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# WASTE TO ENERGY CONVERSION

## ENERGY PRODUCTION FROM ORGANIC WASTES THROUGH ANAEROBIC DIGESTION-2

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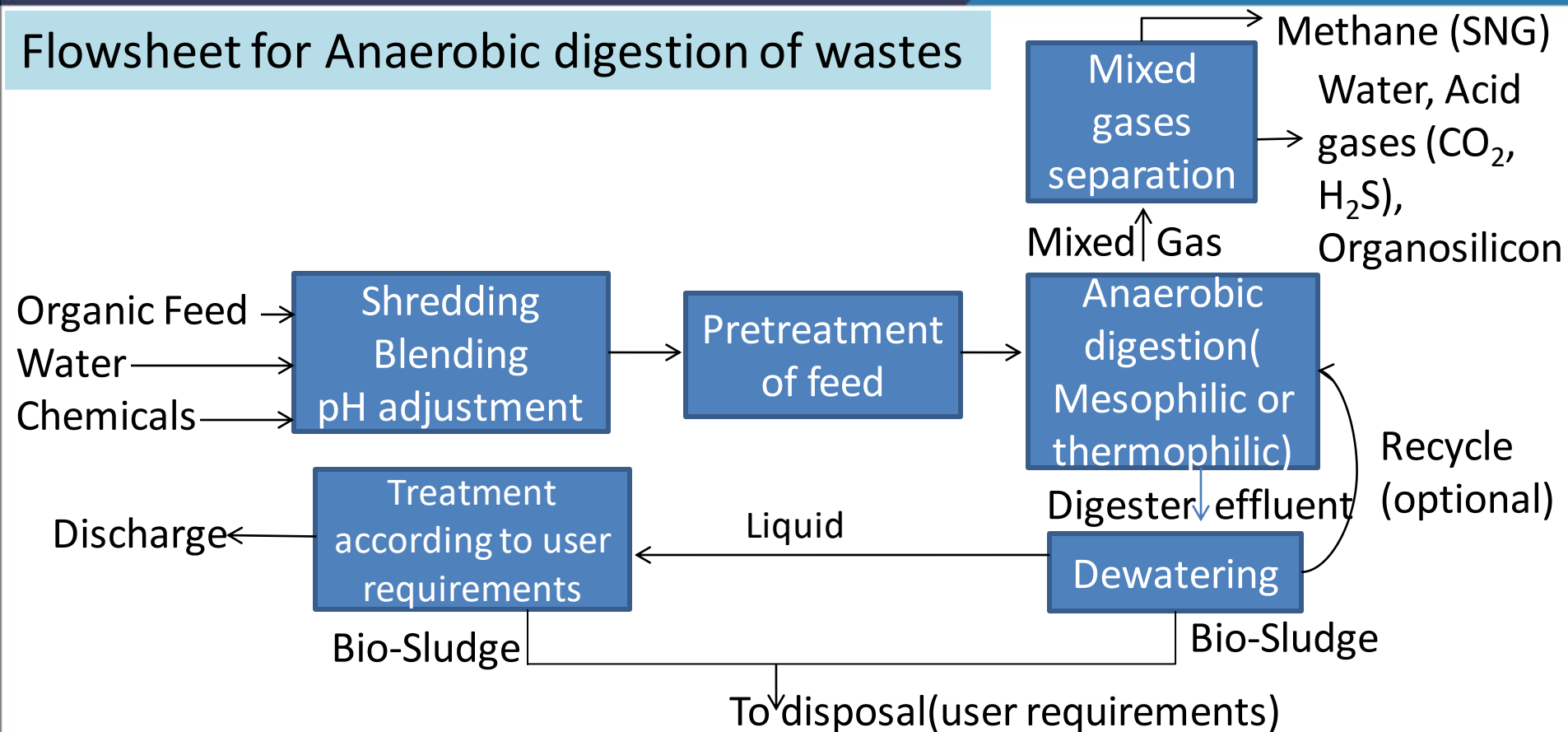


