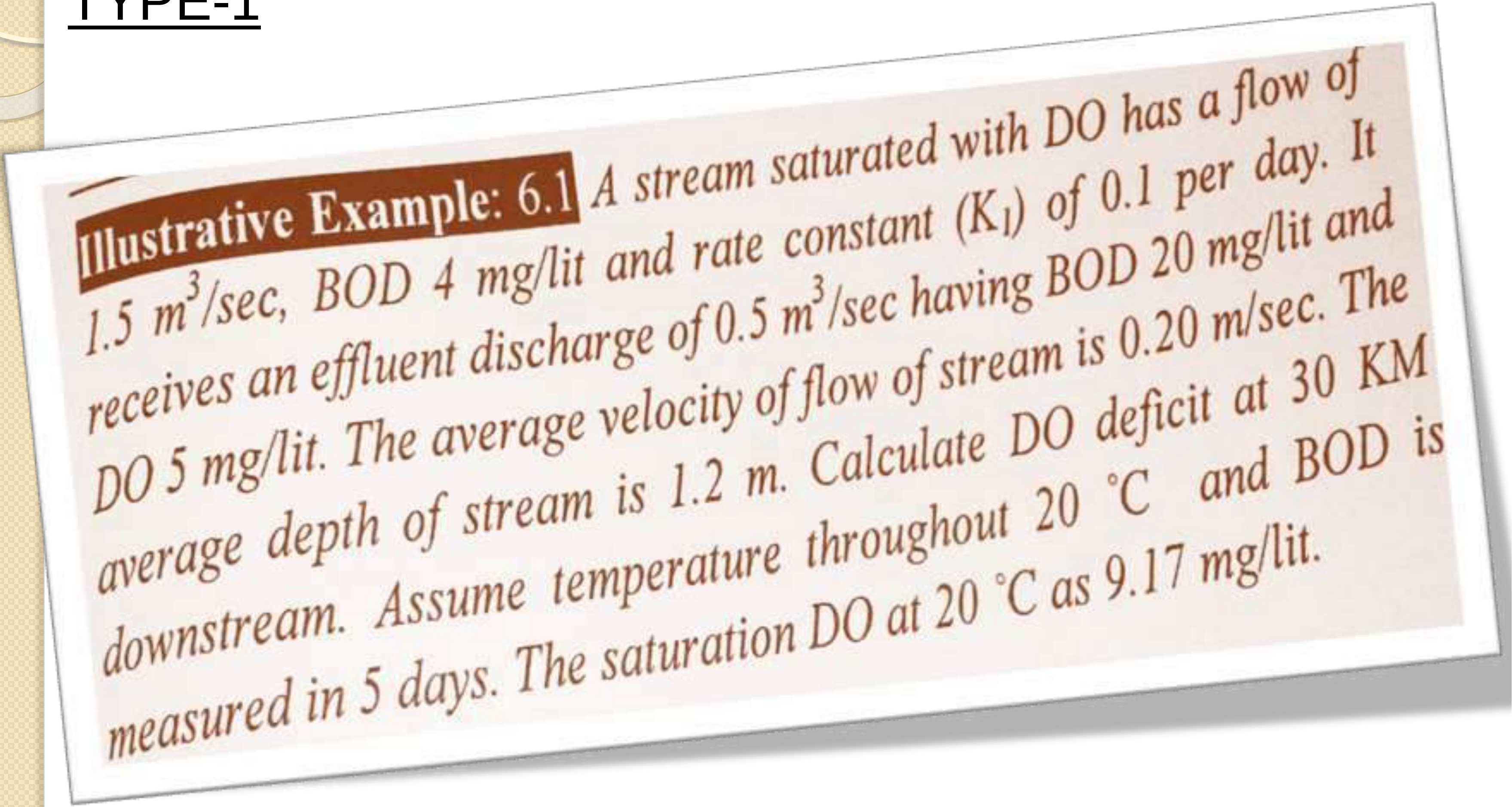
or,

$$\left(\frac{L_0}{f_s D_c} \right)^{f_s-1} = f_s \left\{ 1-(f_s-1)\frac{D_0}{L_0} \right\} \quad \cdots (f)$$

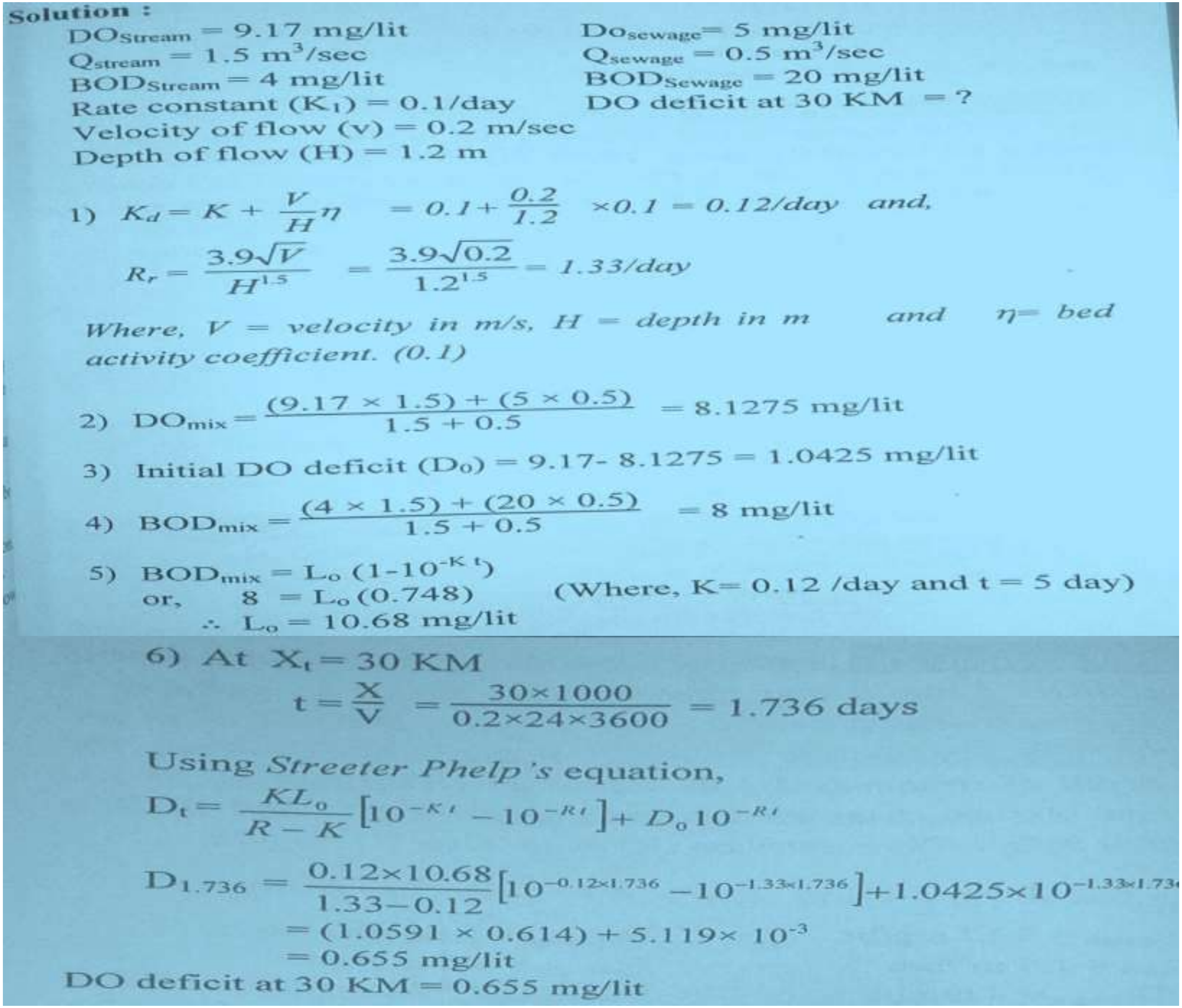
Eqn (f) is simplification of eqns (d1) & (e1).

6.8.Numericals on self purification of rivers/streams

TYPE-1



Illustrative Example: 6.1 *A stream saturated with DO has a flow of 1.5 m^3/sec, BOD 4 mg/lit and rate constant (K_1) of 0.1 per day. It receives an effluent discharge of 0.5 m^3/sec having BOD 20 mg/lit and DO 5 mg/lit. The average velocity of flow of stream is 0.20 m/sec. The average depth of stream is 1.2 m. Calculate DO deficit at 30 KM downstream. Assume temperature throughout 20 °C and BOD is measured in 5 days. The saturation DO at 20 °C as 9.17 mg/lit.*



Solution :

$DO_{Stream} = 9.17$ mg/lit
$Q_{stream} = 1.5\ m^3/sec$
$BOD_{Stream} = 4$ mg/lit
Rate constant (K_1) = 0.1/day
Velocity of flow (v) = 0.2 m/sec
Depth of flow (H) = 1.2 m

$Do_{sewage} = 5$ mg/lit
$Q_{sewage} = 0.5\ m^3/sec$
$BOD_{Sewage} = 20$ mg/lit
DO deficit at 30 KM = ?

1) $K_d = K + \frac{V}{H}\eta \quad = 0.1 + \frac{0.2}{1.2} \times 0.1 = 0.12/day$ *and,*

$$R_r = \frac{3.9\sqrt{V}}{H^{1.5}} \quad = \frac{3.9\sqrt{0.2}}{1.2^{1.5}} = 1.33/day$$

Where, V = velocity in m/s, H = depth in m and η= bed activity coefficient. (0.1)

2) $DO_{mix} = \frac{(9.17 \times 1.5) + (5 \times 0.5)}{1.5 + 0.5} = 8.1275$ mg/lit

3) Initial DO deficit (D_0) = 9.17- 8.1275 = 1.0425 mg/lit

4) $BOD_{mix} = \frac{(4 \times 1.5) + (20 \times 0.5)}{1.5 + 0.5} = 8$ mg/lit

5) $BOD_{mix} = L_o\,(1-10^{-K\,t})$
or, $8 = L_o\,(0.748)$ (Where, K= 0.12 /day and t = 5 day)
$\therefore\ L_o = 10.68$ mg/lit

6) At $X_t = 30$ KM

$$t = \frac{X}{V} = \frac{30 \times 1000}{0.2 \times 24 \times 3600} = 1.736 \text{ days}$$

Using *Streeter Phelp's* equation,

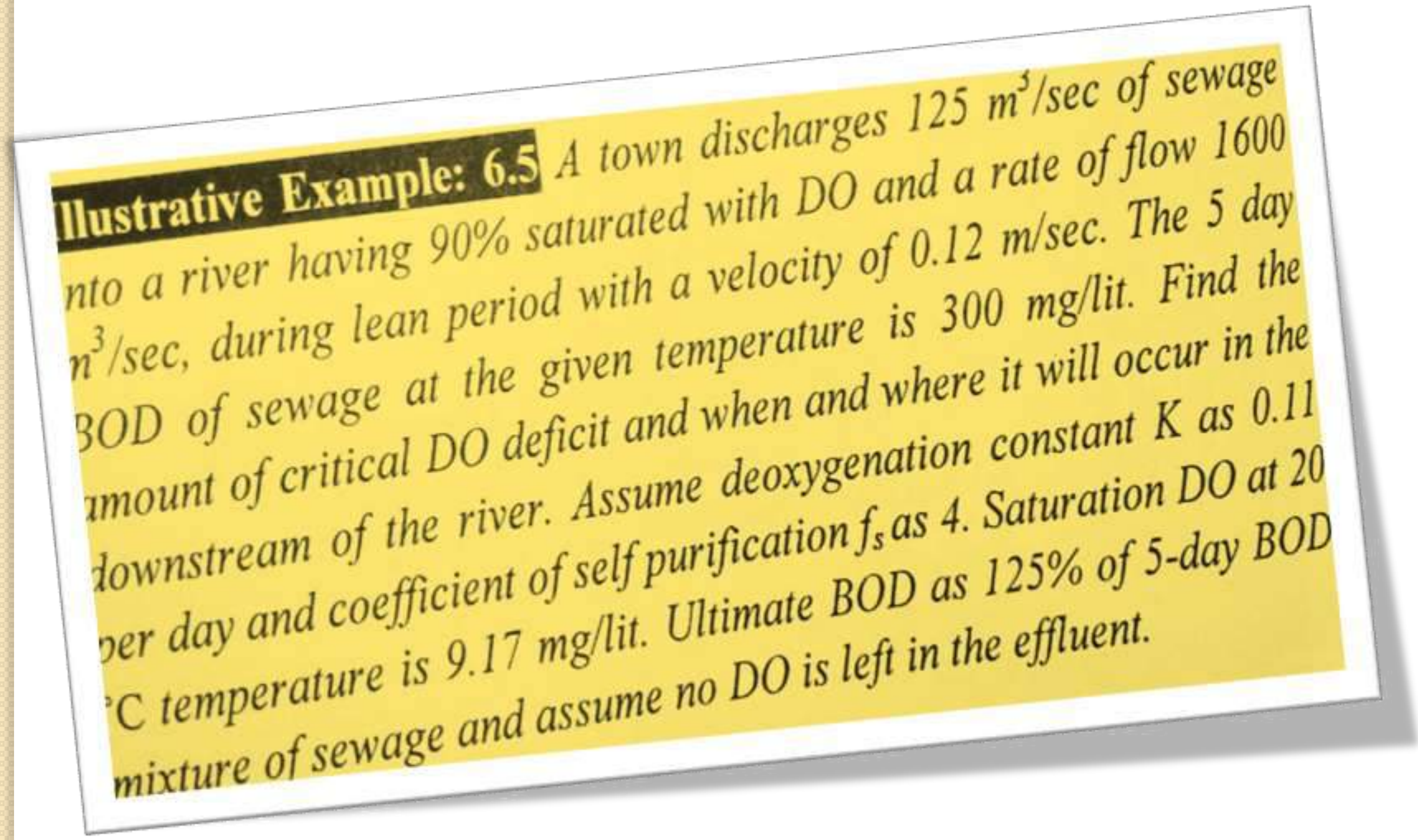
$$D_t = \frac{KL_0}{R-K}\left[10^{-Kt} - 10^{-Rt}\right] + D_o 10^{-Rt}$$

$$D_{1.736} = \frac{0.12 \times 10.68}{1.33 - 0.12}\left[10^{-0.12\times1.736} - 10^{-1.33\times1.736}\right] + 1.0425 \times 10^{-1.33\times1.73}$$

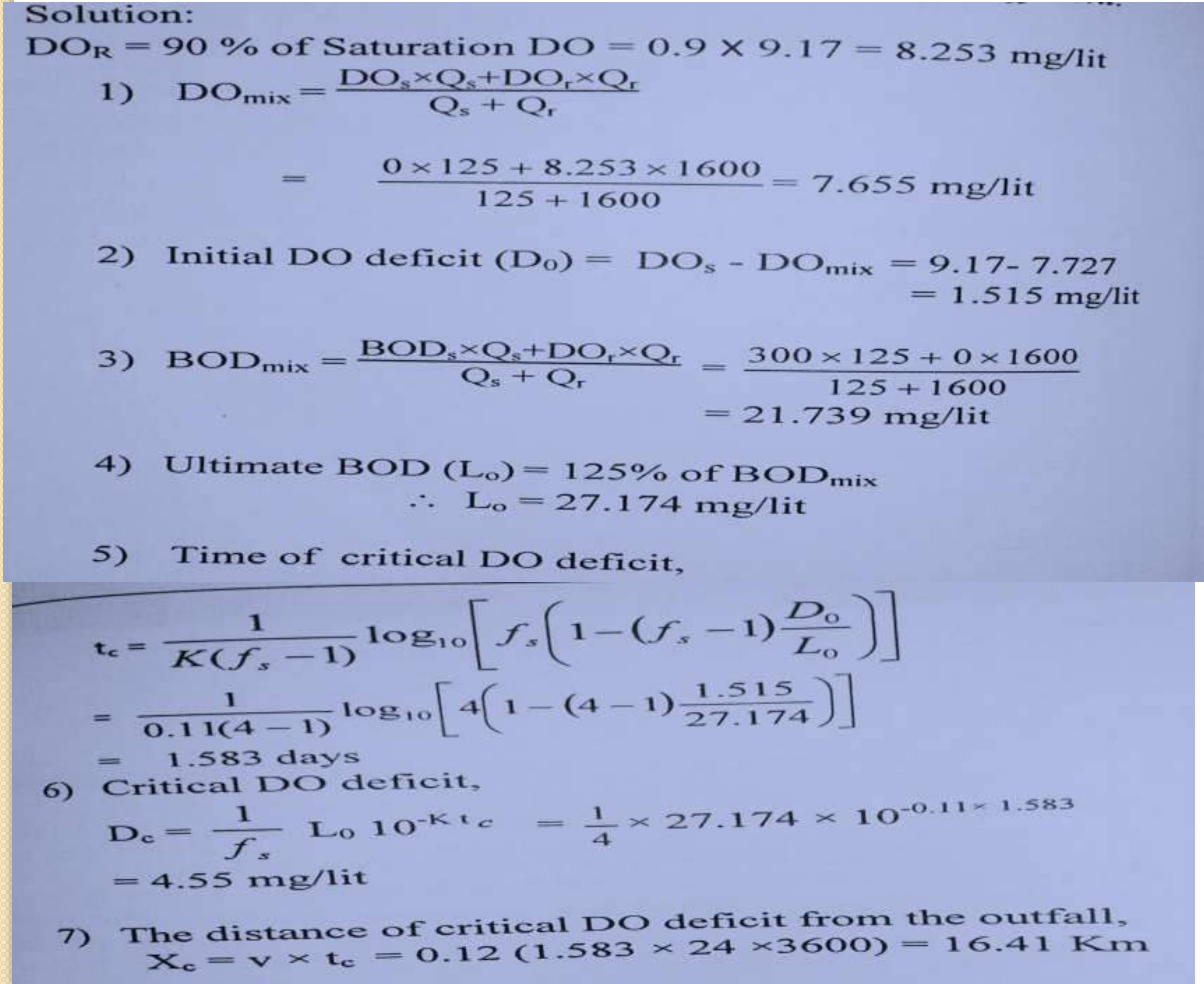
$= (1.0591 \times 0.614) + 5.119 \times 10^{-3}$
$= 0.655$ mg/lit

DO deficit at 30 KM = 0.655 mg/lit

TYPE 2



Illustrative Example: 6.5 *A town discharges 125 m^3/sec of sewage nto a river having 90% saturated with DO and a rate of flow 1600 n^3/sec, during lean period with a velocity of 0.12 m/sec. The 5 day 3OD of sewage at the given temperature is 300 mg/lit. Find the amount of critical DO deficit and when and where it will occur in the downstream of the river. Assume deoxygenation constant K as 0.11 per day and coefficient of self purification f_s as 4. Saturation DO at 20 °C temperature is 9.17 mg/lit. Ultimate BOD as 125% of 5-day BOD mixture of sewage and assume no DO is left in the effluent.*



Solution:

DO_R = 90 % of Saturation DO = 0.9 X 9.17 = 8.253 mg/lit

1) $$DO_{mix} = \frac{DO_s \times Q_s + DO_r \times Q_r}{Q_s + Q_r}$$

$$= \frac{0 \times 125 + 8.253 \times 1600}{125 + 1600} = 7.655 \text{ mg/lit}$$

2) Initial DO deficit (D_0) = DO_s - DO_{mix} = 9.17- 7.727 = 1.515 mg/lit

3) $$BOD_{mix} = \frac{BOD_s \times Q_s + DO_r \times Q_r}{Q_s + Q_r} = \frac{300 \times 125 + 0 \times 1600}{125 + 1600} = 21.739 \text{ mg/lit}$$

4) Ultimate BOD (L_o) = 125% of BOD_{mix}

$\therefore$ L_o = 27.174 mg/lit

5) Time of critical DO deficit,

$$t_c = \frac{1}{K(f_s - 1)} \log_{10}\left[f_s\left(1 - (f_s - 1)\frac{D_o}{L_o}\right)\right]$$

$$= \frac{1}{0.11(4-1)} \log_{10}\left[4\left(1 - (4-1)\frac{1.515}{27.174}\right)\right]$$

$$= 1.583 \text{ days}$$

6) Critical DO deficit,

$$D_c = \frac{1}{f_s} L_o 10^{-K t_c} = \frac{1}{4} \times 27.174 \times 10^{-0.11 \times 1.583}$$

$$= 4.55 \text{ mg/lit}$$

7) The distance of critical DO deficit from the outfall,

$X_c = v \times t_c$ = 0.12 (1.583 × 24 ×3600) = 16.41 Km

6.9 Disposal by land treatment

- It is wastewater spread on the surface of land.

