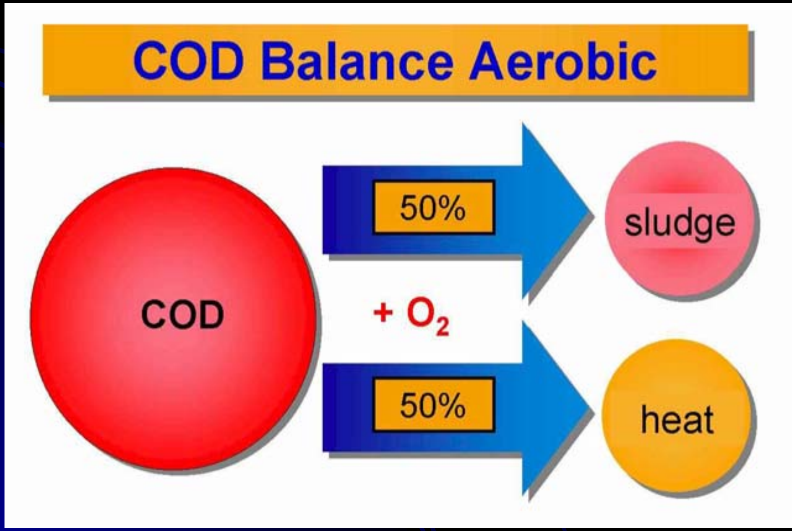
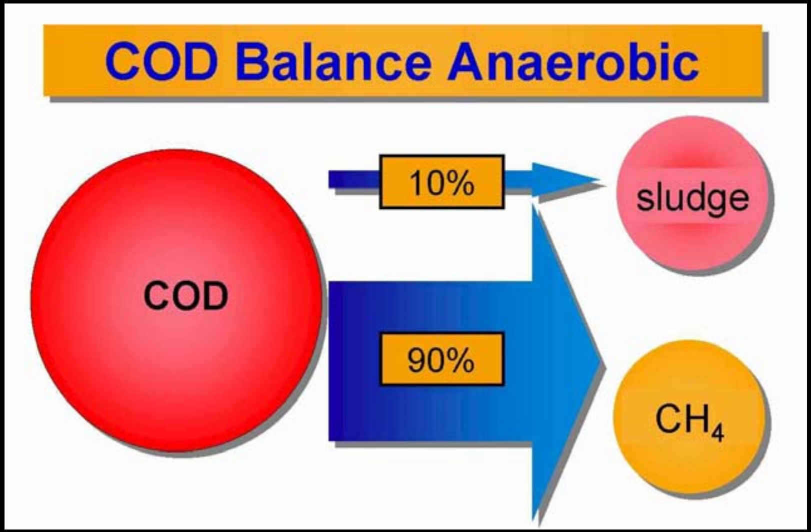
Anaerobic Treatment:

Advantages	Disadvantages
Low energy consumption	Sensitive and vulnerable process
Low nutrients/chemicals requirements	Odor problem
Great efficiency at high loading rate	Long period at start-up
Pathogen removal	Necessity of post treatment for standard
Producing energy gas	





Anaerobic Treatment: some kinetic parameters

	Doubling Time (days)	Cell Yield g VSS /g COD	Cell Activity g COD/ g VSS·d	Ks (mM)
Active Sludge (sugar) Aerobic Bacteria	0.030	0.40	57.8	0.25
Acidification (sugar) Fermentative Bacteria	0.125	0.14	39.6	ND
Acetogenesis (fatty acids) Acetogenic Bacteria	3.5	0.03	6.6	0.4
Methanogenesis Autotrophic (H_2)	0.5	0.07	19.6	0.004
Acetoclastic (acetate) Methanosarcina	1.5	0.04	11.6	5.0
Methanosaete	7.0	0.02	5.0	0.3