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# Flowsheet for Anaerobic digestion of wastes



Source: Donald L. Klass, Biomass for Renewable Energy, Fuels, and Chemicals

## Type of anaerobic digestion

| Processing mode            | Dry                 | Wet                |
|----------------------------|---------------------|--------------------|
| Total solids content       | High 25-45 %        | Low 2-15 %         |
| Reactor volume             | Minimized           | Increased          |
| Solid liquid separation    | Simple              | Expensive          |
| Energy Balance             | More Improved       | Less improved      |
| Economic performance       | More improved       | Less improved      |
| Retention time             | Shorter             | Bigger             |
| Type of feedstock accepted | Greater flexibility | Lesser flexibility |

# KINETICS OF METHANE PRODUCTION

- One of the steps might be rate-limiting among hydrolysis, acidogenesis, acetogenesis and methanogenesis for high rate digestion.
- Normally the methanogenesis is the rate limiting step.
- If cellulose content is higher in feedstock, hydrolysis may be rate limiting step
- Presence of lignin decreases the rate of hydrolysis.
- Transfer of the gaseous products to the gas phase may also be the rate-limiting step for some cases.



- Theoretical substrate conversion rates per unit reactor volume can be estimated as:

$$R = \frac{S_o (\mu_{\max} \theta - 1) - K_s}{\theta (\mu_{\max} \theta - 1)}$$

where R is the substrate converted per liquid volume at hydraulic retention time  $\theta$ ,

$S_o$  is the substrate concentration in the feed,

$\mu_{\max}$  is maximum specific growth rate

and  $K_s$  is saturation constant or substrate concentration at which the specific growth rate is  $\frac{1}{2} \mu_{\max}$ .

At 30 – 37°C , optimum conversion of glucose can be achieved at  $\theta$  's of 4 h and 4 days in the acid- and methane-phase reactors respectively.



For cellulosics, the corresponding  $\theta$  's are much higher, about 1 to 2 days for acid-phase digestion and 5 to 8 days for methane-phase digestion

| Kinetic constant                 | Acidogenesis of |           | Methanogenesis of acetate |
|----------------------------------|-----------------|-----------|---------------------------|
|                                  | Glucose         | Cellulose |                           |
| $\mu_{\max}$ , day <sup>-1</sup> | 7.2             | 1.7       | 0.49                      |
| $K_s$ , g/L                      | 0.4             | 36.8      | 4.2                       |

Kinetic constants are:  $\mu_{\max}$ , maximum specific growth rate; and  $K_s$ , saturation constant or substrate concentration at which the specific growth rate is  $\frac{1}{2} \mu_{\max}$ .