Mechanism:

Some part of the wastewater evaporates;other part percolates in the ground leaving behind suspended solids which are partly acted upon by the bacteria and partly oxidised by exposure to atmospheric actions of air, heat & light.

6.9.1 Suitability of land Treatment

Alternative to river

- Not located in the vicinity
- Very small flow

Land

- Percolating land eg. Sandy , Loamy, or alluvial soil

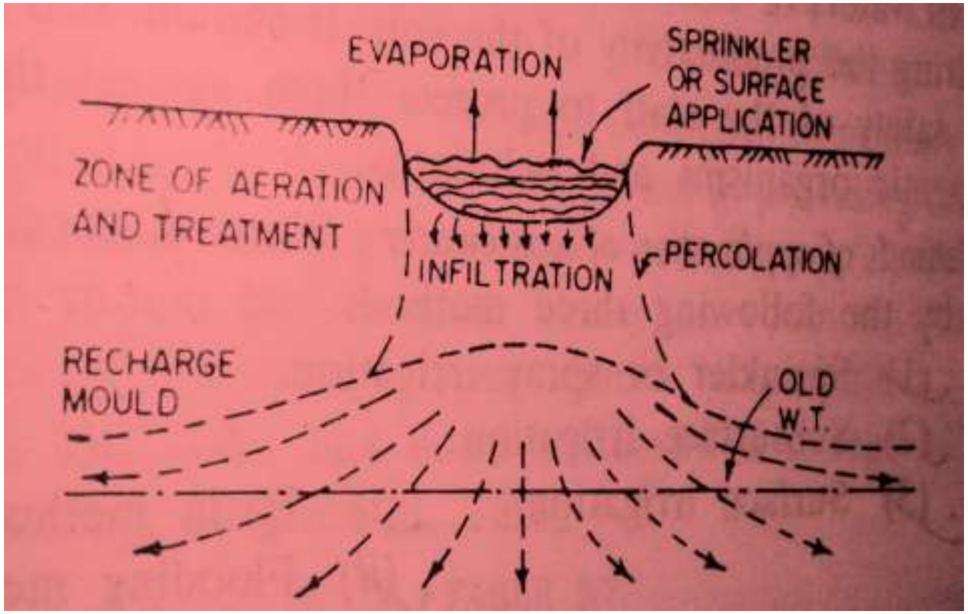
Climate

- Arid climate
- Low watertable
- Demand for irrigation water

Percolation Rate	Method Used
6-25 mm/min	rapid infiltration
2-6 mm/min	irrigation
<2 mm/min	overland flow

According to the percolating capacity of soil

6.9.2. Methods of Land Treatment

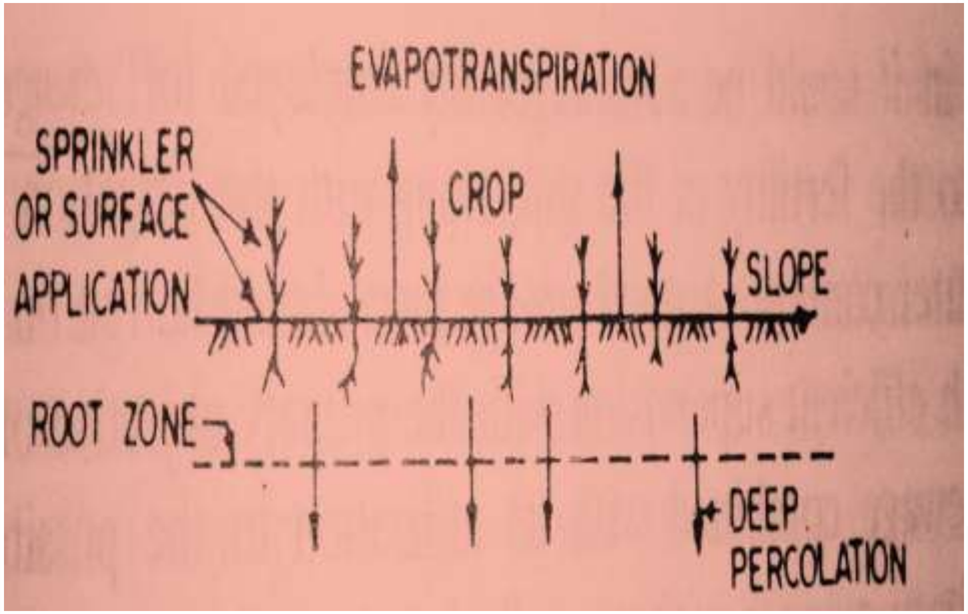


Rapid Infiltration

- Great basin or pond is prepared where sewage is applied and allowed to percolate down.

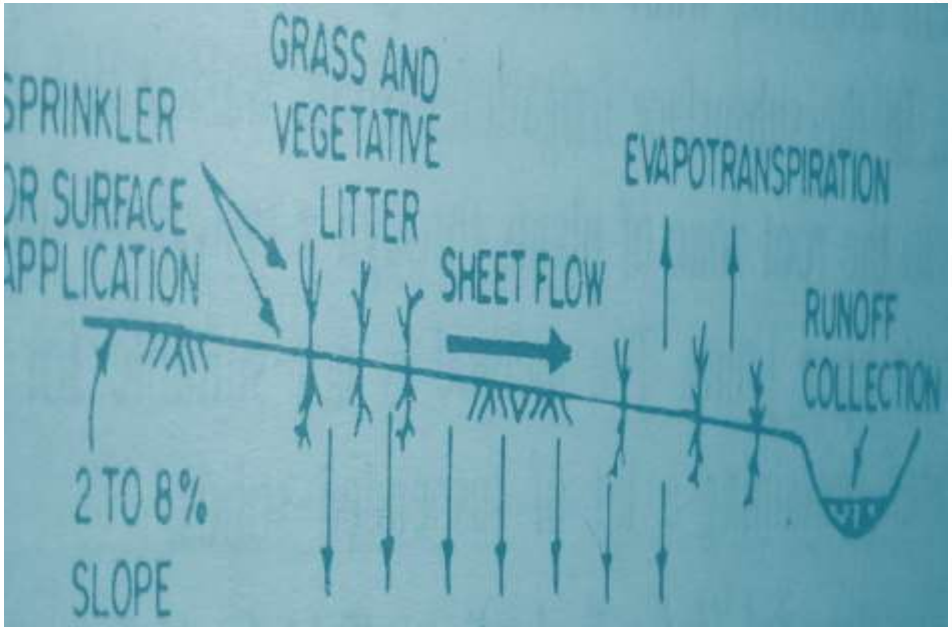
-Two or more basins are used to maintain adequate infiltration capacity

-Rate of infiltration is high(6 to 25 mm/min)



Irrigation

In sewage farming, to support plant growth, controlled discharge of sewage is applied to the land



Overland Runoff

The controlled discharge of sewage is applied on ground having a slope 2 to 8% where it follows down from vegetative areas and appears as runoff which is collected than disposed off.

Broad Irrigation	Sewage Farming
Successful disposal of Sewage	Successful growing of the Crops
Raw or settled sewage is applied	Raw sewage isn’t used
Suitable for relatively more pervious soil.	

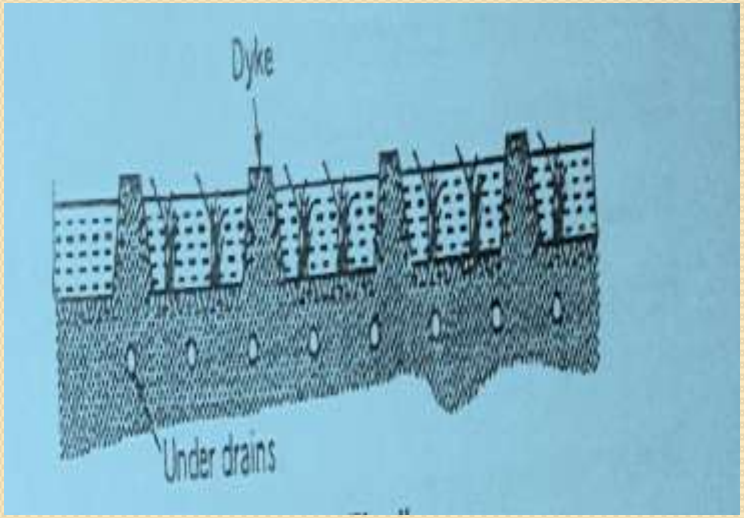
Result: Crop is raised & Sewage is disposed by land application

6.9.3 Broad Irrigation & Sewage Farming

6.9.4 Methods of application of sewage on Land

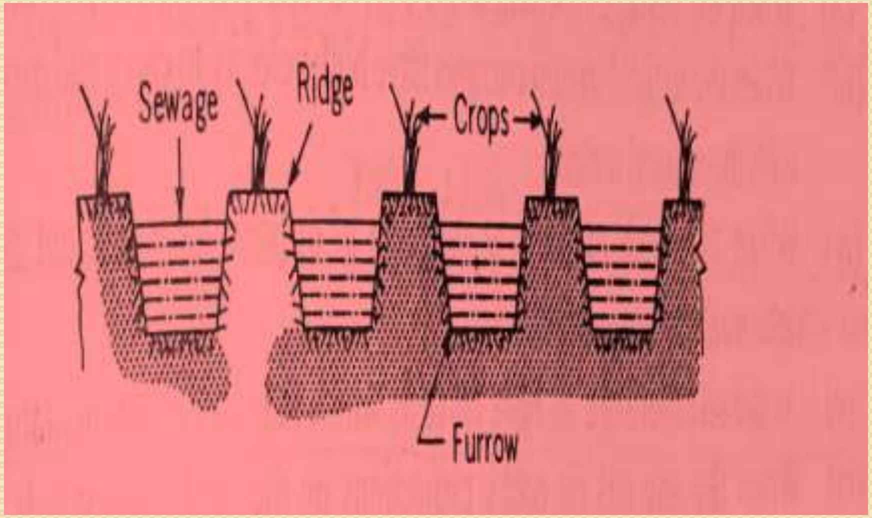
A. Surface Irrigation
   a. Flooding Method
   b. Ridge & Furrow Method
B. Subsurface irrigation
C. Spray Irrigation

In this method, land is divided into rectangular plots and sewage is flooded over these plots at depth of 30 to 60 cm. The under drains are provided to remove the percolated effluent through soil.



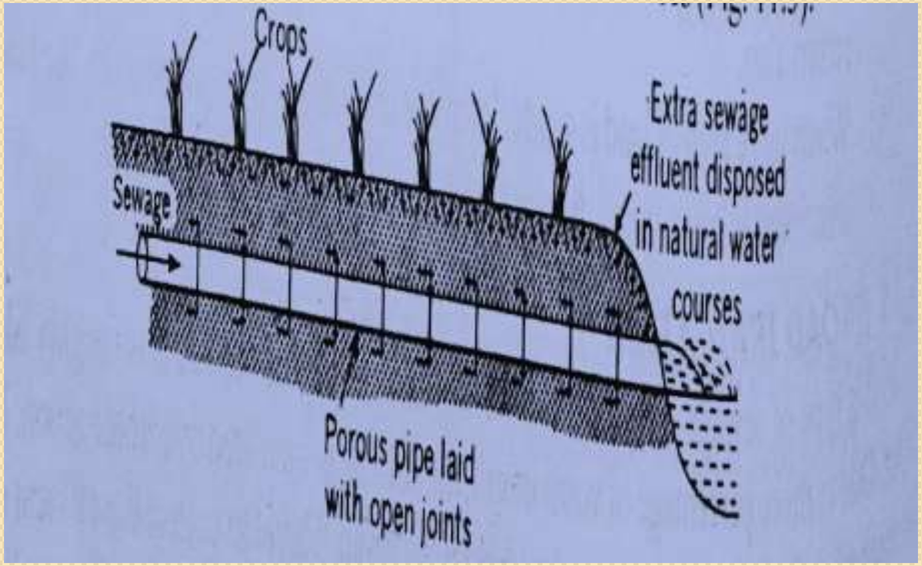
A.a Flooding Method

- Furrows are the ditches of depth 30 to 50 cm and width of 120 to 150 cm.
- Ridges have length 15 to 30m and width 120 to 250 cm.
- Furrows are filled up to 2/3 depth and on ridge crops are grown.



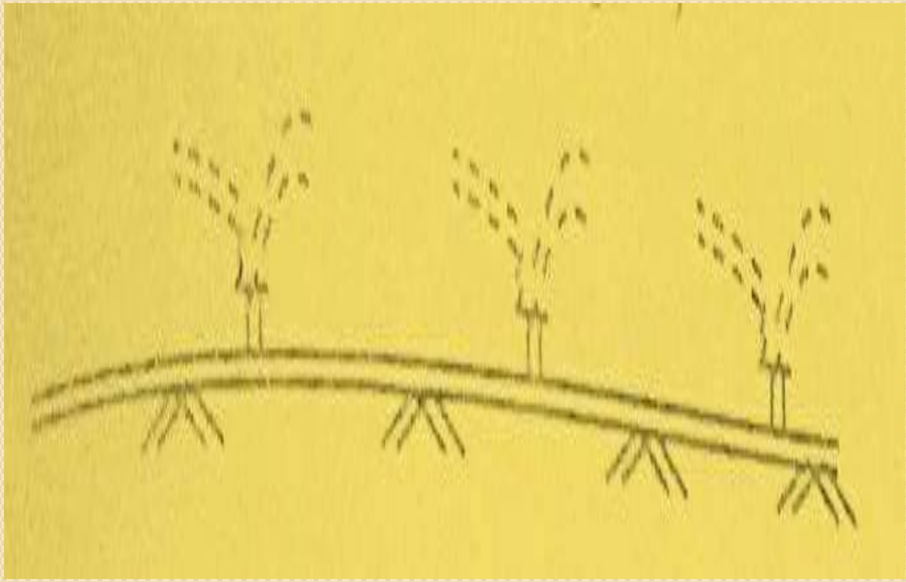
A.b. Ridge & Furrow method

- Sewage is applied directly to root zone of the plants through perforated pipe or pipe with open joints.
- Pipe network laid about 30 cm below the ground level. The sewage rises up due to capillary action and utilized by plant.



B. Subsurface Irrigation

- Effluent sewage is spread over the land through nozzle of pipe under pressure.
- If sufficient head available and wastewater have no any solid matters the only it can be sprayed under pressure through pipe fitted at tips of pipes.



C. Spray Irrigation

6.9.5 Sewage Sickness & its Prevention

- ❖ The phenomenon of inability to take any further load of sewage by the land.
- ❖ The pores of soil gets clogged, preventing oxidation and causing noxious smells.

Its Prevention

- Pretreatment of Sewage
- Provision of extra land
- Under Drainage of soil
- Proper choice of land
- Rotation of crops
- Shallow depth application

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- Birdie, G.S., and Birdie, J.S., (2006), " Water Supply and Sanitary Engineering", Including Environmental Engineering Water and Air Pollution Act's, Dhanpat Rai Publishing Company (P) Ltd., New Delhi.
- Modi, Dr. P.N., "Sewage Treatment & Disposal & Waste Water Engineering", Standard Book House, New Delhi.
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Thank you for the listening!