Anaerobic Treatment: History of Treatment

- **Originally: Slurry Digestion**

  Manures, Sludge

- **60 to 80's: Agro-industrial Effluents**

  Brewery, Distillery, Food Processing

- **80 to 90's: Pulp/Paper Effluents**

  Condensates, (C)TMP, Bleach

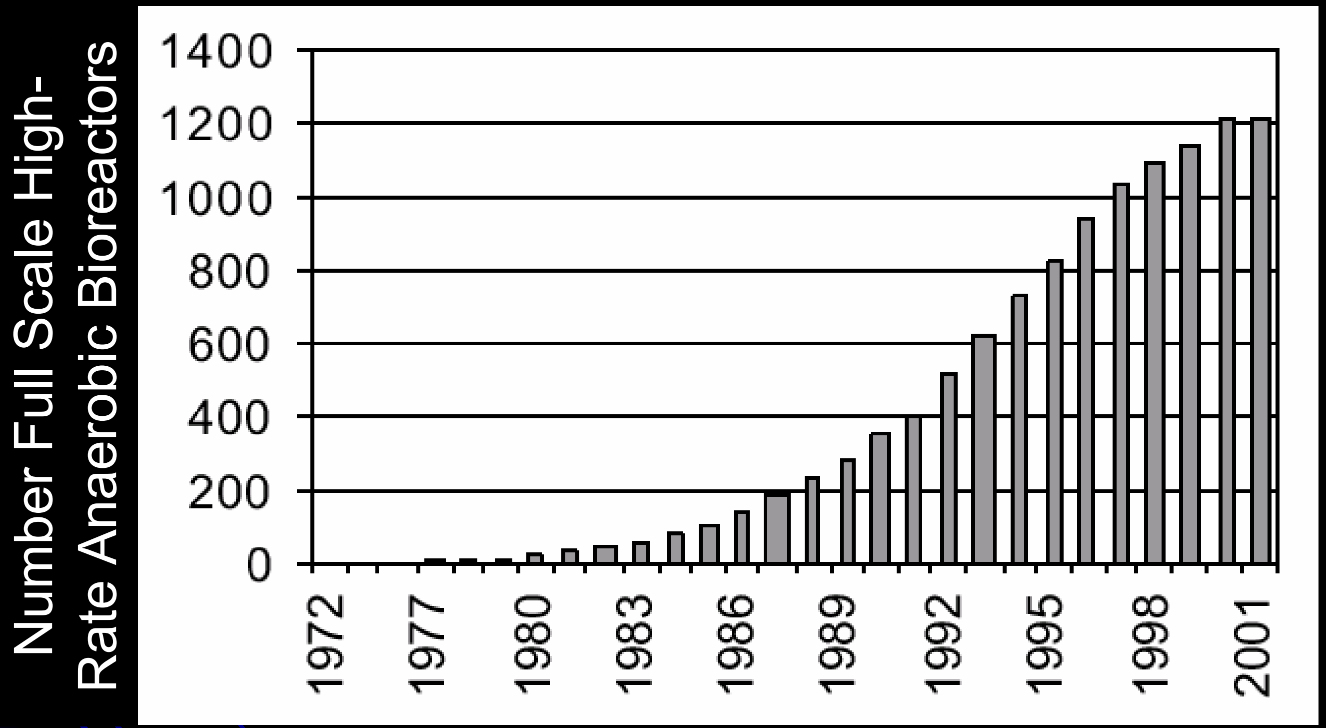
- **90's: Chemical/Petrochemical Effluents**