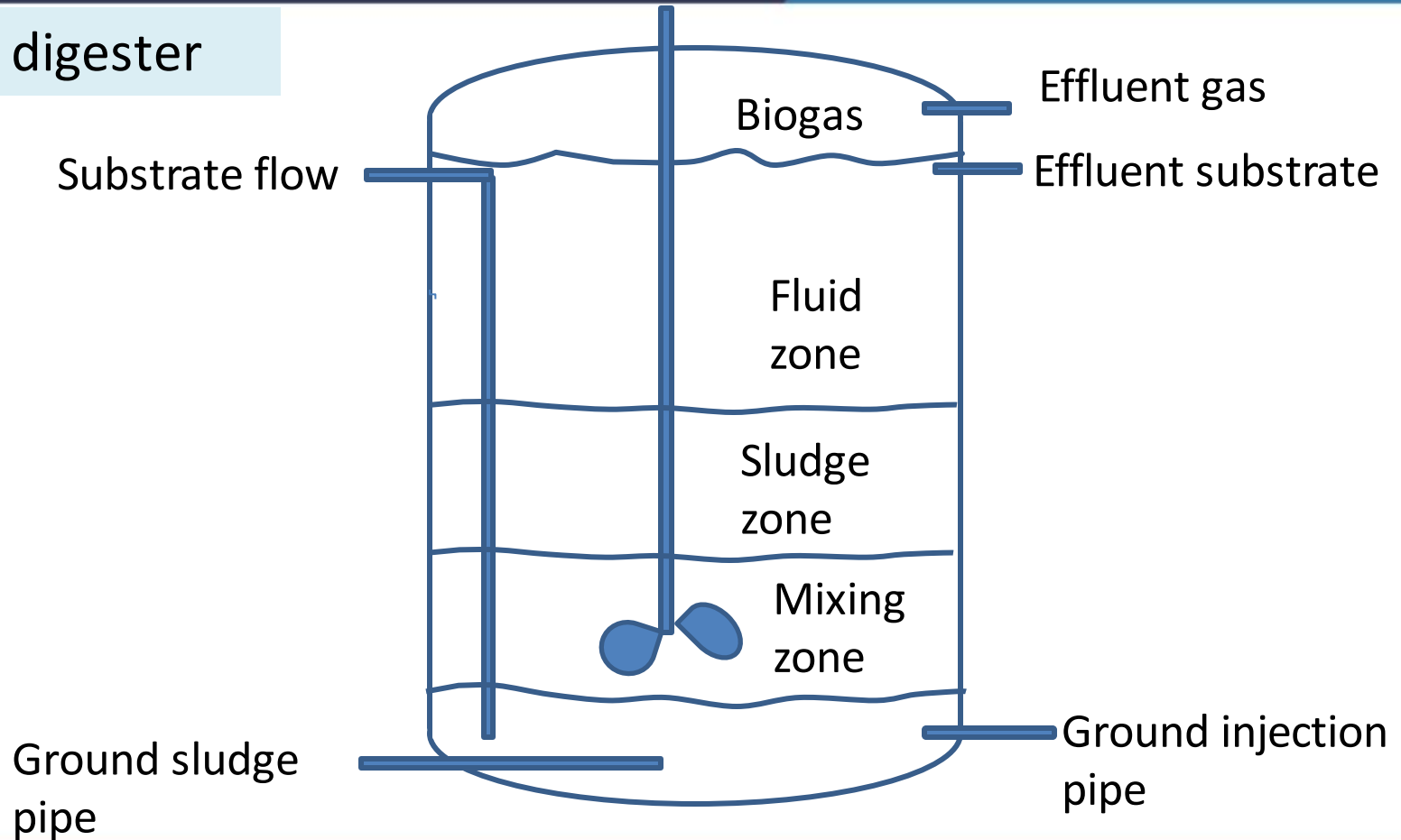
Source: Donald L. Klass, Biomass for Renewable Energy, Fuels, and Chemicals

## Some important facts

- Methane fermentation at thermophilic temperatures increases the methane production rate because of higher reaction rates.
- Reduced pressure also provides little or no benefit (Hashimoto, 1982).
- Low pH and short retention time precludes growth of methanogenic bacteria and thus reduces methane production.
- Rapid, continuous agitation of anaerobic digesters is not necessary, and in some cases is even harmful (Stafford, 1982).
- Specific methane yield is directly proportional to biodegradable COD or VS loading in the digester.



# Anaerobic digester



Mixing helps to reduce the natural stratification that occurs in a low profile tank.

Mixing can be accomplished with a variety of gas mixers, **mechanical mixers**, and draft tubes with mechanical mixers or simply recirculation pumps.

Completely mixed reactors can have fixed covers, floating covers or gas holding covers.

Most municipal digesters have floating covers.

Floating covers are more expensive than fixed covers and standard diameters range from 15 to 125 ft.