VI. Wastewater Treatment Technologies

Sludge Treatment: Processes, Facilities, Basic Technological Parameters

Processes of Sludge Treatment

- Sludge thickening

- Sludge stabilisation
    - Anaerobic stabilisation
    - Aerobic stabilisation
    - Lime stabilisation

- Sludge dewatering

- Sludge drying

- Sludge incineration

Sludge Thickening Facilities

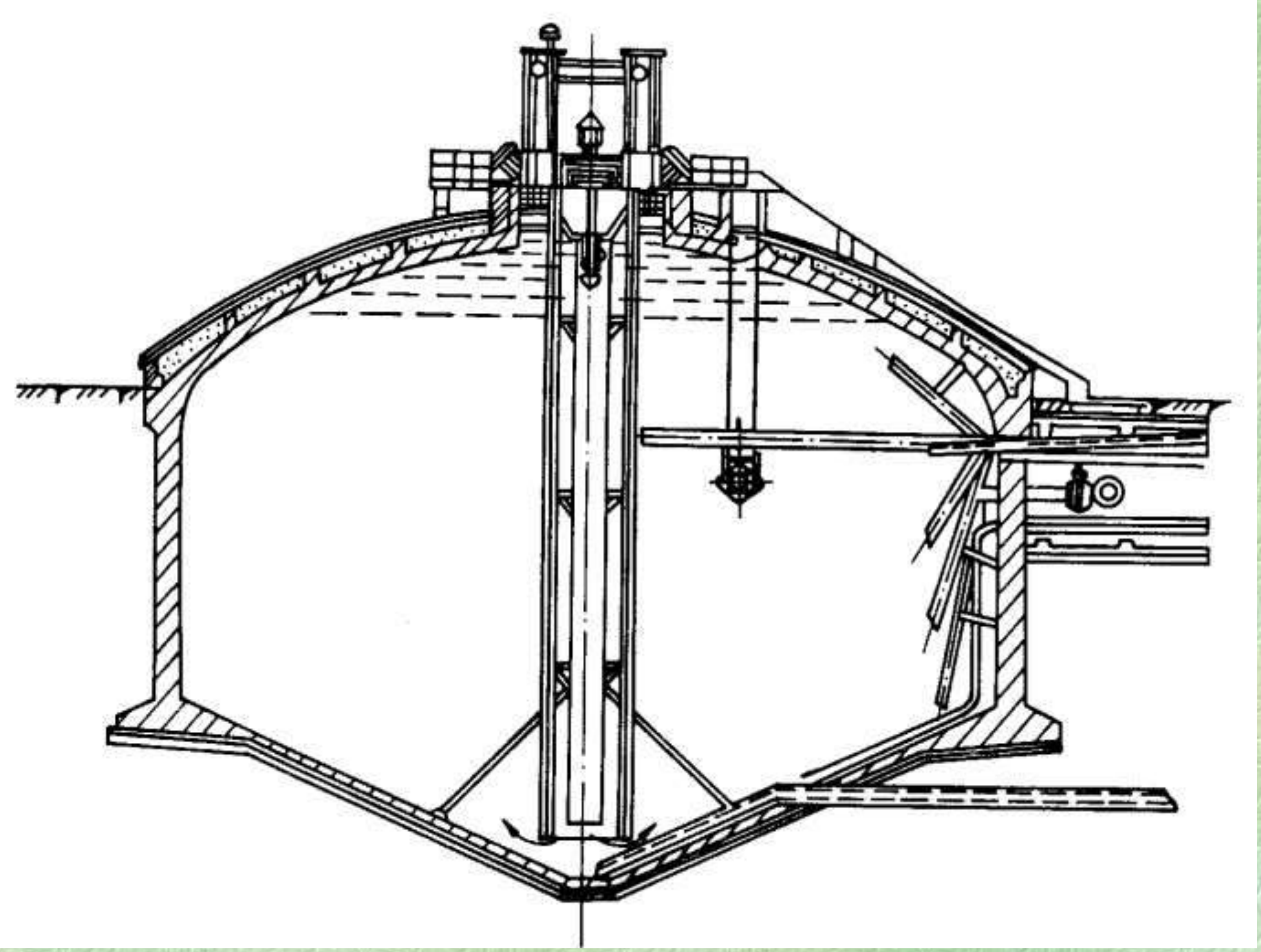
I. Gravity thickeners

- Vertical thickening tanks
- Radial thickening tanks

II. Mechanical thickeners

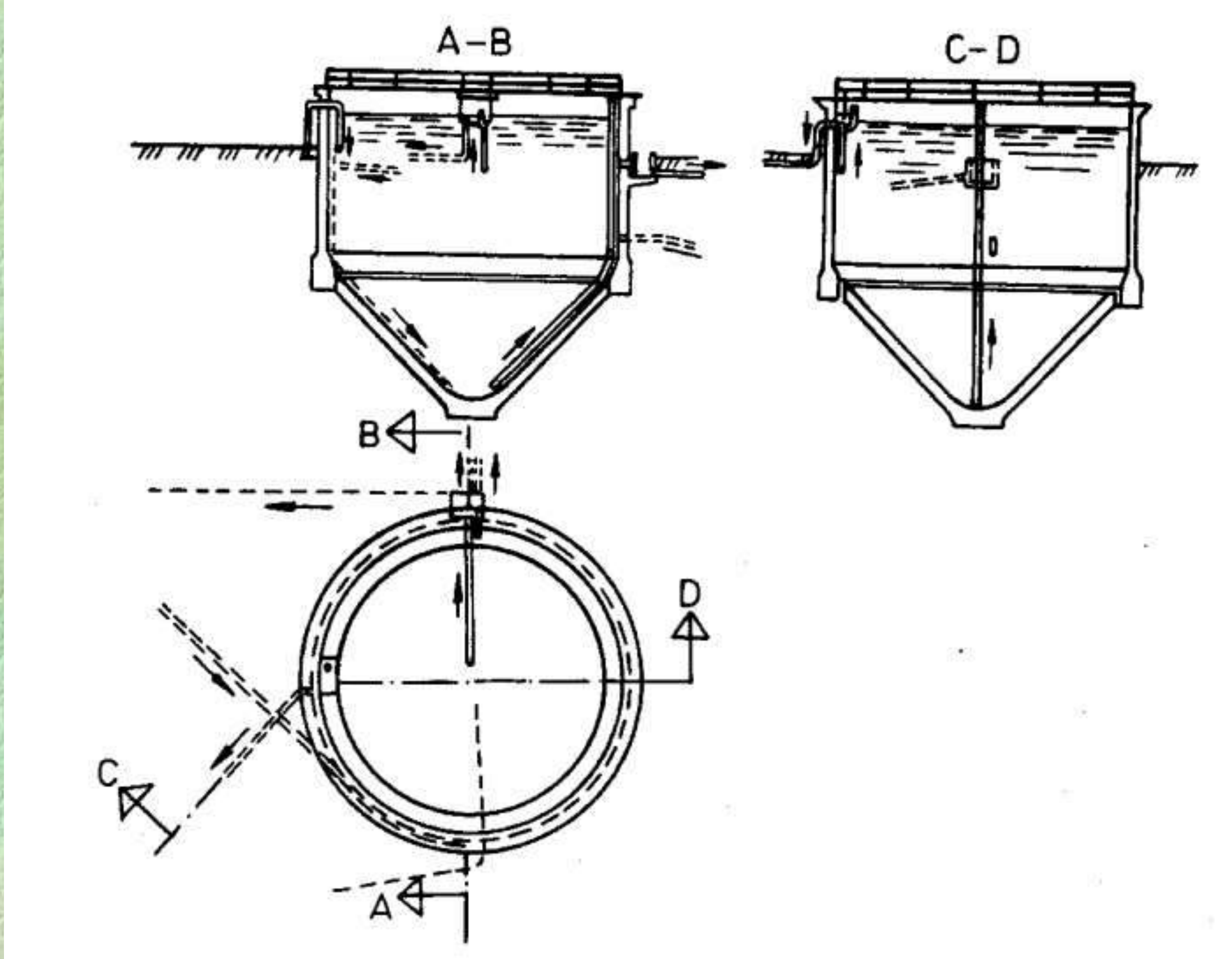
- Floatation thickeners
- Filtering thickeners
- Centrifugal thickeners

Sludge Biological Stabilisation Facilities



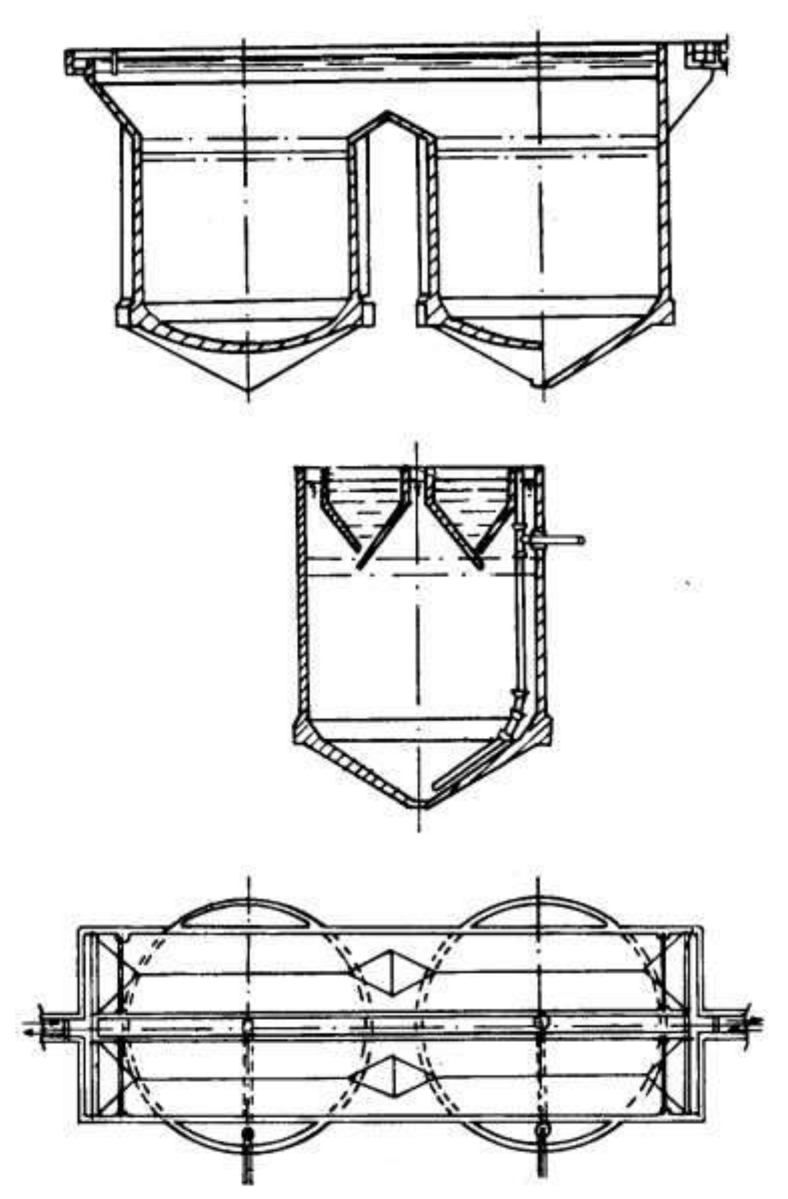
High Rate Anaerobic Digester (Methanetank)

Sludge Biological Stabilisation Facilities



Low Rate (Open Air) Anaerobic Digester

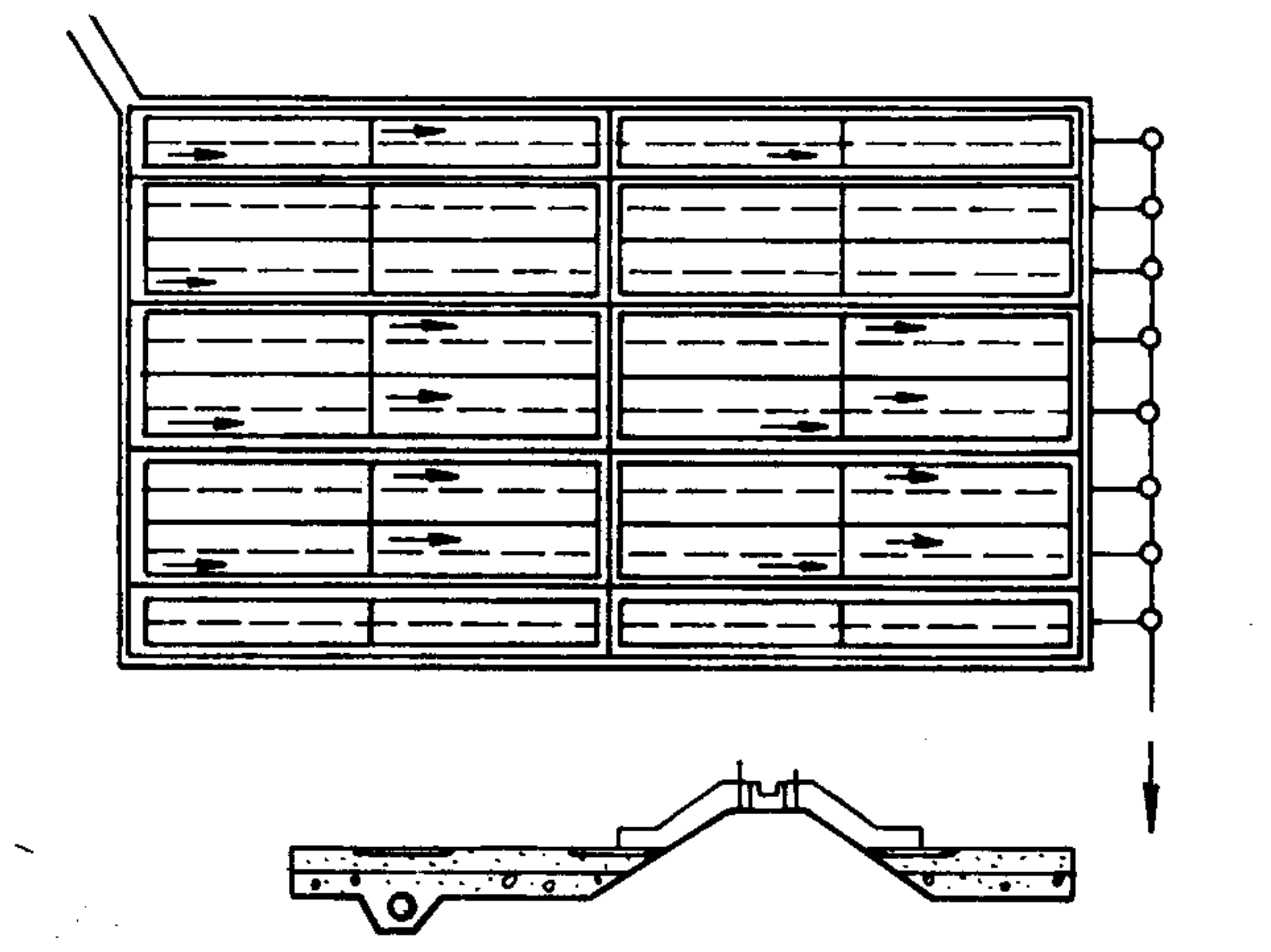
Sludge Biological Stabilisation Facilities



Imhoff Tank

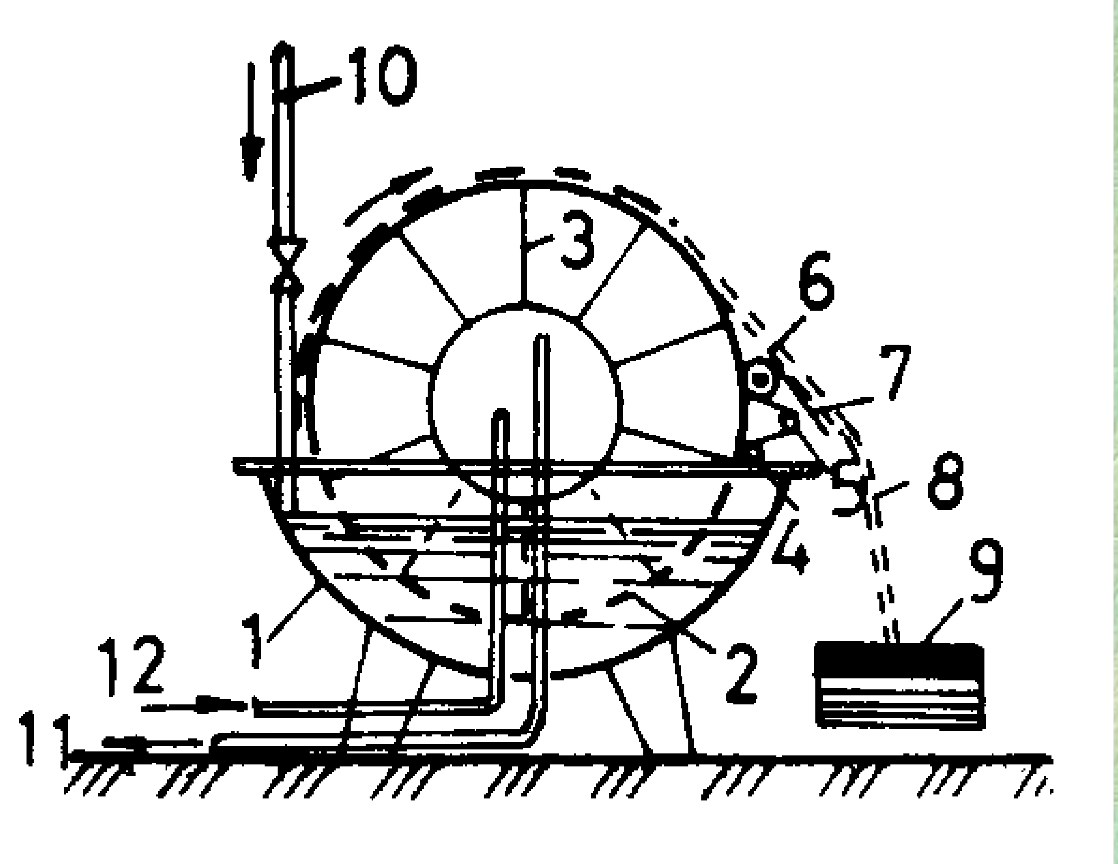
(Combine Facility)