  Terephthalate, phenols

- **90 to 00's: Anaerobic Bioremediation**

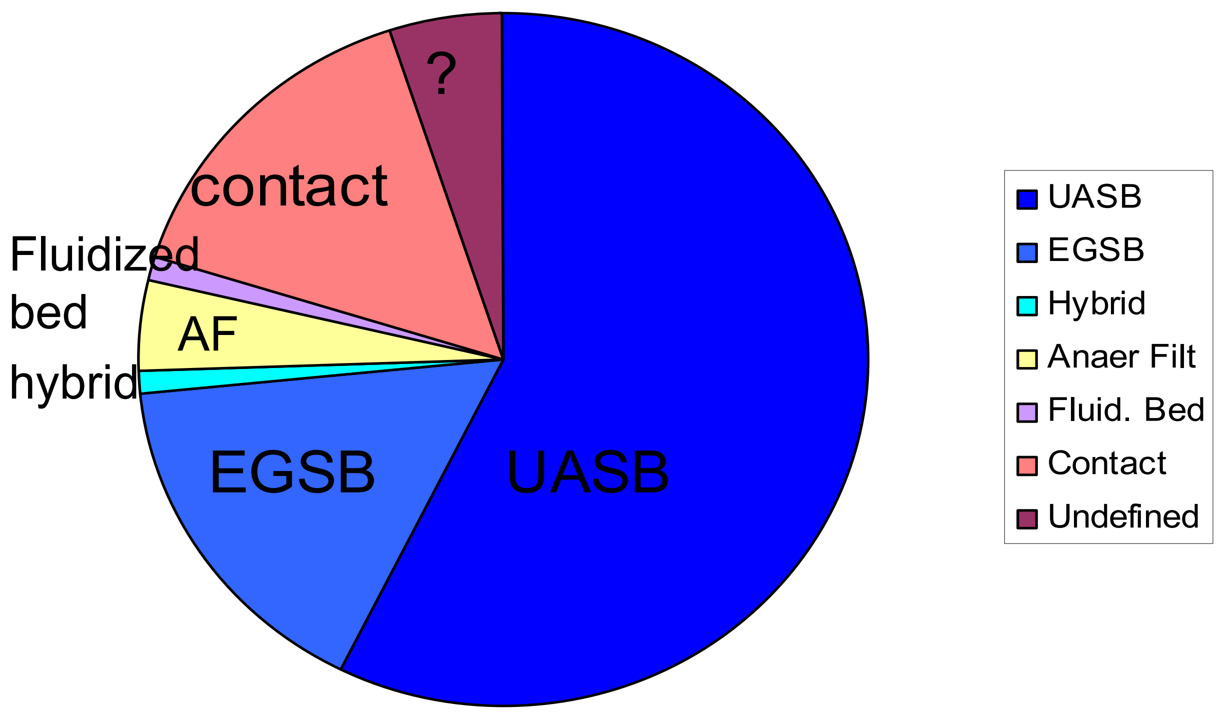
  PCE, BTEX

Anaerobic Treatment: History of Treatment



Cumulative number of high rate anaerobic treatment plants for industrial applications