# Types of anaerobic digesters

## ➤ Low rate (Conventional digesters)

- Intermittent mixing, sludge feeding and sludge withdrawal
- Detention time = 30-60 days
- Feeding rate 0.5 to 1.5 kgVS/m<sup>3</sup>.day

## ➤ High rate digesters

- Continuous mixing (homogenous)
- Continuous or intermittent sludge feeding and sludge withdrawal
- Detention time = < 15 days
- Feeding rate 1.6 to 6.4 kgVS/m<sup>3</sup>.day

➤ Most digesters are heated and operated in the mesophilic range and usually made of concrete or steel

## Digester operation

- Most digesters operate in the temperature range of 30-38<sup>0</sup> C to optimize time.
- The digester gas produced from the process may be used for the heating purposes.
- Optimum pH range is 7.0 - 7.2.
- ✓ Maintained by properly seeding fresh added sludge and not excessively withdrawing sludge (should not exceed 3-5 % of dry solids weight in digester).
- ✓ Temporary solution for acidification: lime addition.
- Heavy metals may inhibit digestion process. Must be eliminated at the source.
- The supernatant liquor is the water released during digestion.
- ✓ May have BOD as high as 2000 mg/l and SS concentration as high as 1000 mg/l.
- ✓ Fed back to the influent to primary clarifiers.