Sludge Dewatering Facilities



Classical Sludge Drying Beds

Sludge Dewatering Facilities

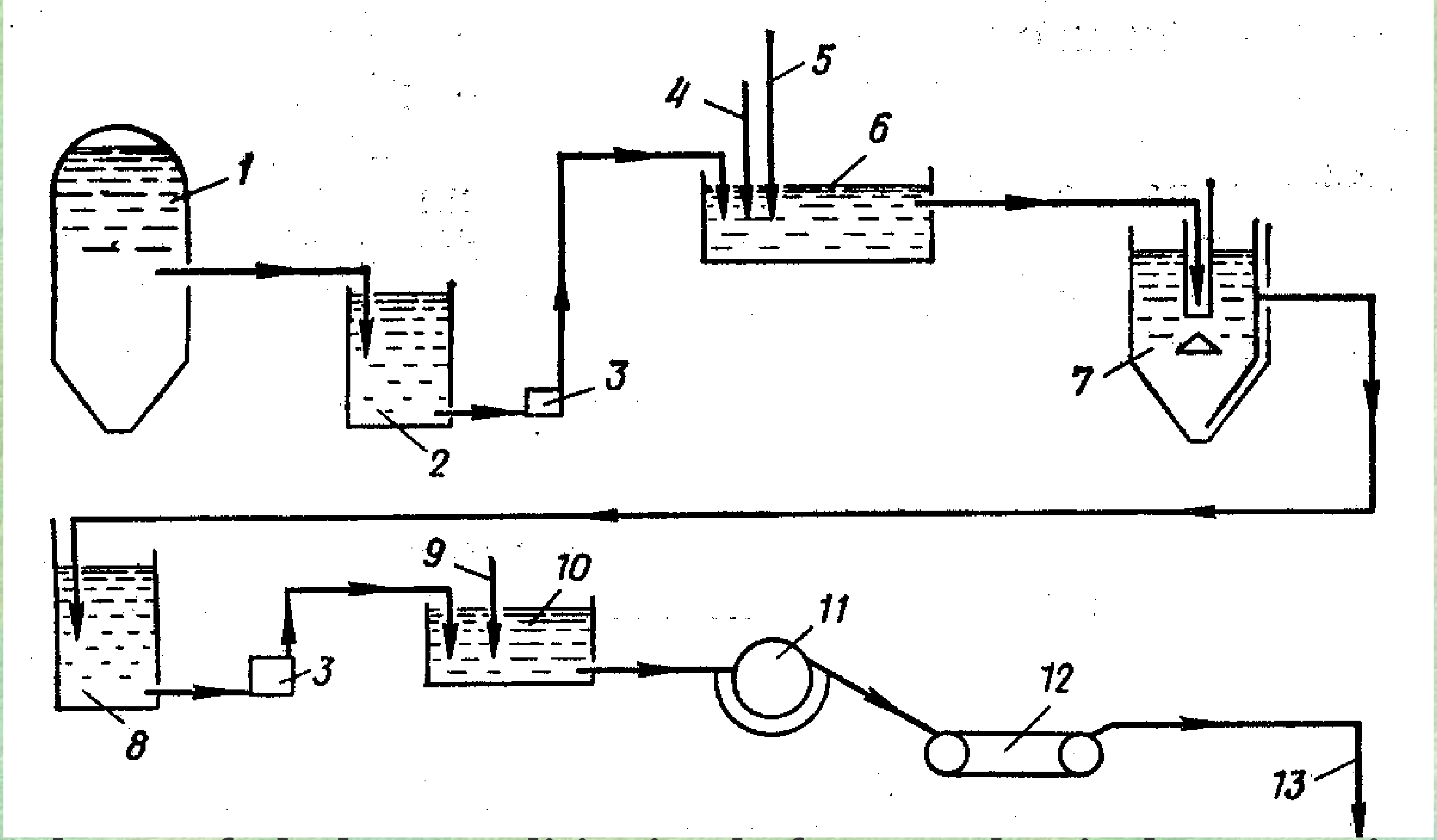


Scheme of Drum Vacuum Filter

1 - sludge vessel; 2 - drum; 3 - sector baffle; 4, 5 - filtering cloth adjusting rolls; 6 - rolls and washing jets; 7 - sludge cutting device; 8 - dewatered sludge; 9 - conveying belt

10 - gravity sludge inlet pipe; 11 - vacuum pipe; 12 - pressure air pipe

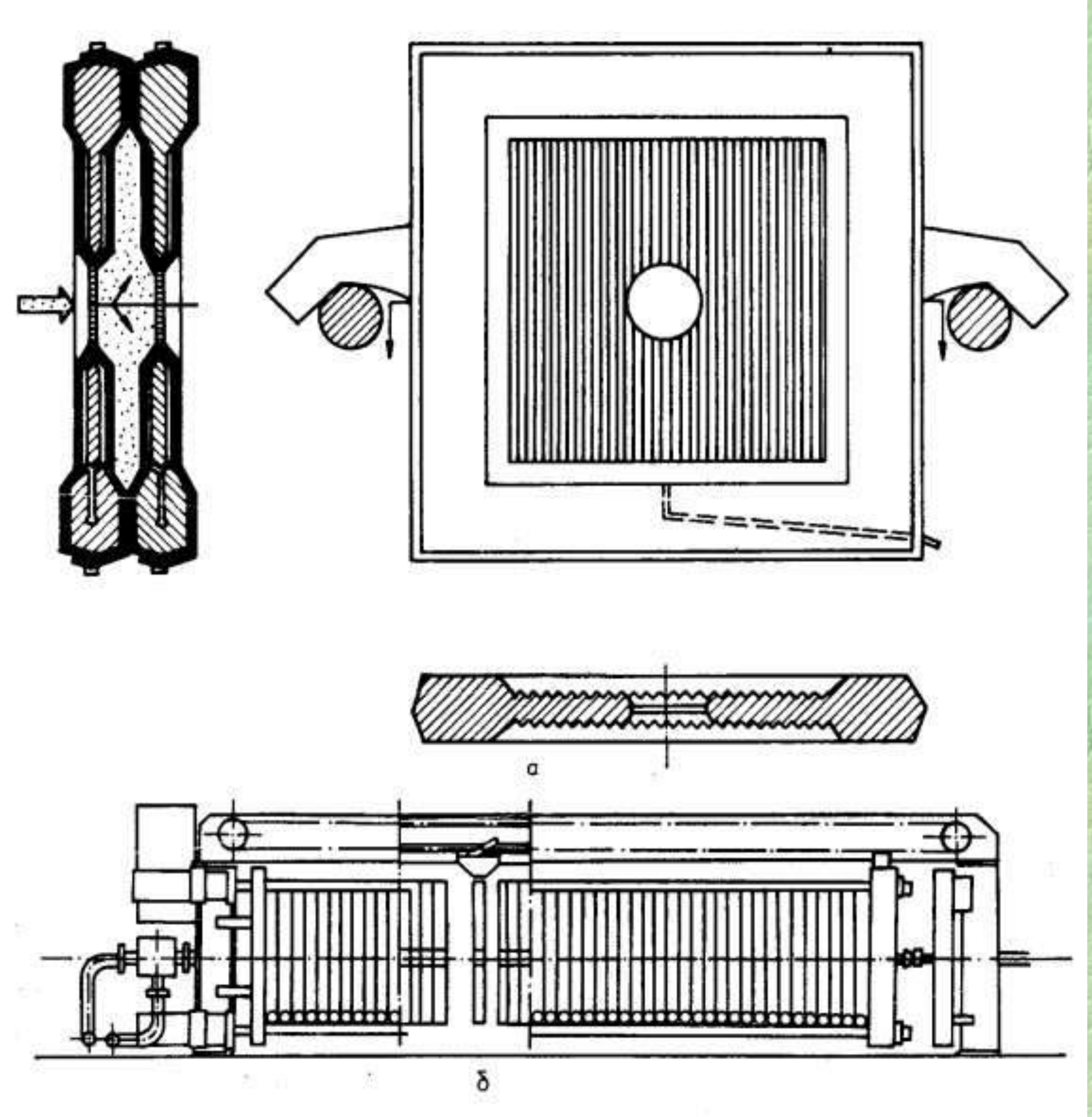
Sludge Dewatering Facilities



Scheme of Sludge Conditioning before Mechanical Dewatering

1 - high rate anaerobic digester; 2 -sludge reservoir; 3 - pump; 4 - washing water; 5 - compressed air; 6 - sludge washing chamber; 7 - sludge thickener; 8 - thickened sludge reservoir; 9 - coagulant; 10 - mixing/flocculation chamber; 11 - vacuum filter; 12 - belt conveyer; 13 - dewatered sludge (filtering cake)

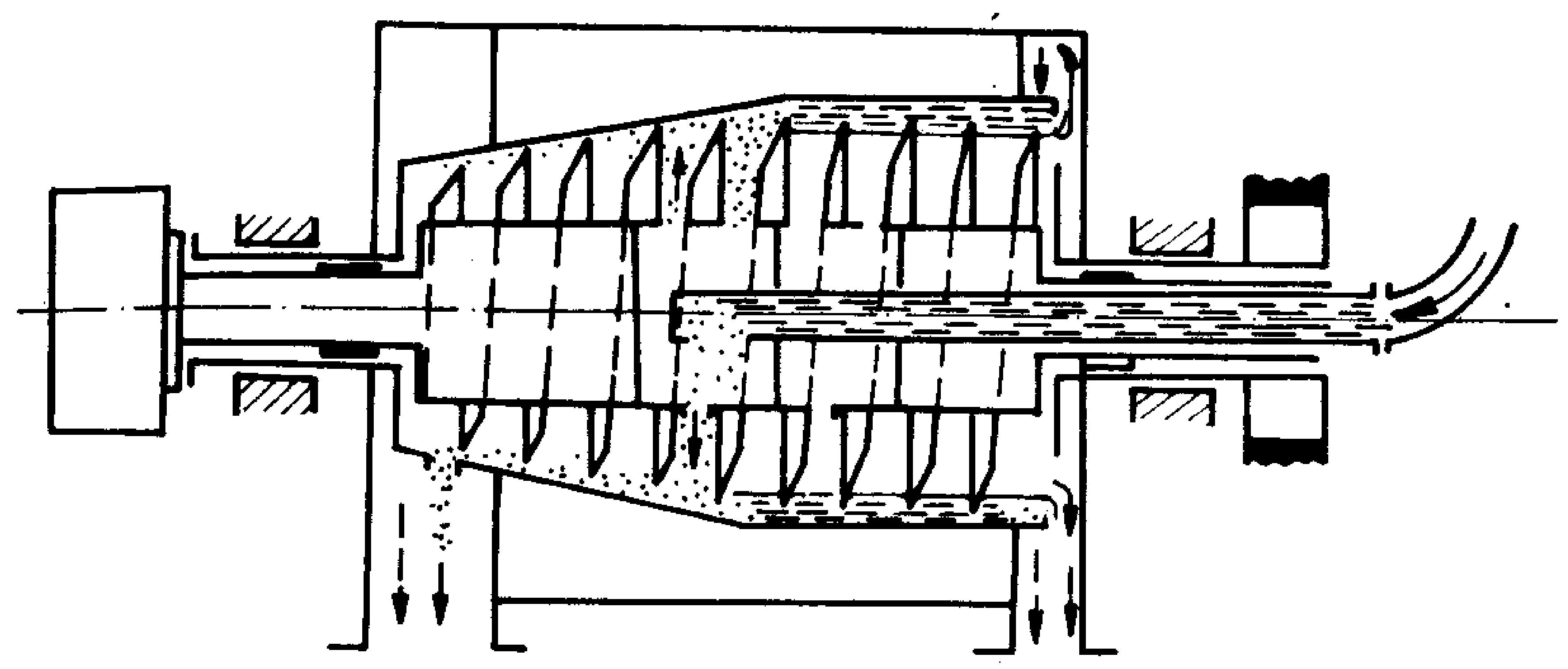
Sludge Dewatering Facilities



Filter-press

(Camera Type)

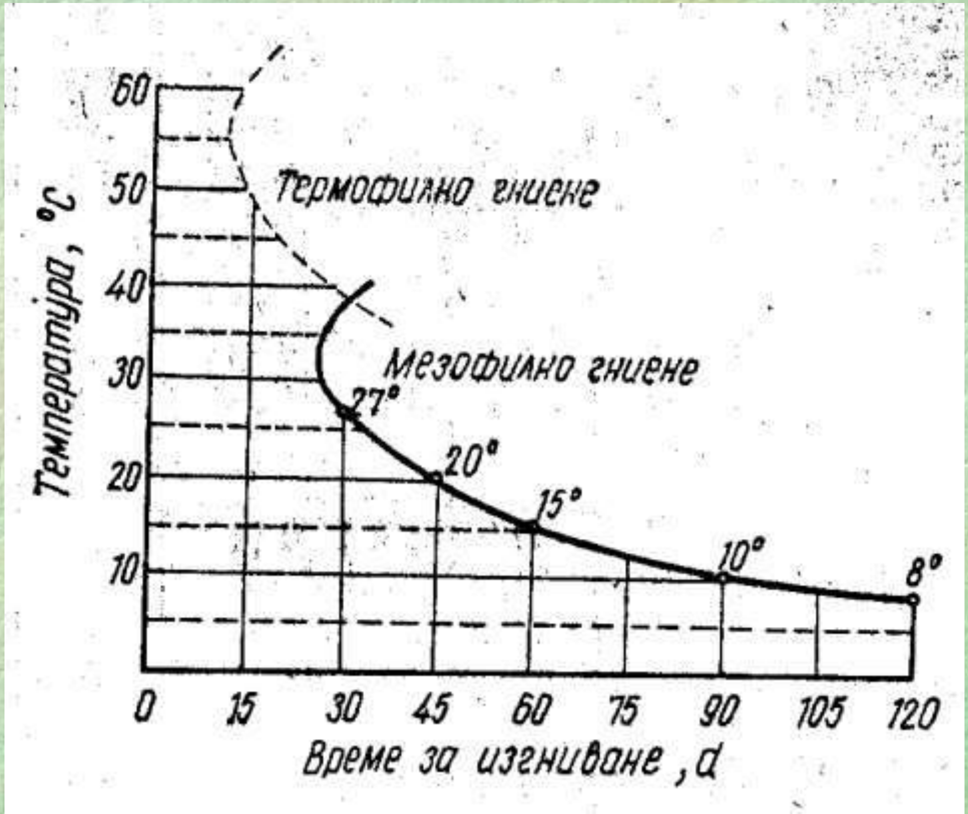
Sludge Dewatering Facilities



Scheme of Centrifuge (Settling Type)