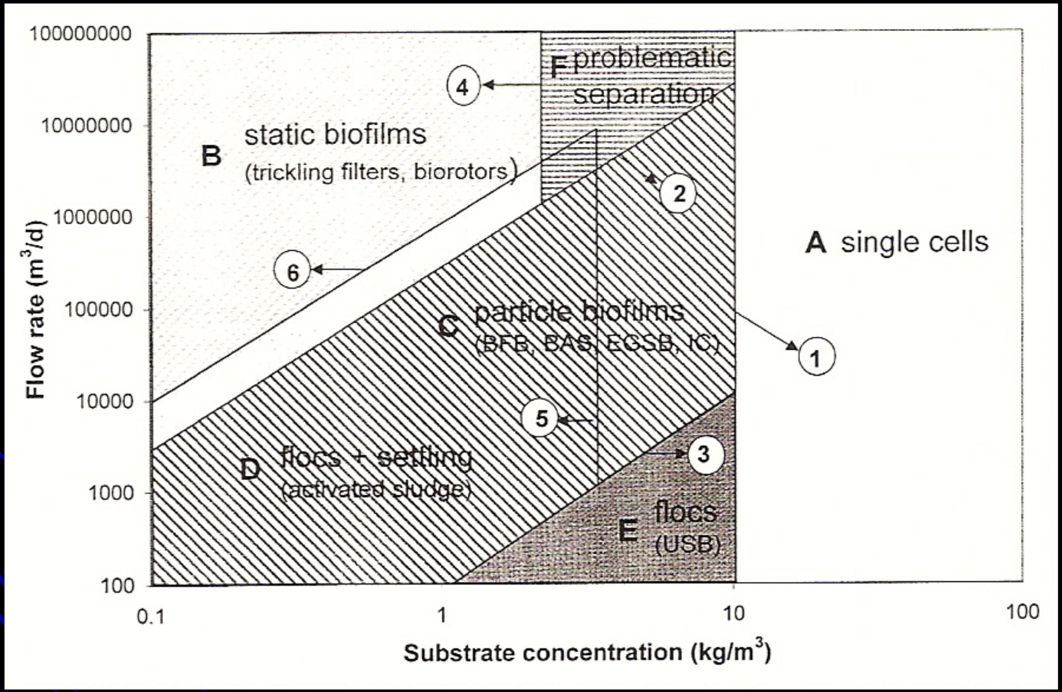
Anaerobic Treatment: Market share



UASB + EGSB = 72%

Granulation:

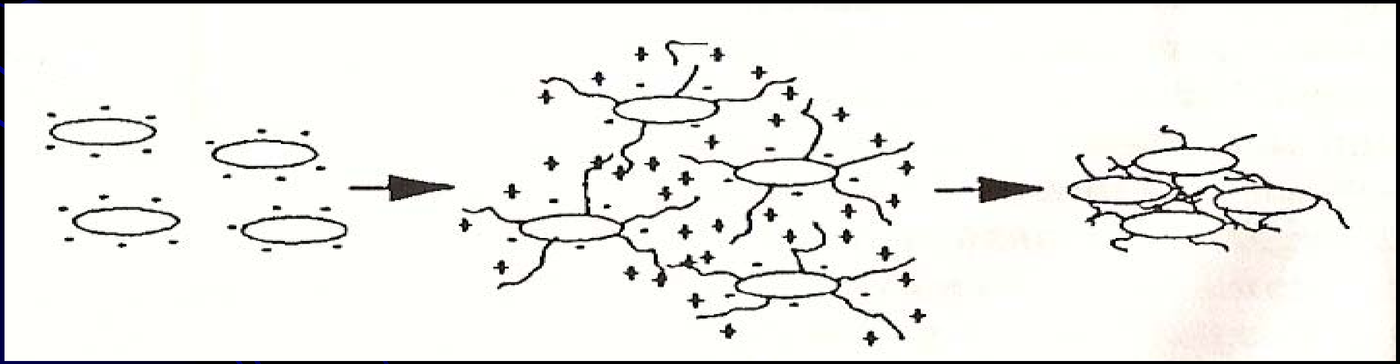
- Complex and not clearly understood yet.
- Affected by many factors such as characteristics of microorganisms, growth rate of organisms, and death & decay rate of the organisms in granules.



Concentration-flow rate diagram for sludge granulation

Granulation: Extracellular Polymer Substrates

- Because of negative charge of cell, EPS content and surface charge of substrate are very important factors to form granules based on the Derjaguin-Landau-Verwey-Overbeek (DLVO) theory in a UASB reactor.
- Dispersed bacteria are negatively charged. So, electrostatic repulsion between cells. The production of EPS can change the surface charge of bacteria, resulting in aggregation.
- The amount of EPS is affected by the condition. The concentration of EPS is lower in thermophilically grown granules compared to mesophilcially grown.