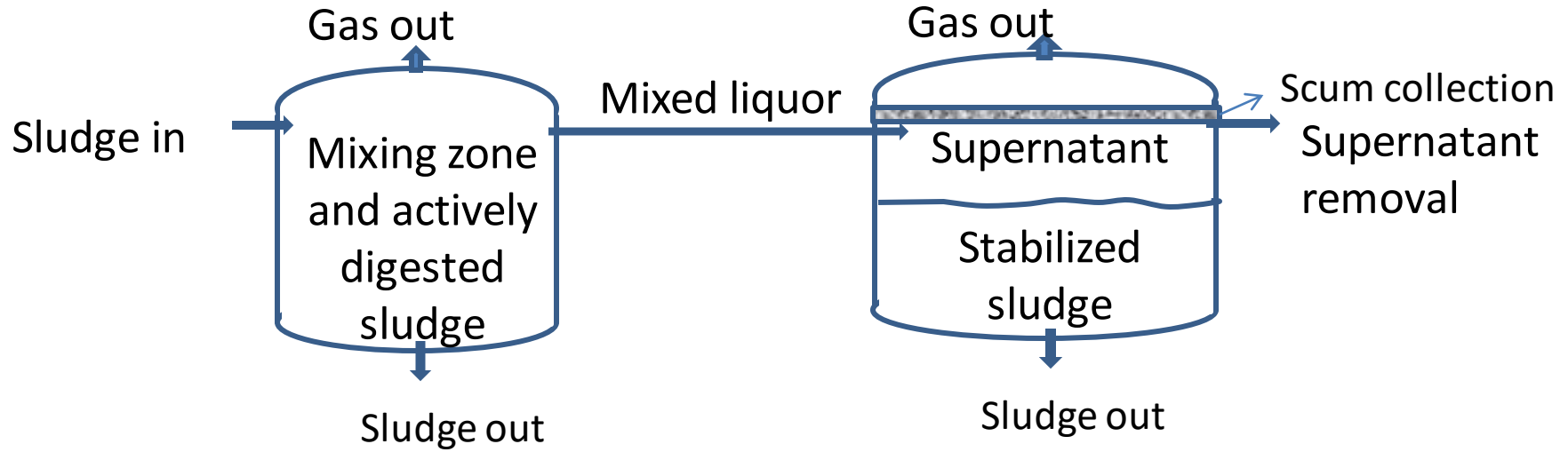
## Two stage digester

In a single phase digester optimum pH is 7

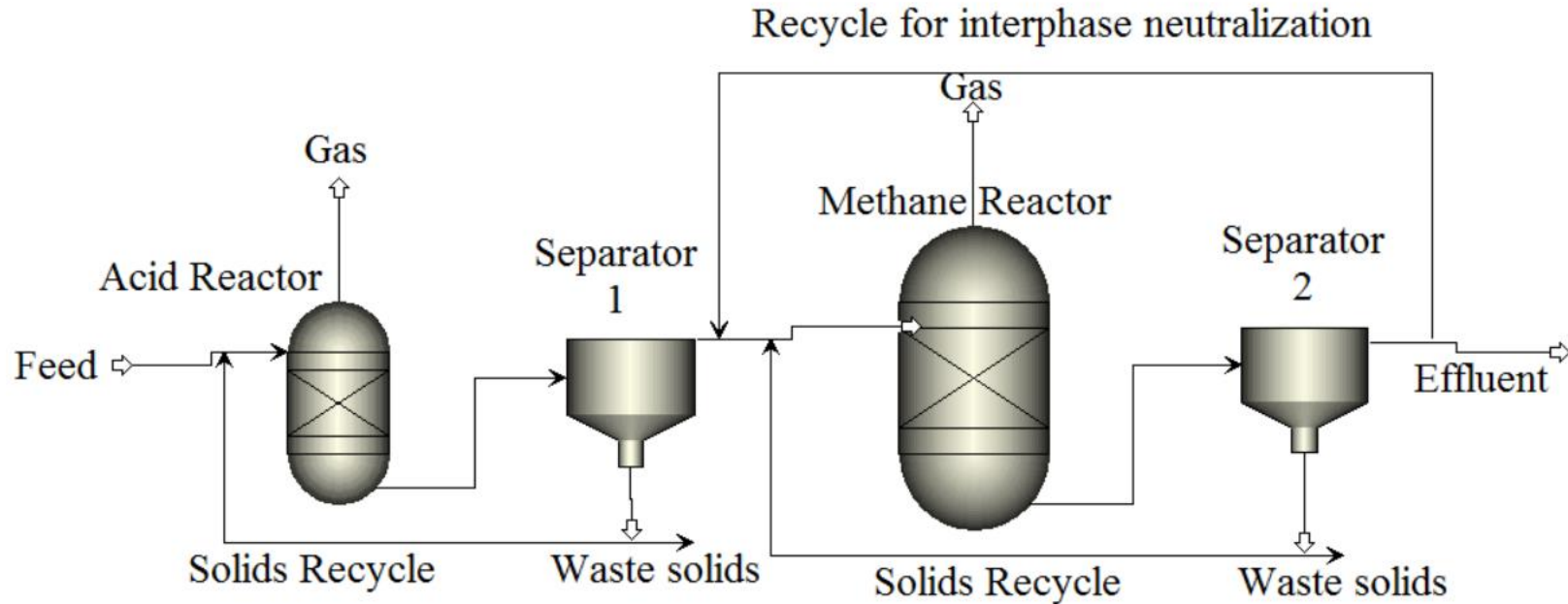
The acidogenic reactions favours at the pH range of 5.5 -5.9

Methanogenic reactions favour at pH 7.4 -7.9

Thus two phase reactor improves the over all gas yield



# Schematic of two-phase digestion model



Source: Donald L. Klass, Biomass for Renewable Energy, Fuels, and Chemicals

## Two stage anaerobic digestion

### First stage:

- Main biochemical reaction is liquefaction of organic solids, digestion of soluble organic materials.
- Usually a high rate digester with fixed cover and continuous mixing.