Basic Technological Parameters

Anaerobic Digesters

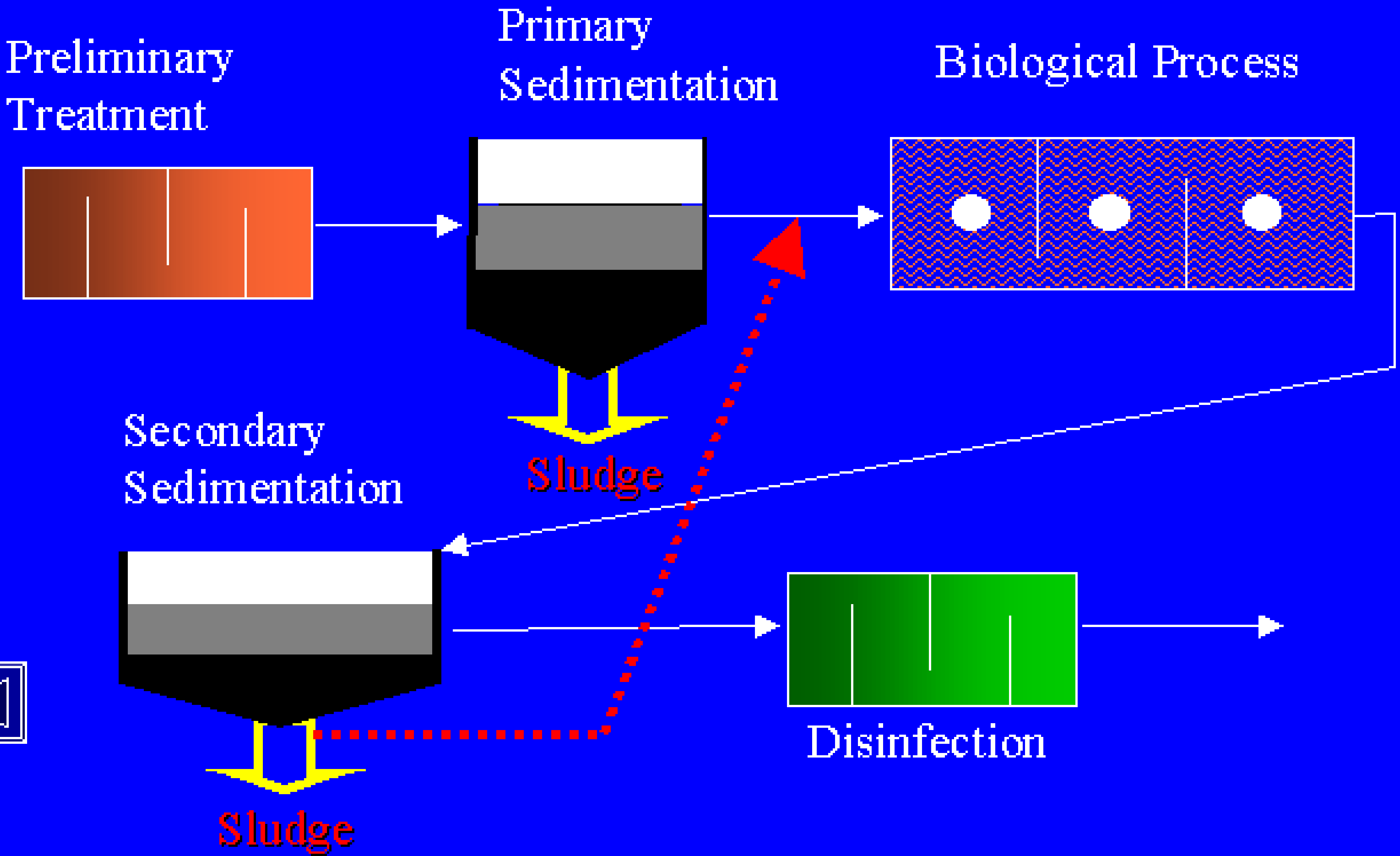


Fair - Moor (Imhoff) Diagramme

WASTEWATER SLUDGE TREATMENT & DISPOSAL

TEJASREE.VEMURI
Asst. PROFESSOR
SMGG

Conventional WW Treatment



Preliminary Treatment

Primary Sedimentation

Biological Process

Sludge

Secondary Sedimentation

Disinfection

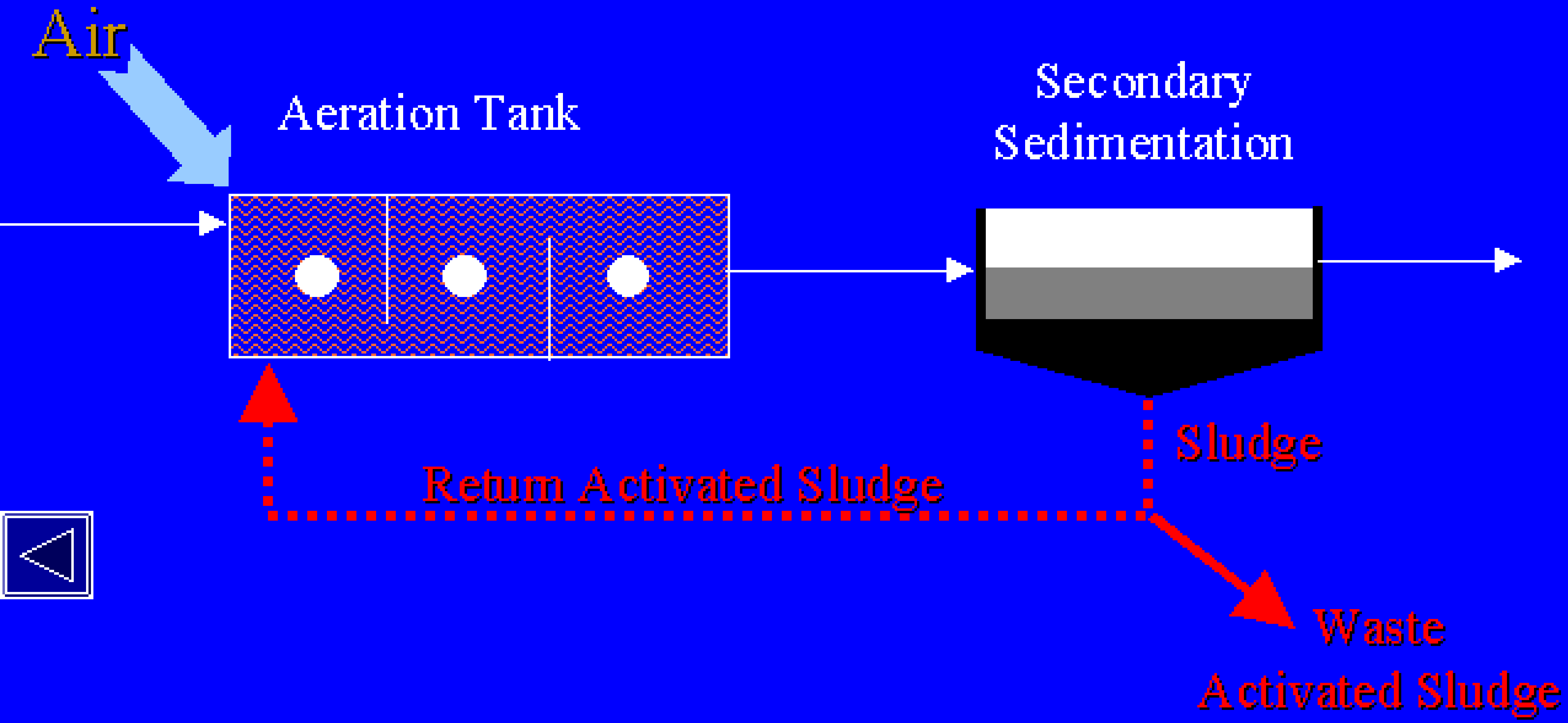
Sludge

Primary Sedimentation

- Purpose: to remove suspended solids (smaller than grit, and less harmful)
- Typical efficiency
  - 67% TSS removal
  - 33% BOD removal
- Design parameters
  - overflow rate
  - weir loading rate
  - detention time

Suspended Growth Systems

Activated Sludge!



Air

Aeration Tank

Secondary Sedimentation

Sludge

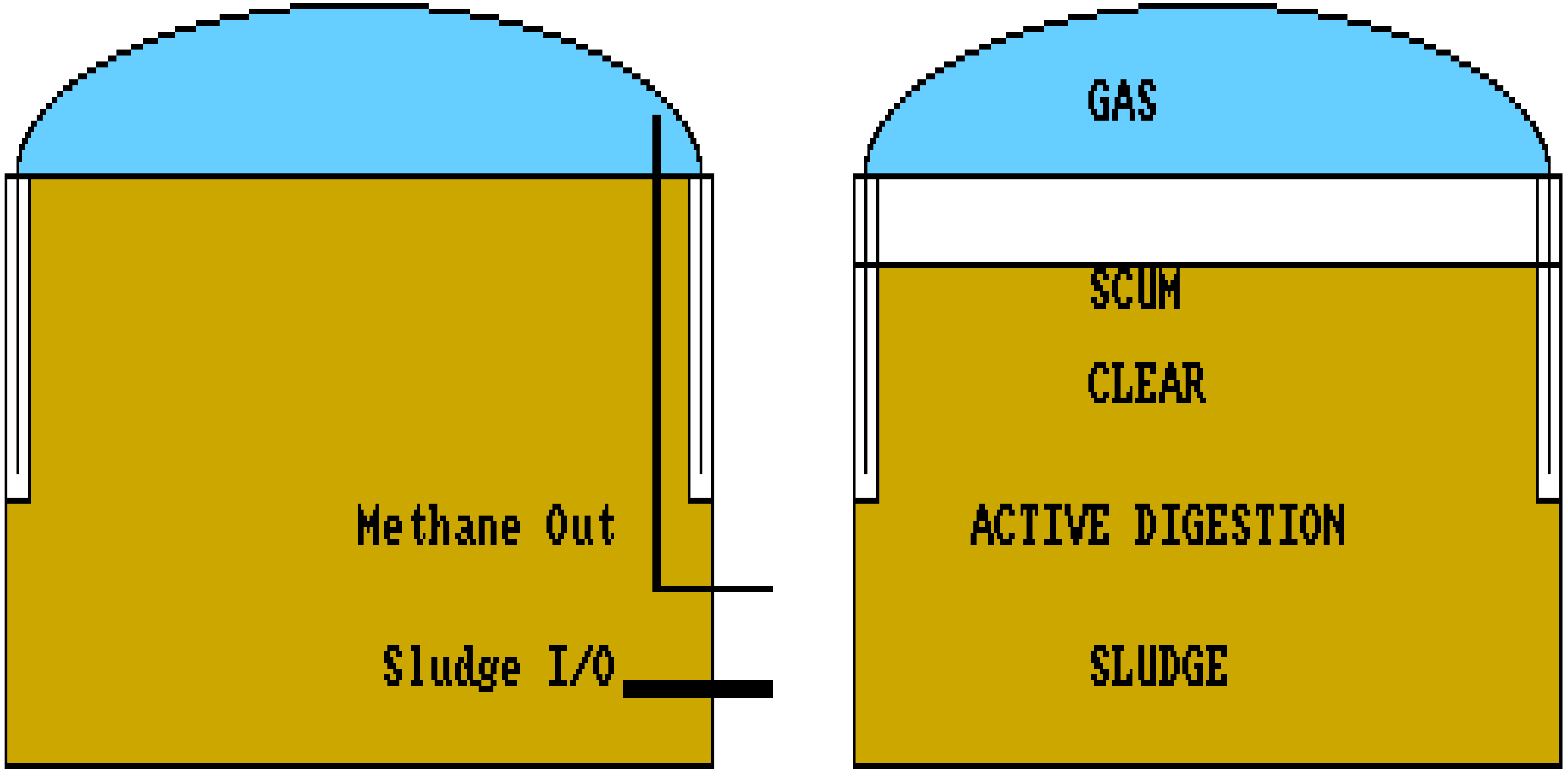
Return Activated Sludge

Waste Activated Sludge

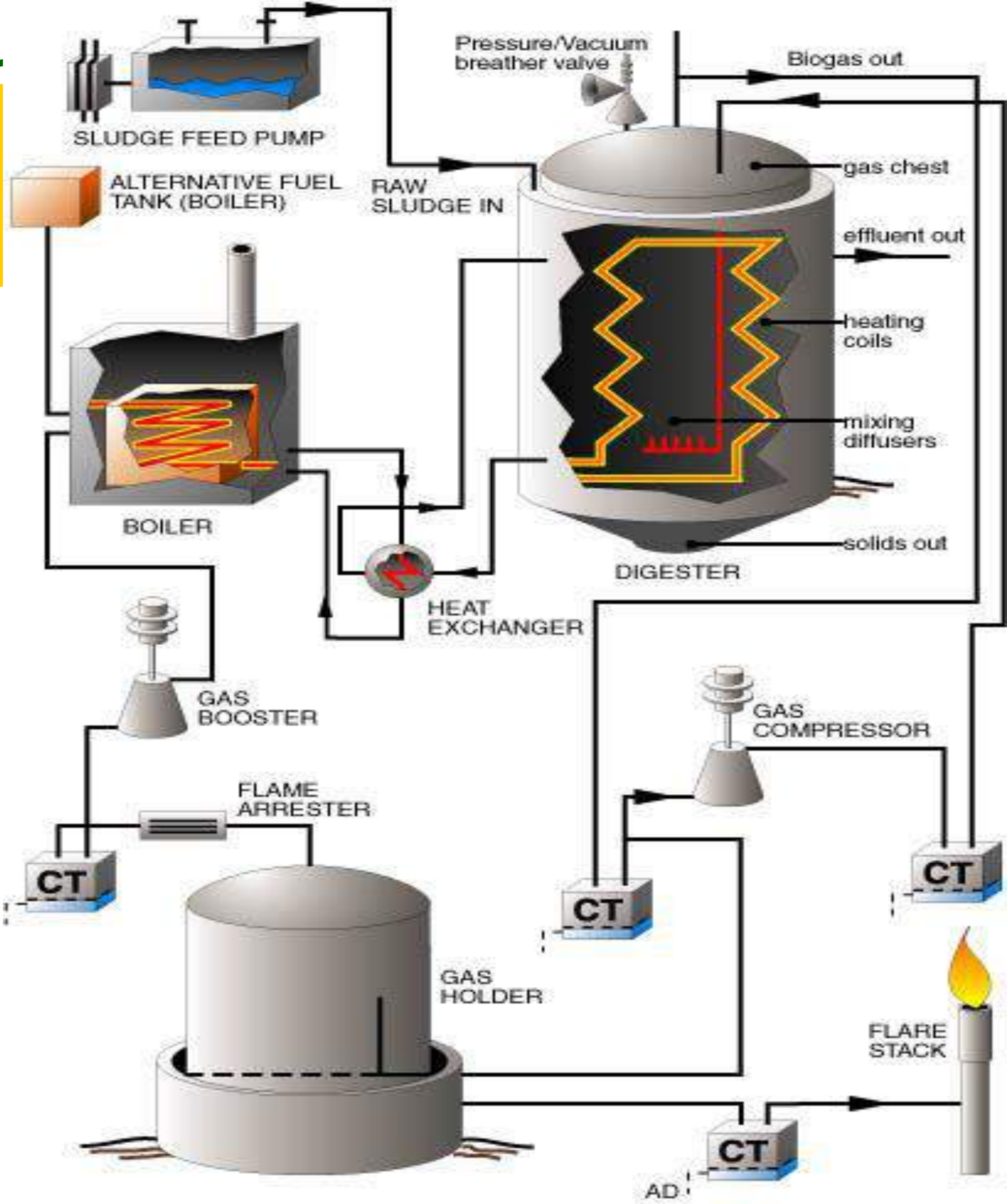
SLUDGE TREATMENT AND DISPOSAL

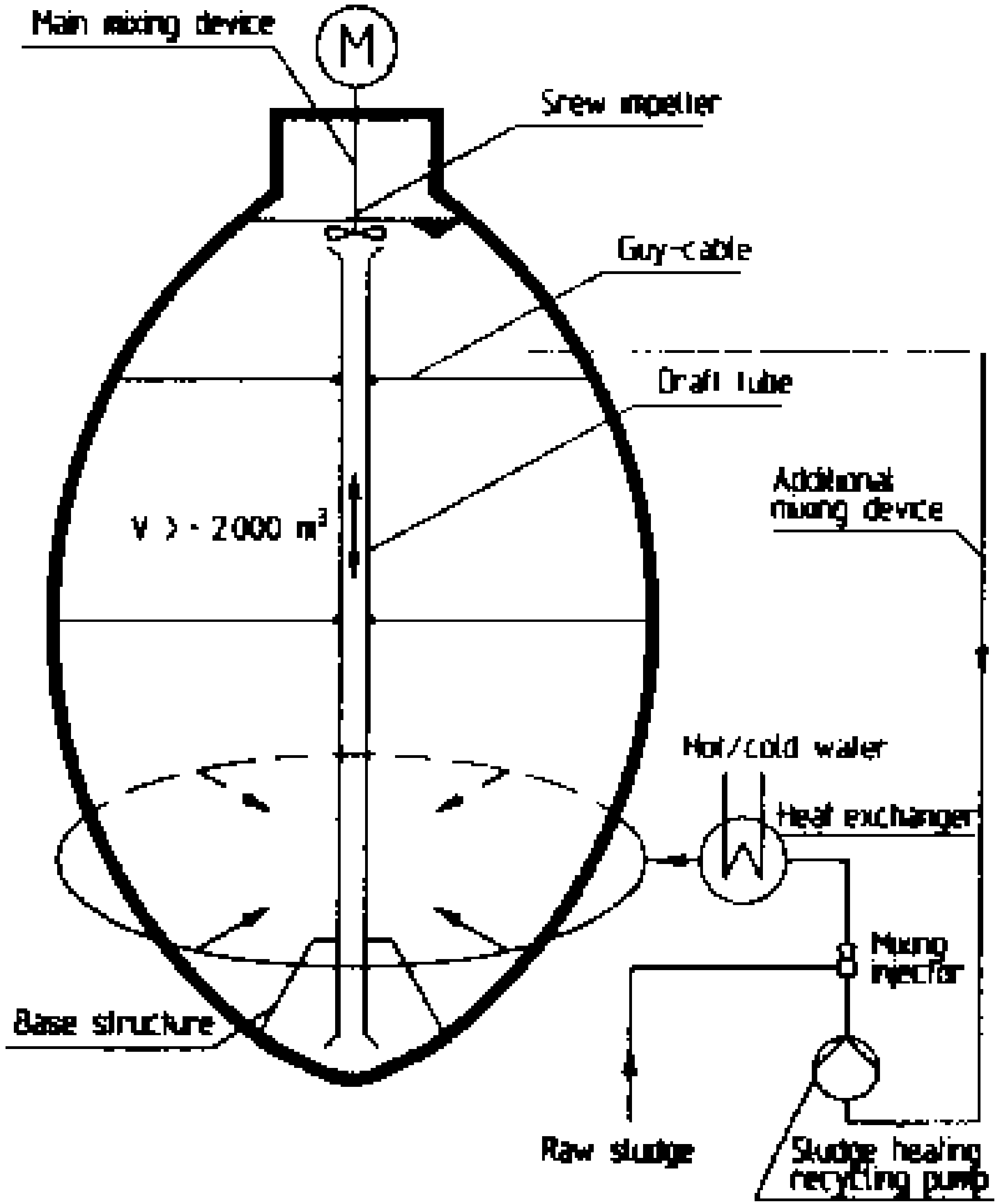
- Thickening
  - gravity, flotation
- Digestion
  - aerobic, anaerobic
- Mechanical Dewatering
  - Vacuum filtration, centrifugation, pressure filtr.
- Disposal
  - land application, burial, incineration