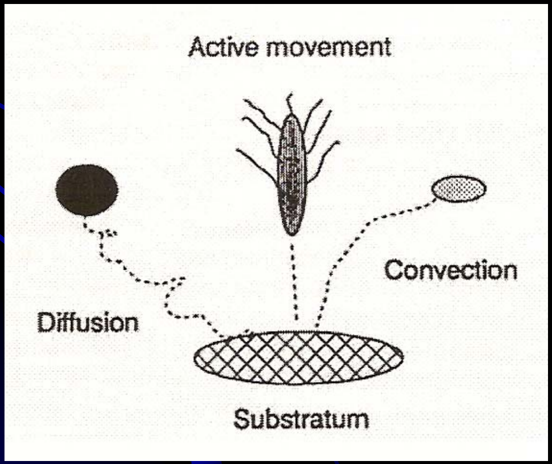


The role of surface charge and production of EPS in the development of granule

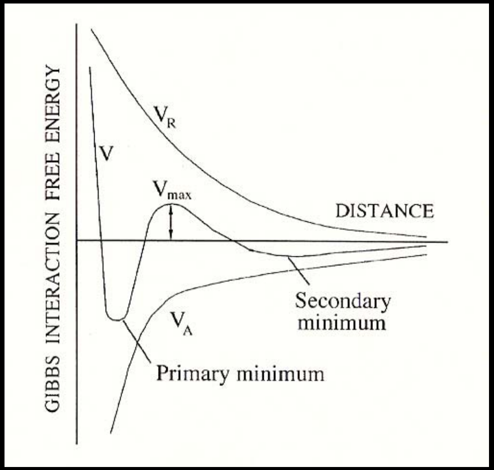
Granulation: Granulation process

Granulation process is not clear understood yet. The four steps of concept for granulation are as follow;

- First, transporting of cell to the surface of an uncolonized inert material or other cells.
- Second, initial reversible adsorption to the substratum by physicochemical force.
- Third, Irreversible adhesion of cells to the substratum by microbial and/or polymers attaching cells to the substratum.
- Finally, multiplication of cells and development of granules.



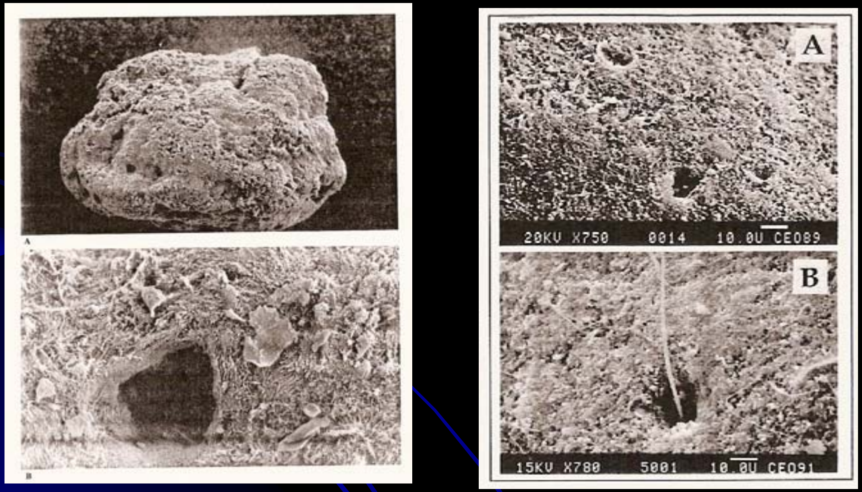
The different transport mechanisms for a cell to substratum



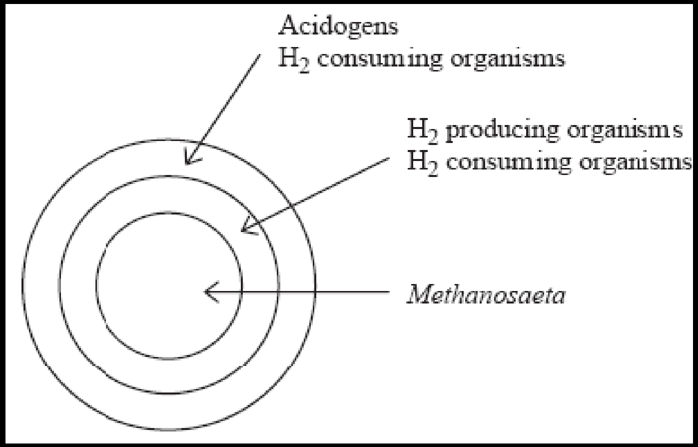
Total interaction Gibbs free energy

Granulation: structure of granules

- Cavities and holes on the granule surfaces may be channel for transporting of gases, substrate, or metabolite.
- Acidogenic and hydrogen consuming bacteria is located in the outer of granule, while most acetogenic bacteria is in the center of granule.