### Second stage:

- Some gasification occurs.
- Main purpose is supernatant separation, gas storage and digested sludge storage
- Conventional digester(low rate) with a floating cover and intermittent mixing

## Biogas impurities and their impacts

| Impurity             | Possible Impacts                                                                                                                                                                                                                                                                           |
|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Water                | Corrosion in compressors and engines due to reaction with $\text{H}_2\text{S}$ , $\text{NH}_3$ and $\text{CO}_2$ to form acids<br>Accumulation of water in pipes<br>Condensation and/or freezing due to high pressure                                                                      |
| Dust                 | Clogging due to deposition in compressors, gas storage tanks and engines                                                                                                                                                                                                                   |
| $\text{H}_2\text{S}$ | Corrosion in compressors and engines<br>Toxic concentration of $\text{H}_2\text{S}$ ( $>5 \text{ cm}^3 \text{ m}^{-3}$ ) remain in the biogas<br>$\text{SO}_2$ & $\text{SO}_3$ are formed due to combustion, which are more toxic than $\text{H}_2\text{S}$ and cause corrosion with water |
| $\text{CO}_2$        | Low calorific value                                                                                                                                                                                                                                                                        |

## Biogas impurities and their impacts

| Impurity                | Possible Impact                                                                                                               |
|-------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| Siloxanes               | Formation of $\text{SiO}_2$ & microcrystalline quartz due to combustion, deposition at spark plugs, valves and cylinder heads |
| Hydrocarbons            | Corrosion in engines due to combustion                                                                                        |
| $\text{NH}_3$           | Corrosion when dissolved in water                                                                                             |
| $\text{O}_2/\text{air}$ | Explosive mixtures due to high concentrations of $\text{O}_2$ in biogas                                                       |
| $\text{Cl}^-$           | Corrosion in combustion engines                                                                                               |
| $\text{F}^-$            | Corrosion in combustion engines                                                                                               |

## Removal of moisture from biogas

| Method                            | Advantages                                                       | Disadvantages                                                                          |
|-----------------------------------|------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Condensation method               | Higher HC's dust & oil are removed                               | Atmospheric pressure: dew point minimum 1°C                                            |
| Demister                          | Simple Techniques                                                | Gas at higher pressure to reach lower dew point (minimal -18°C) but freezing can occur |
| Moisture trap                     | Often used as pretreatment before other techniques               |                                                                                        |
| Silica                            | Low generation cost                                              | Dust & oil need to be removed                                                          |
| Absorption with glycol            | High removal: dew point -5 till 15°C; Higher HC's & dust removal | More expensive investment: high pressure and 20°C for regeneration                     |
| Absorption with hygroscopic salts | High removal efficiency<br>Not toxic or dangerous                | No regeneration done                                                                   |



## Sludge volume

- The volume of a digesting sludge in a digester is a function of a volume of fresh sludge added daily, the volume of digested sludge produced daily and required digestion time.
- Empirical evidence (batch experiments) has shown that if supernatant is removed from a batch of digesting sludge as it is produced, volume of remaining digested sludge vs. digestion time is a parabolic function.
- For a parabolic function, average volume = initial volume – (2/3)(final volume – initial volume) therefore,

$$V_{\text{avg}} = V_1 - (2/3)(V_1 - V_2)$$

$V_{\text{avg}}$  = Average volume of digesting sludge ( $\text{m}^3/\text{day}$ )

$V_1$  = Volume of fresh sludge added daily ( $\text{m}^3/\text{day}$ )

$V_2$  = Volume of digested sludge produced daily ( $\text{m}^3/\text{day}$ )



- The volume of total sludge in the reactor is given by adding both the digesting and the digested sludge.

$$V_s = V_{avg} \cdot t_d + V_2 \cdot t_s$$

where

$V_s$  = Total sludge volume ( $m^3$ )

$V_{avg}$  = average volume of digesting sludge ( $m^3/day$ )

$V_2$  = volume of digested sludge produced daily( $m^3/day$ )

$t_d$  = Time required for digestion(days)

$t_s$  = Time provided for sludge storage(days)

- The sludge volume normally occupies the bottom half of the digester, and the supernatant liquor occupies the upper half therefore the total digester volume,  $V_t$  ( $m^3$ ):

$$V_t = 2V_s$$

where  $V_t$  = total digester volume ( $m^3$ )



Thanks...