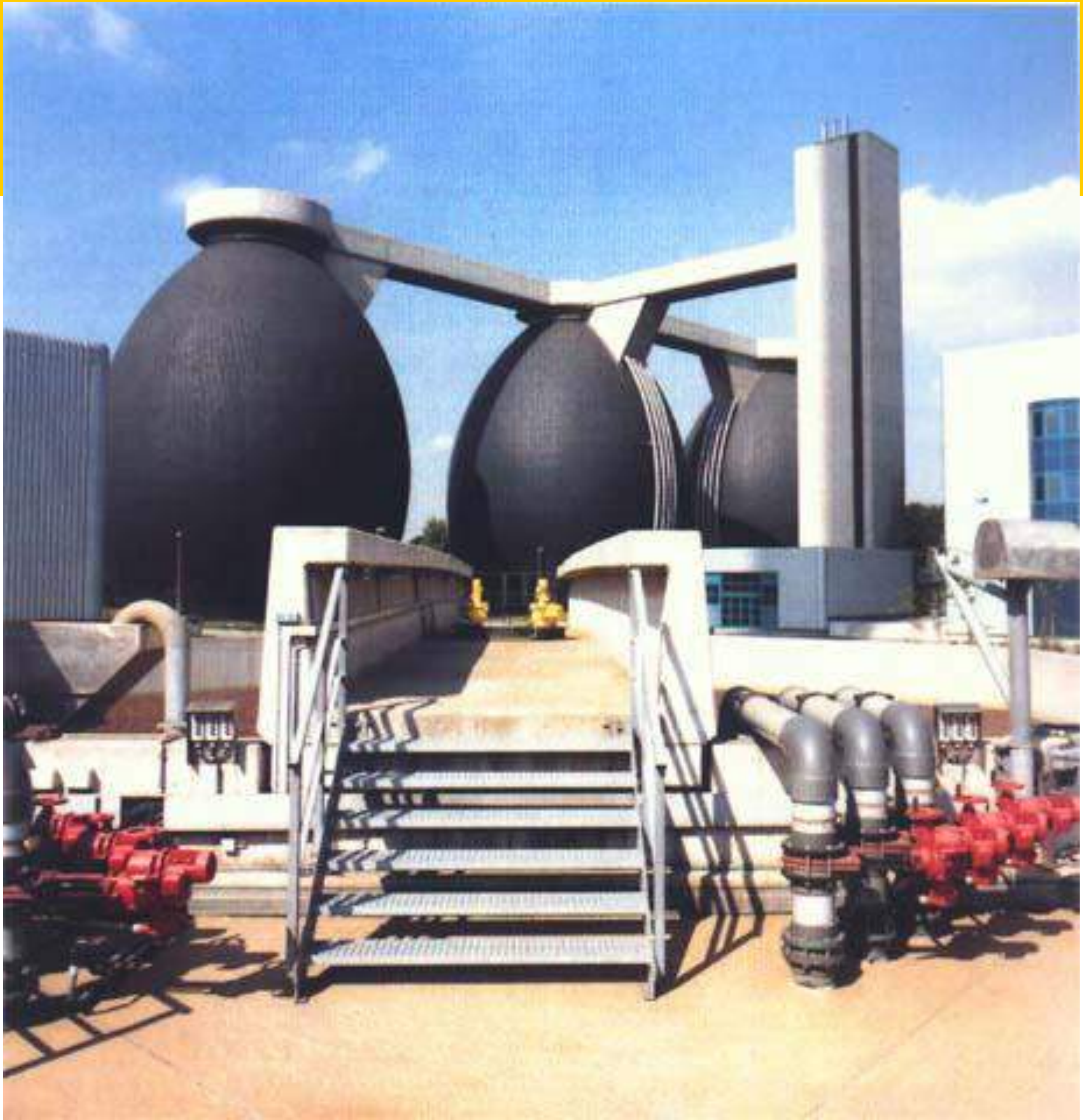
ANAEROBIC SLUDGE DIGESTION



Sludge Digestion: Anaerobic



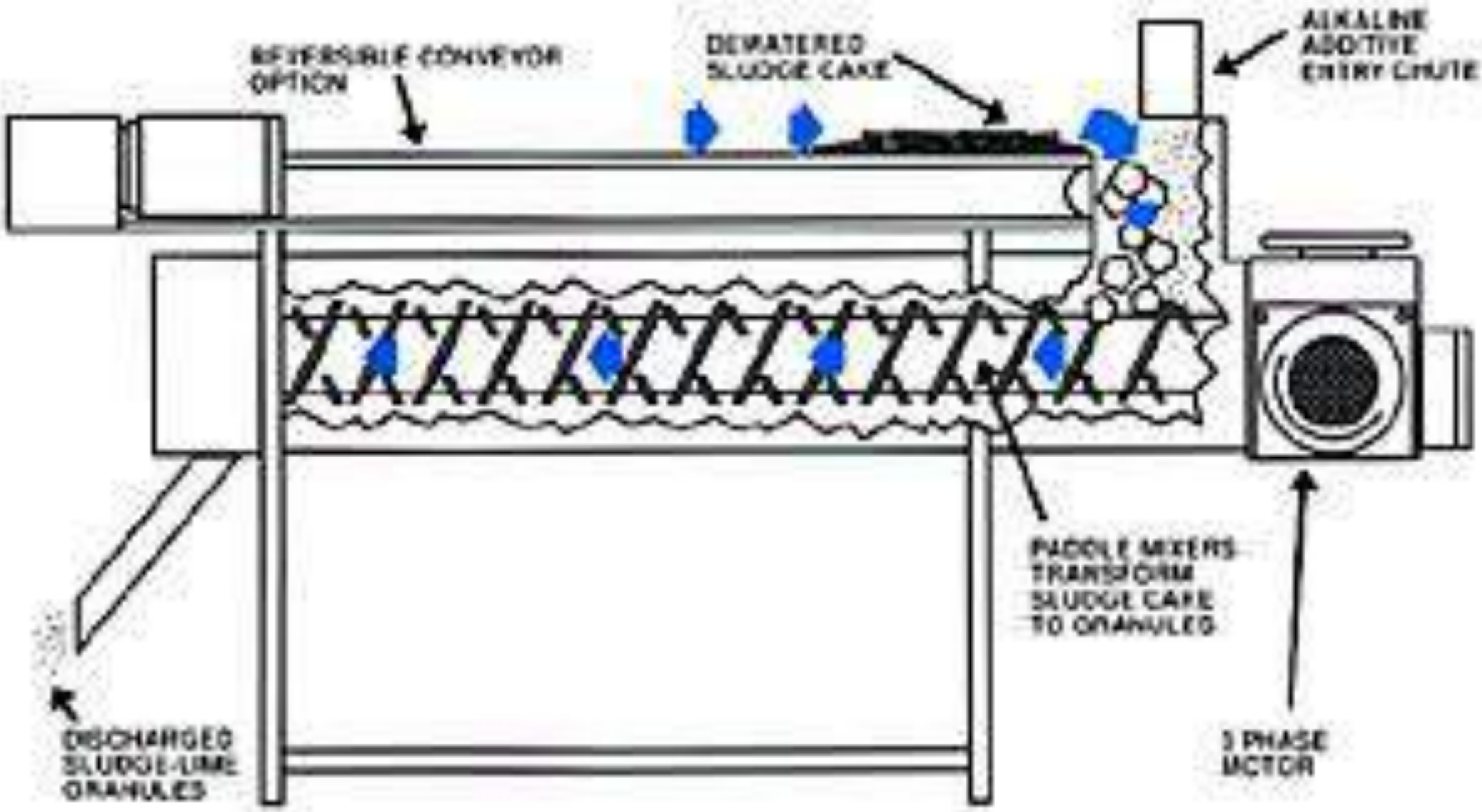

Main mixing device
M
Srew impeller
Guy-cable
Draft tube
V > ~ 2000 m³
Additional mixing device
Hot/cold water
Heat exchanger
W
Mixing injector
Base structure
Raw sludge
Sludge heating recycling pump



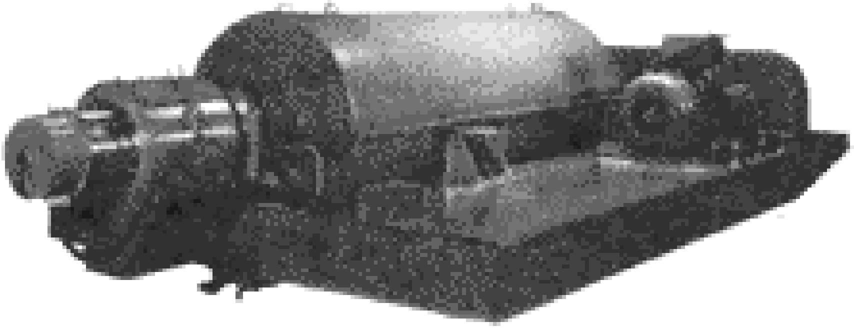
Sludge Characteristics

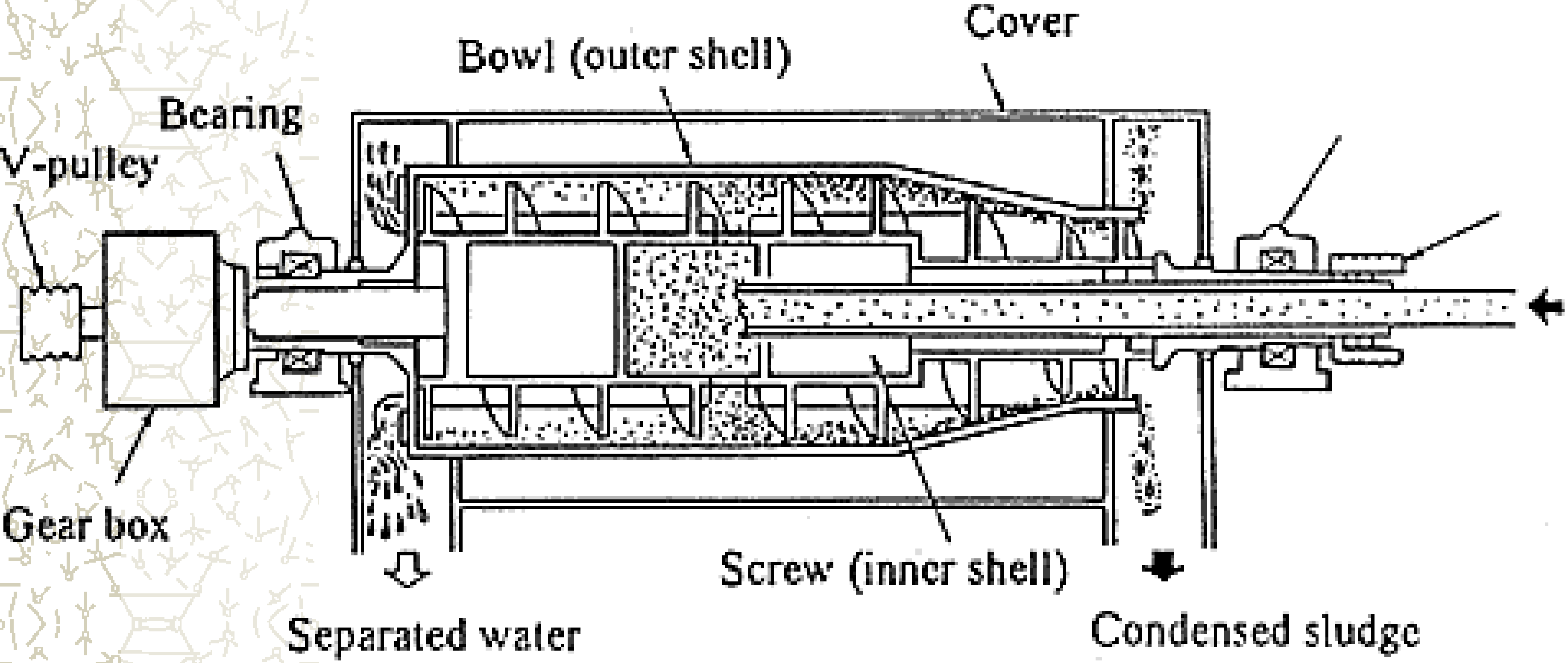
Source	Typical Concentration, percent
Primary sludge, without thickening	2 - 7
Waste activated sludge	0.5 - 1.5
Waste trickling filter sludge	1 - 5
Digested sludge	4 - 10
Dewatered sludge	12 - 50

Sludge dewatering: Centrifugation

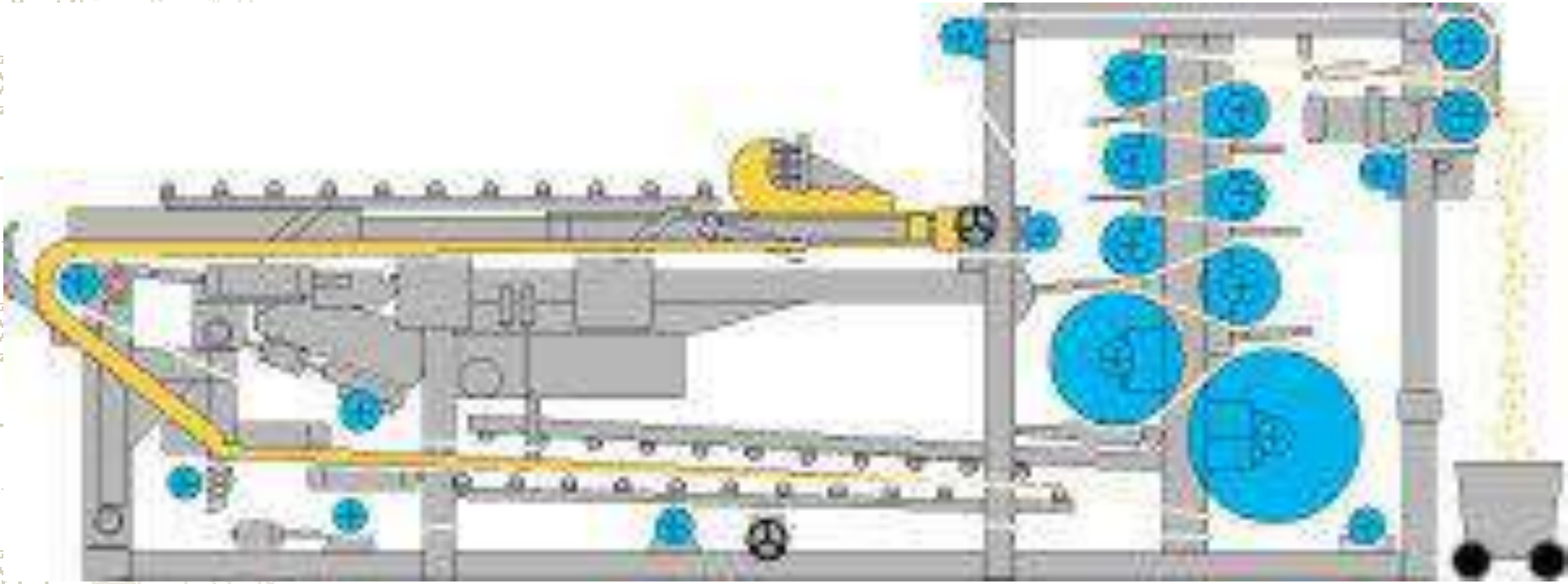


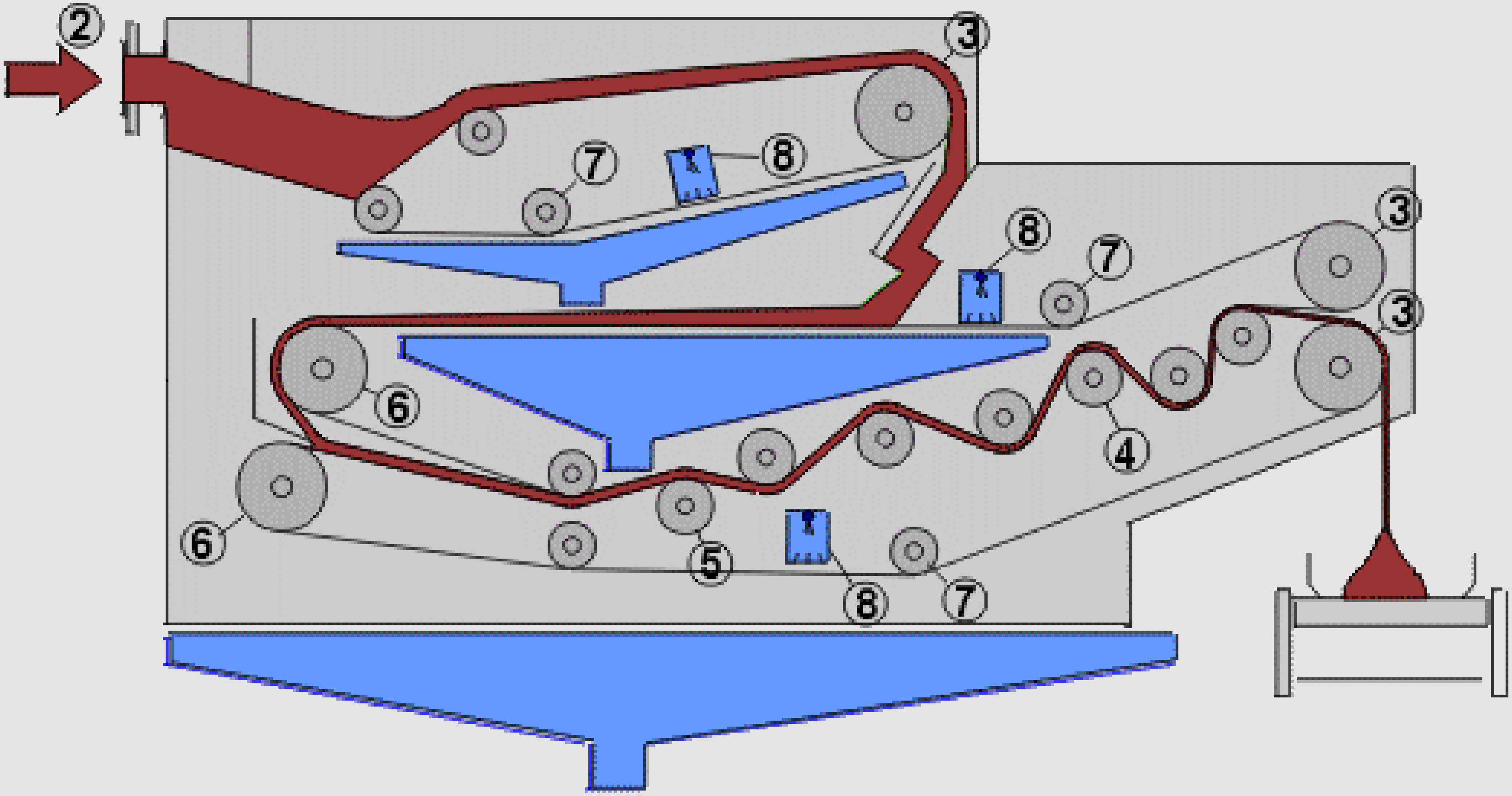
Centrifugation





Sludge dewatering: filter press




2
3
7
8
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5
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7

Filter press

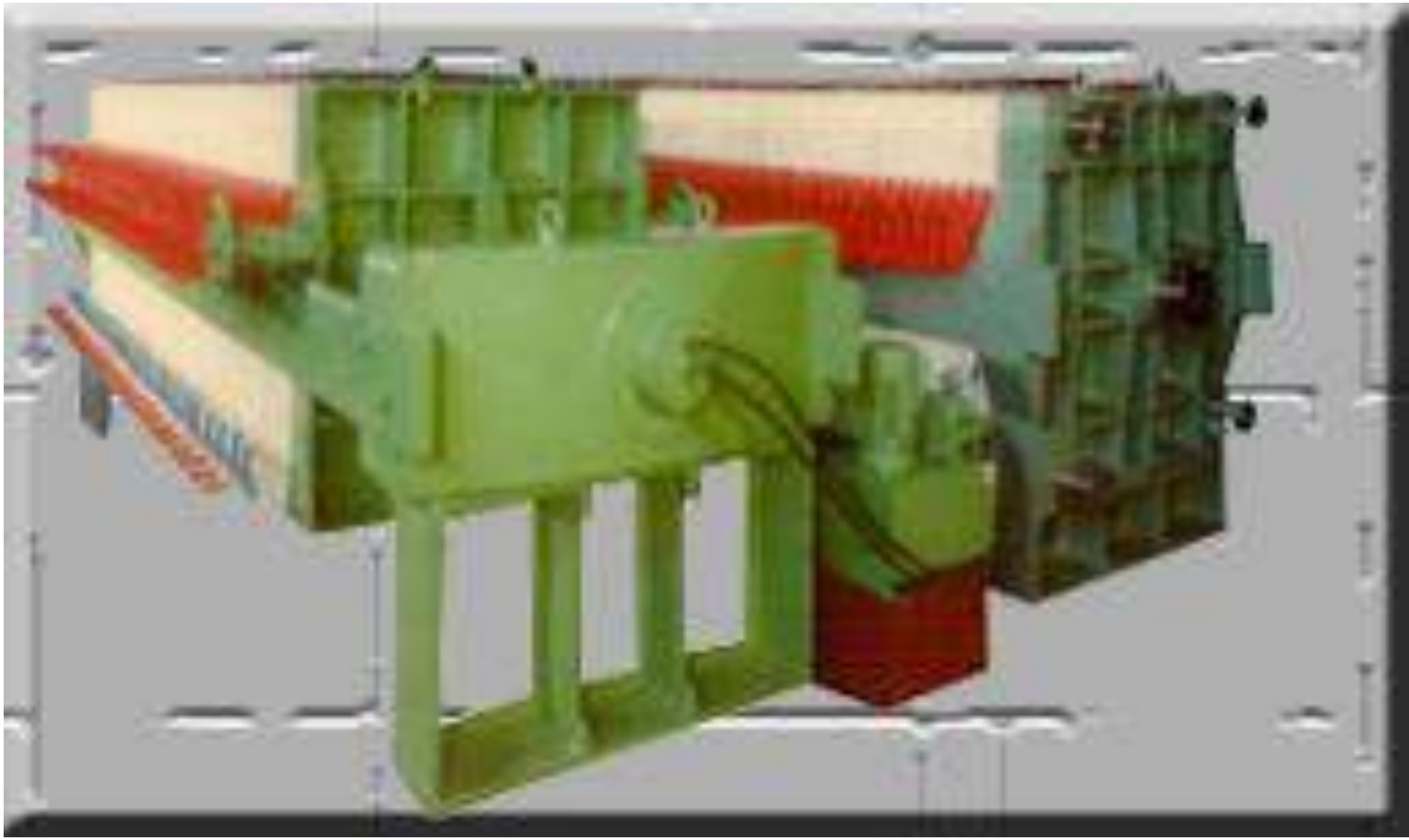
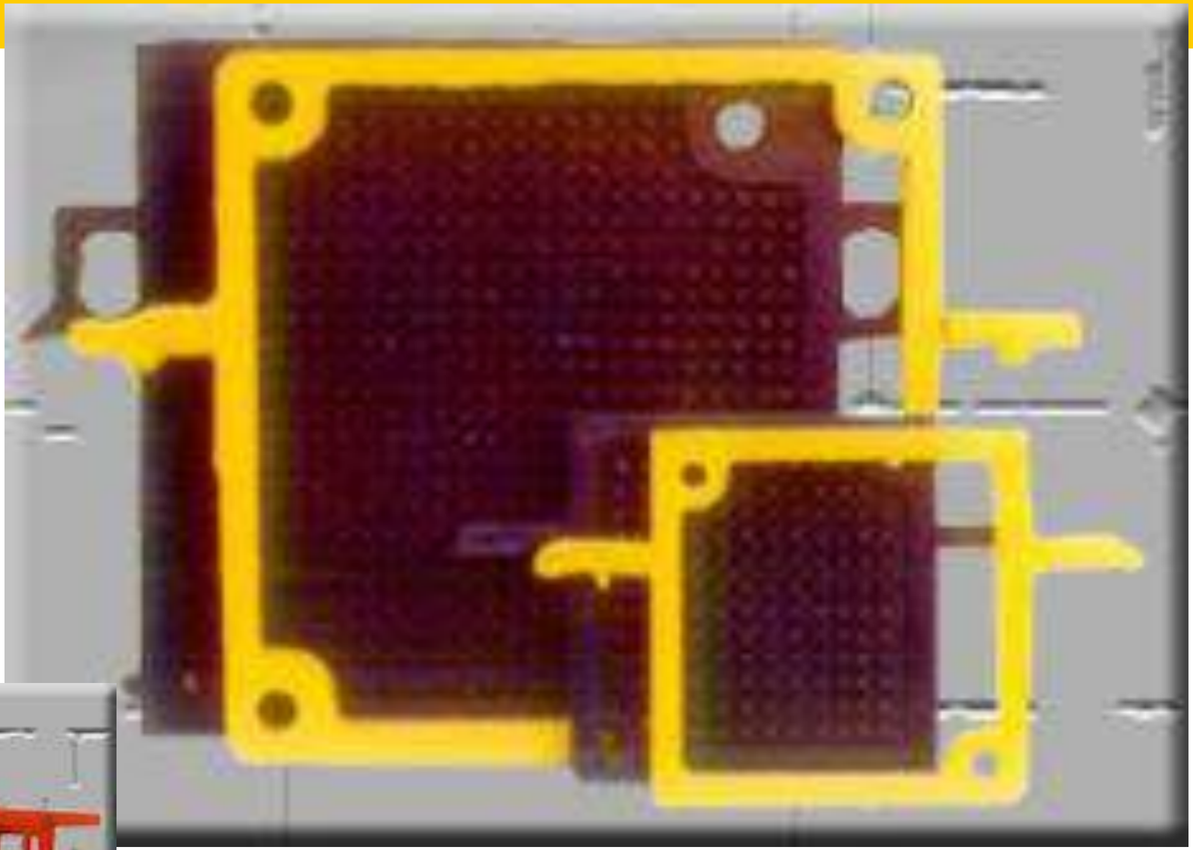
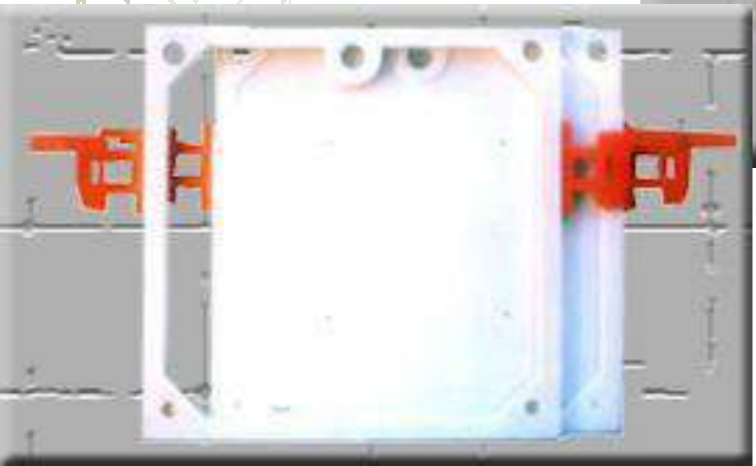


PLATE AND FRAME FILTER PARTS



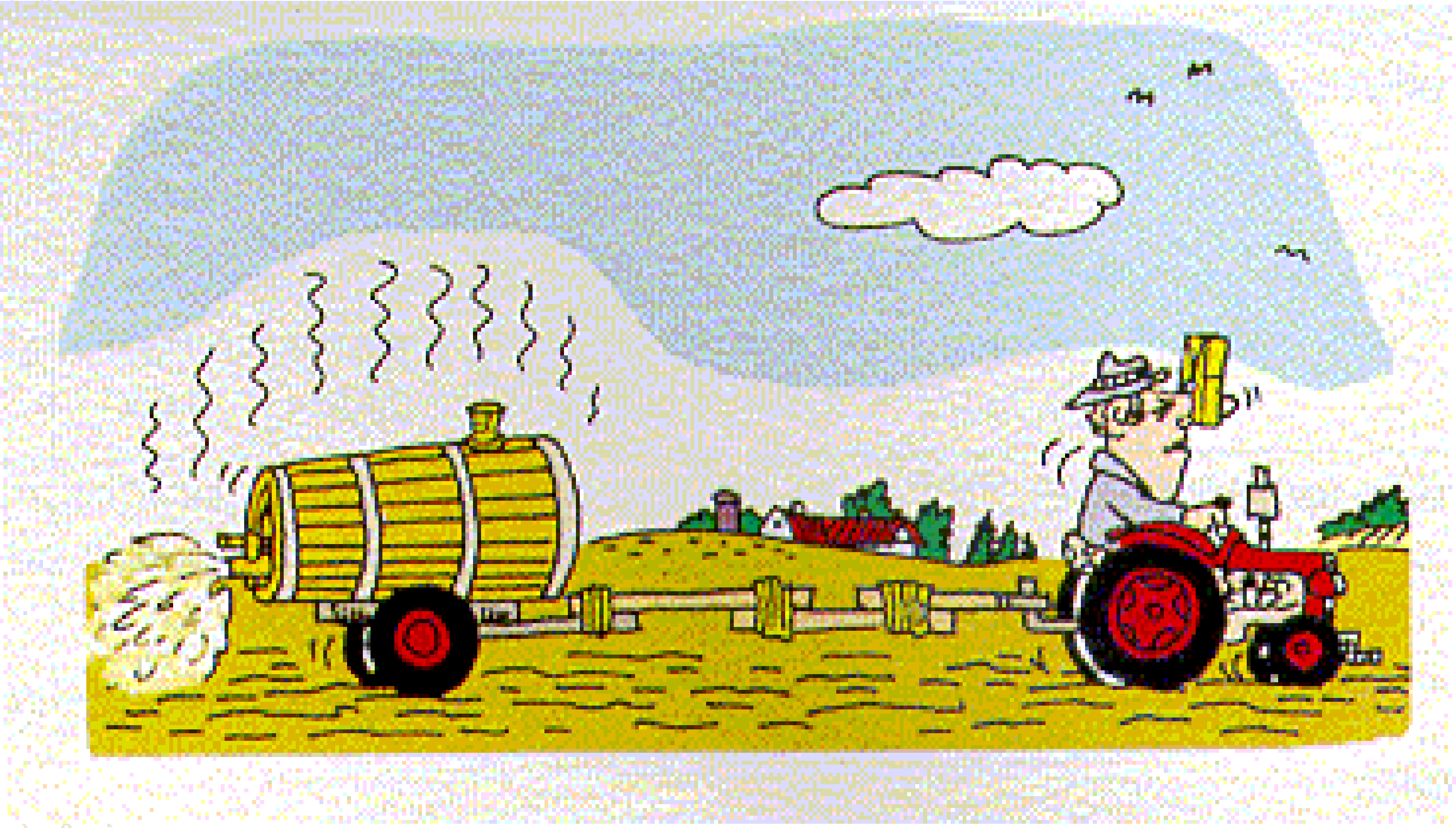


Sludge drying bed: preparation

Filling the drying bed with sludge

Starting the drying process

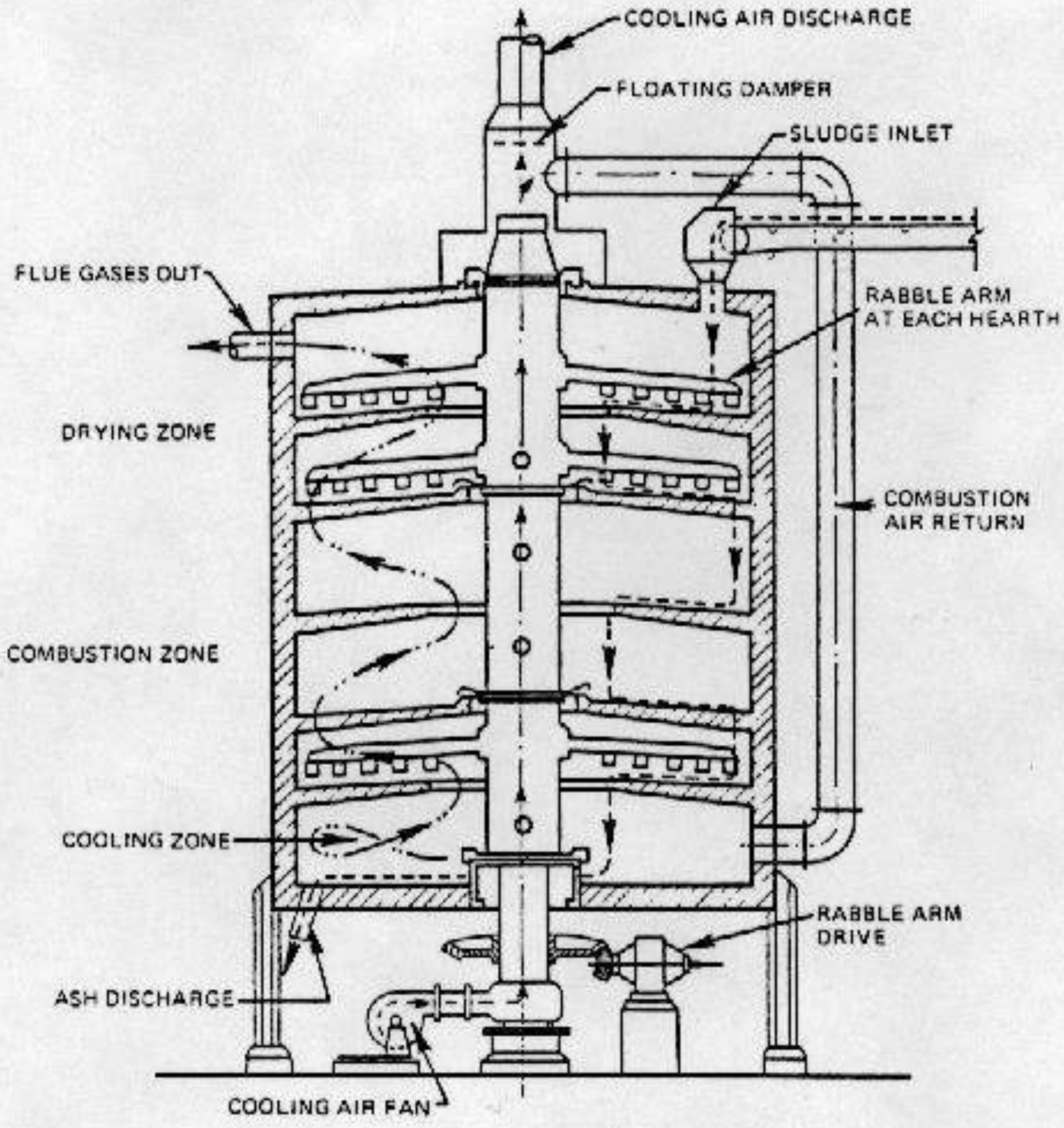
Sludge disposal: Land application



Sludge Incineration:

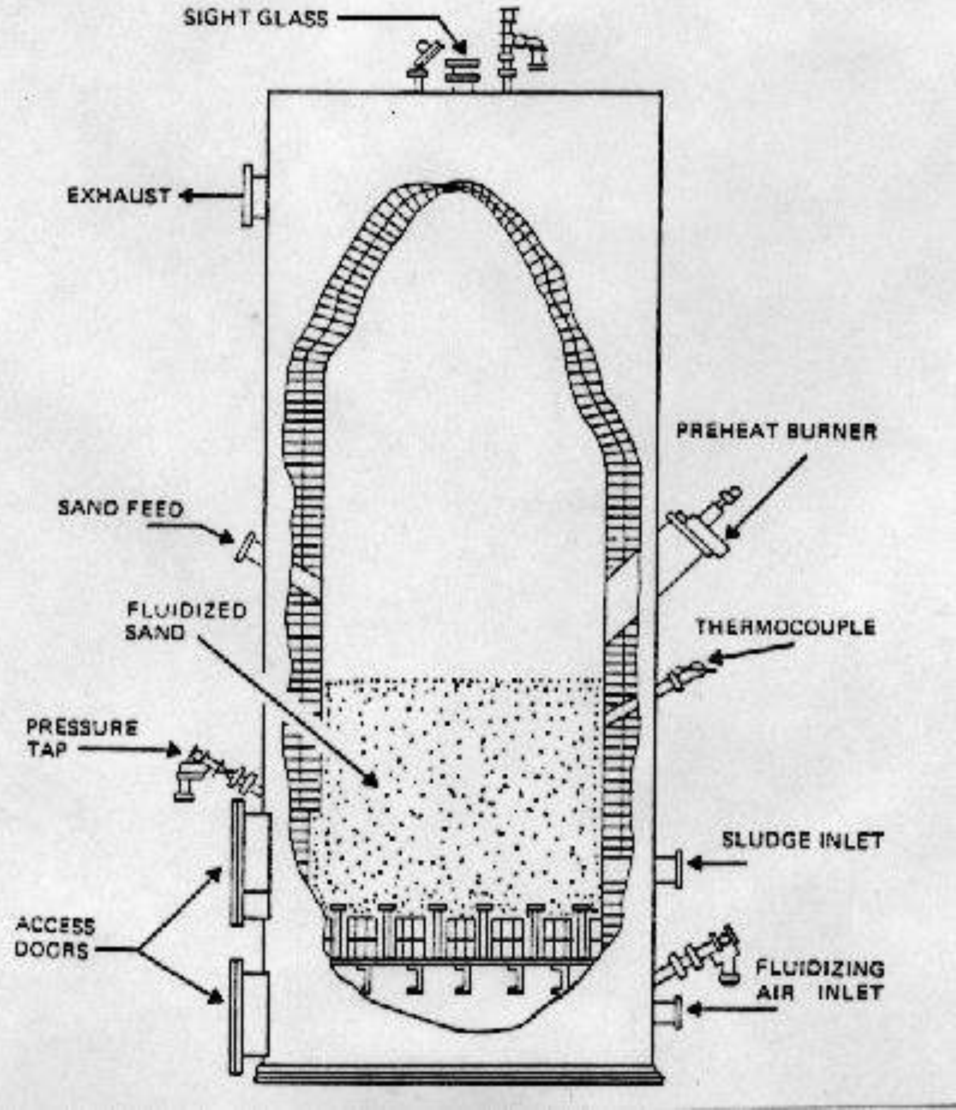
Multiple Hearth

Figure 5.1: Cross Section of a Typical Multiple Hearth Furnace



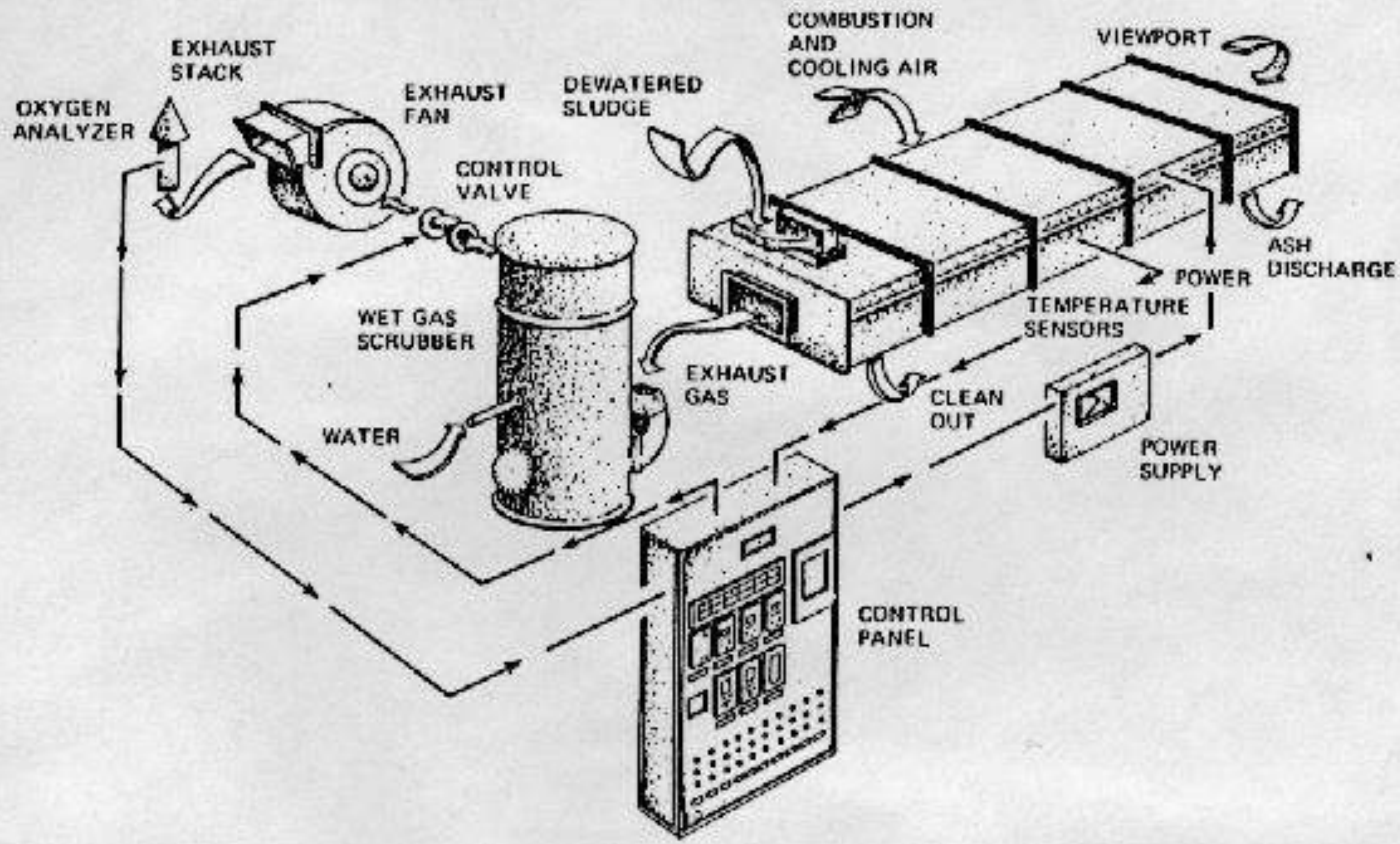
Fluidized bed sludge incineration

Figure 5.2: Cross Section of a Fluid Bed Reactor

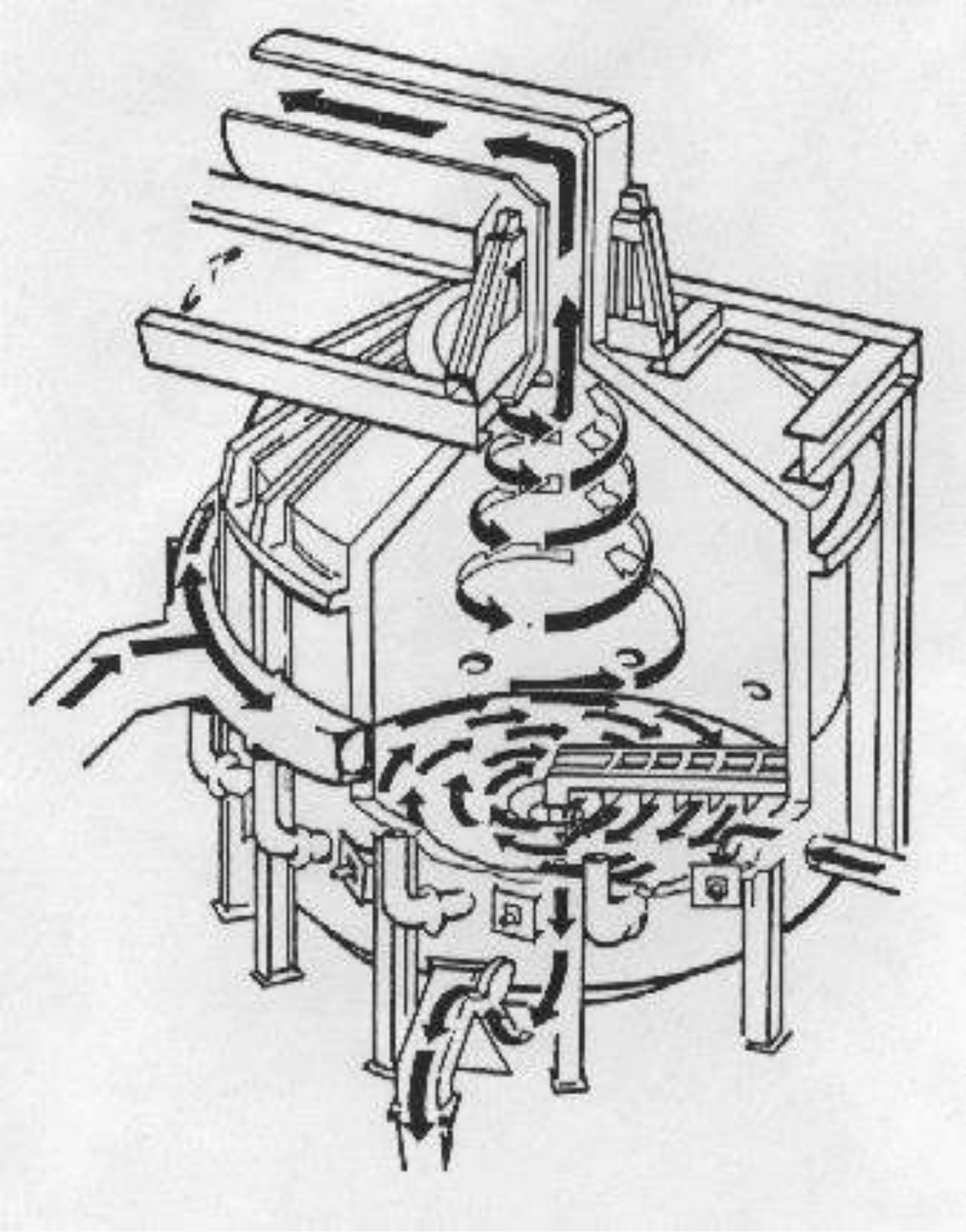


Radiant heat (electric) incineration

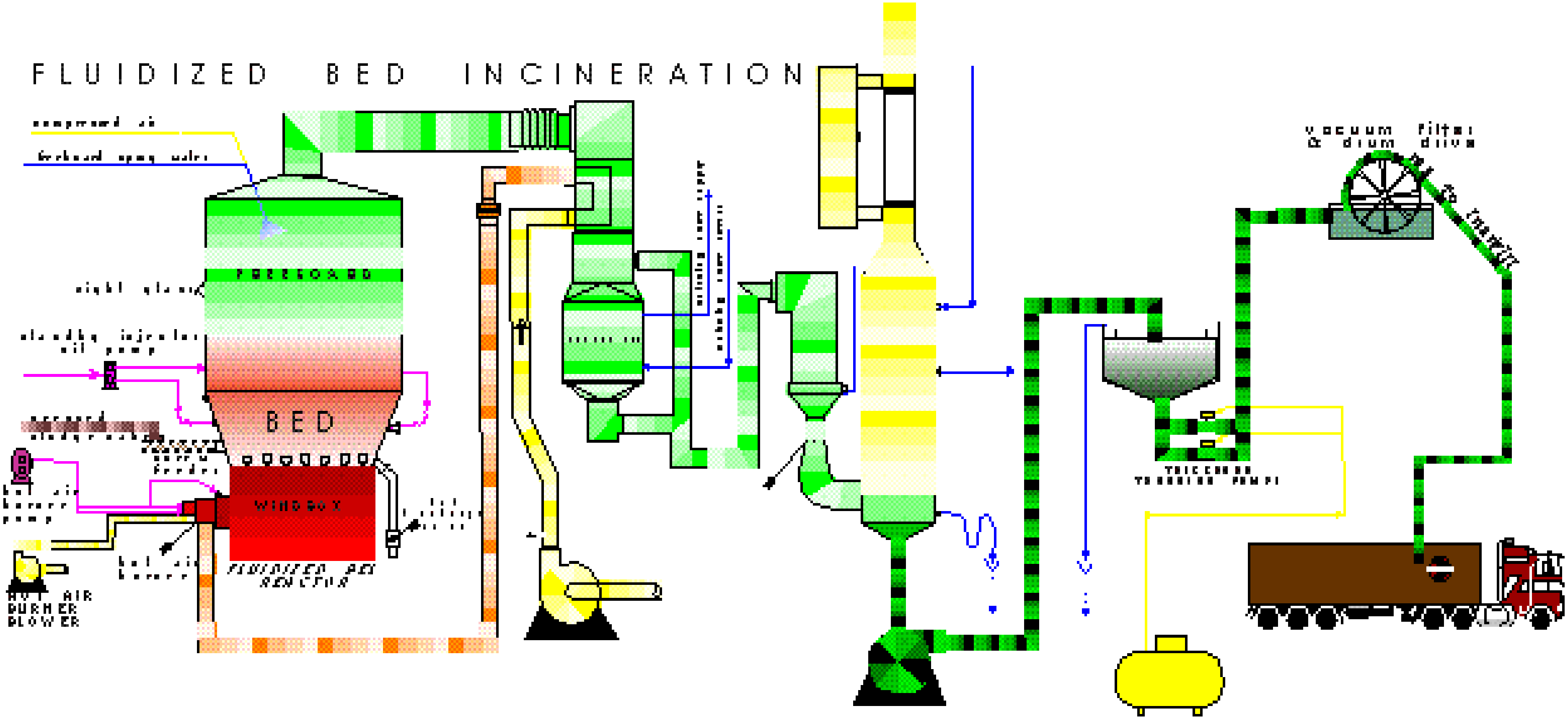
Figure 5.4: Radiant Heat (Electric) Incineration System



Cyclone Furnace



Fluidized bed incineration system



Sludge disposal: transport

RESOURCE RECOVERY FROM SEWAGE SLUDGE

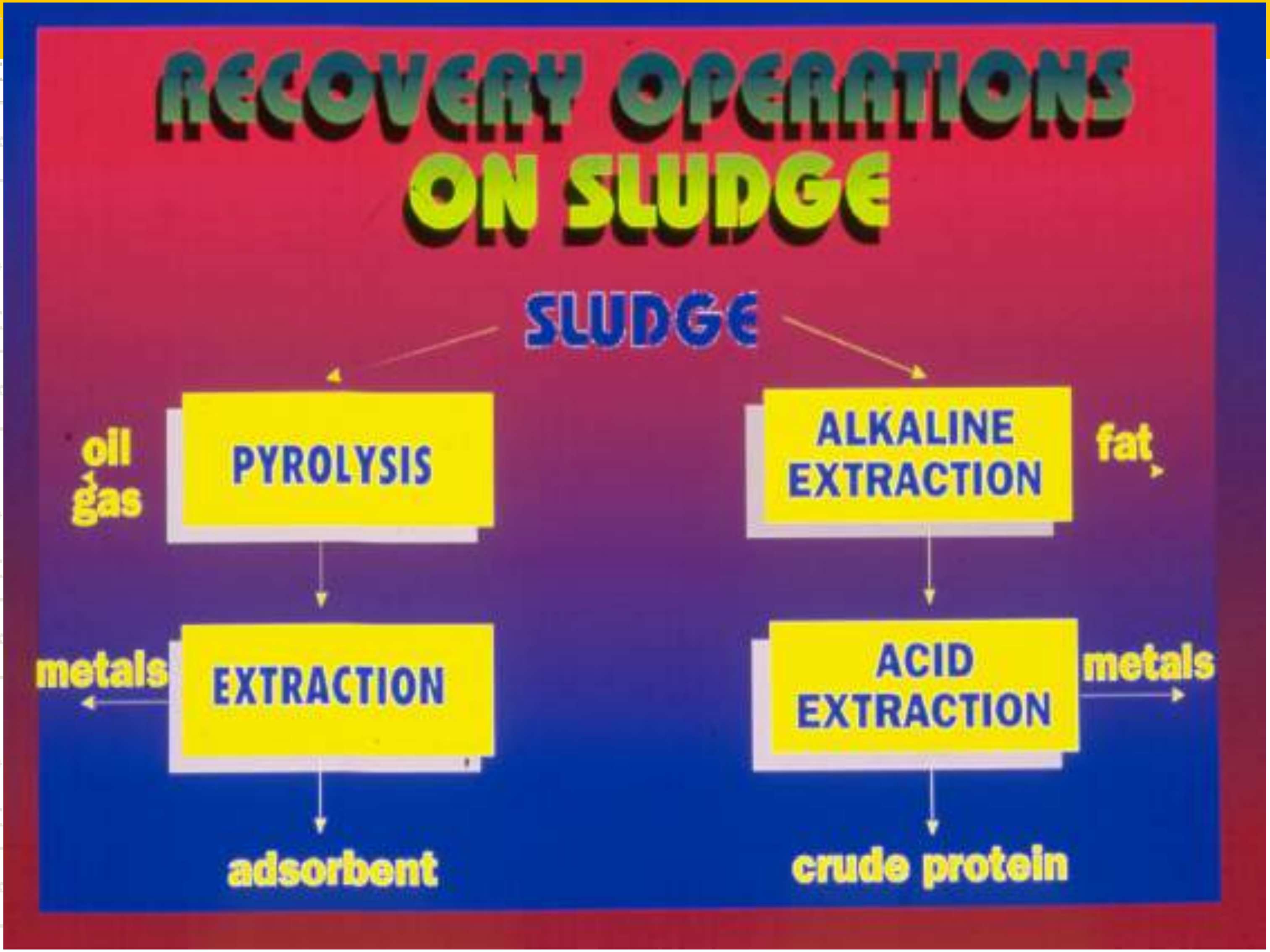
* Feed
* Energy
* Minerals

VALUE OF SLUDGE COMPONENTS

Constituent	kg/ton	Gross value $A/ton
Protein	320	130
Fat	150	60
N	50	25
P	15	18
B_{12}	0.0025	20
Oil	30	10
Energy		70-150
Metals	3	35
		$300

METALS IN SEWAGE SLUDGE

Metal	g/ton	Gross value $A/ton
Zn	1 400	1.5
Cr	700	6
Cu	700	1.4
Ni	130	1.0
Sn	100	1.8
Pb	50	0.4
Ag	17	5
Au	1	17



RECOVERY OPERATIONS ON SLUDGE

SLUDGE

PYROLYSIS

oil
gas

EXTRACTION

metals

adsorbent

ALKALINE EXTRACTION

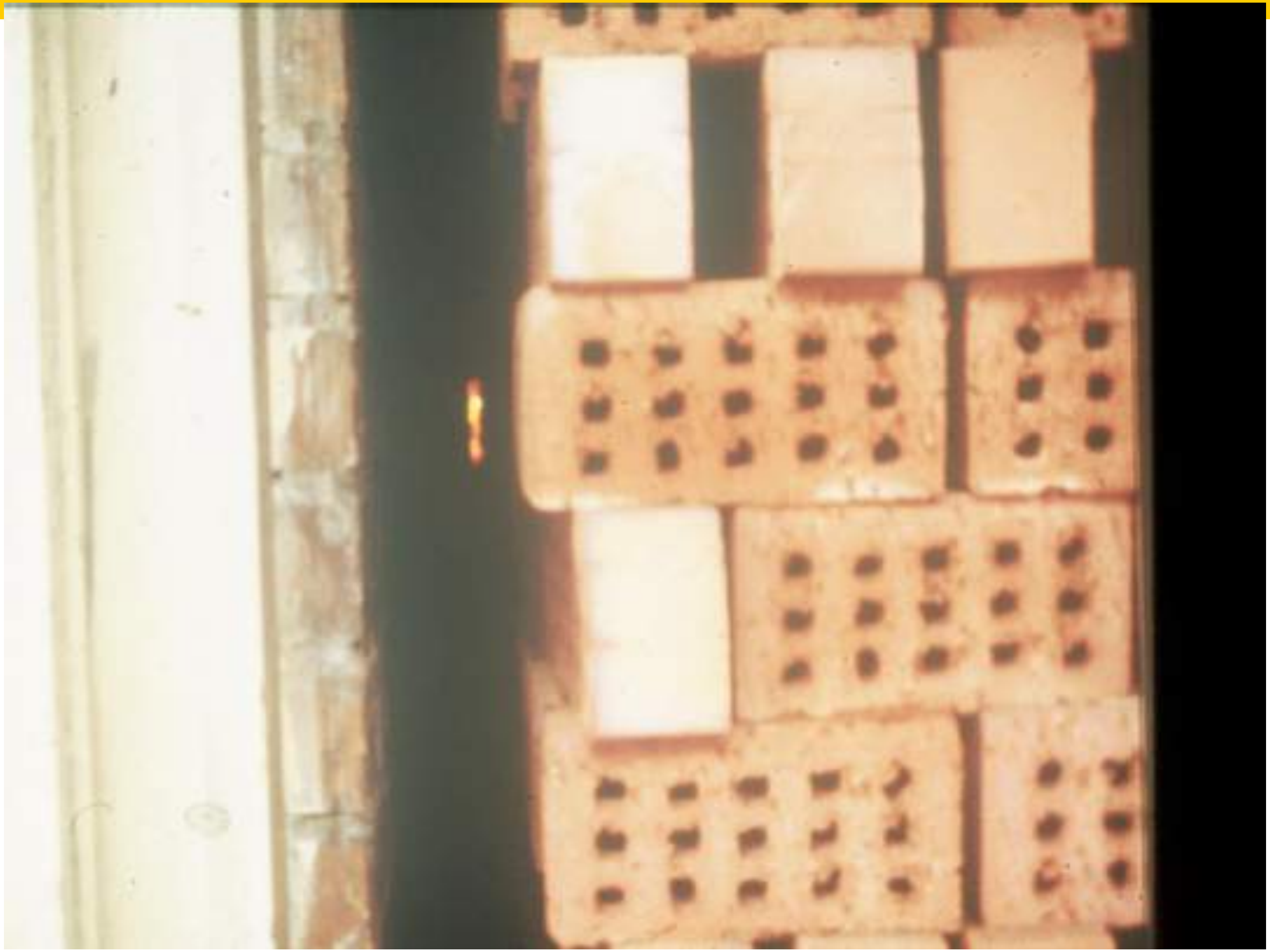
fat

ACID EXTRACTION

metals

crude protein

INCORPORATING BIOMASS INTO BRICKS



Destination of wastewater solids