Granules and Cavities



Distribution of microorganisms

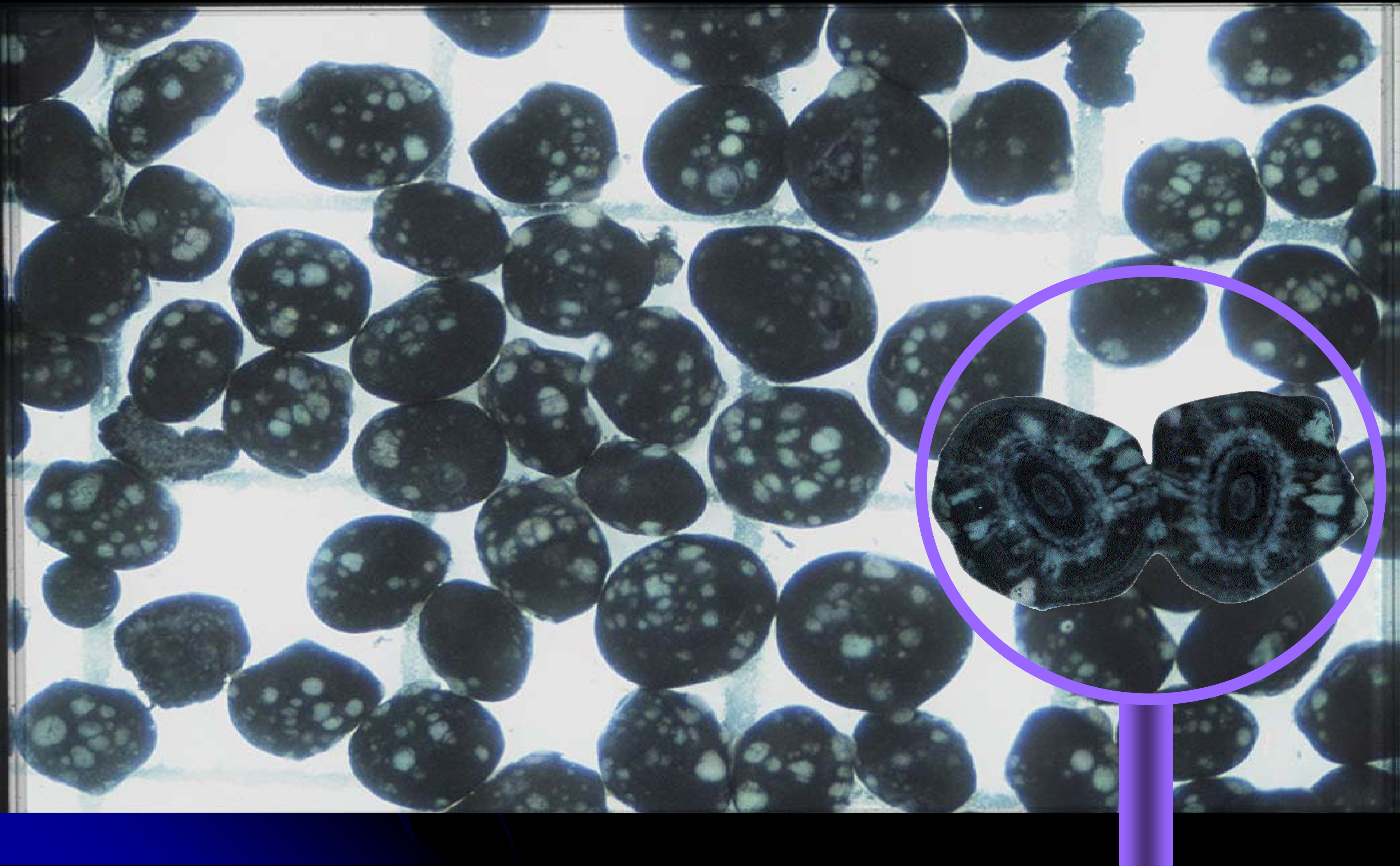
Granulation: structure of granules

- More substrate is complex, various microorganisms are observed in granule.

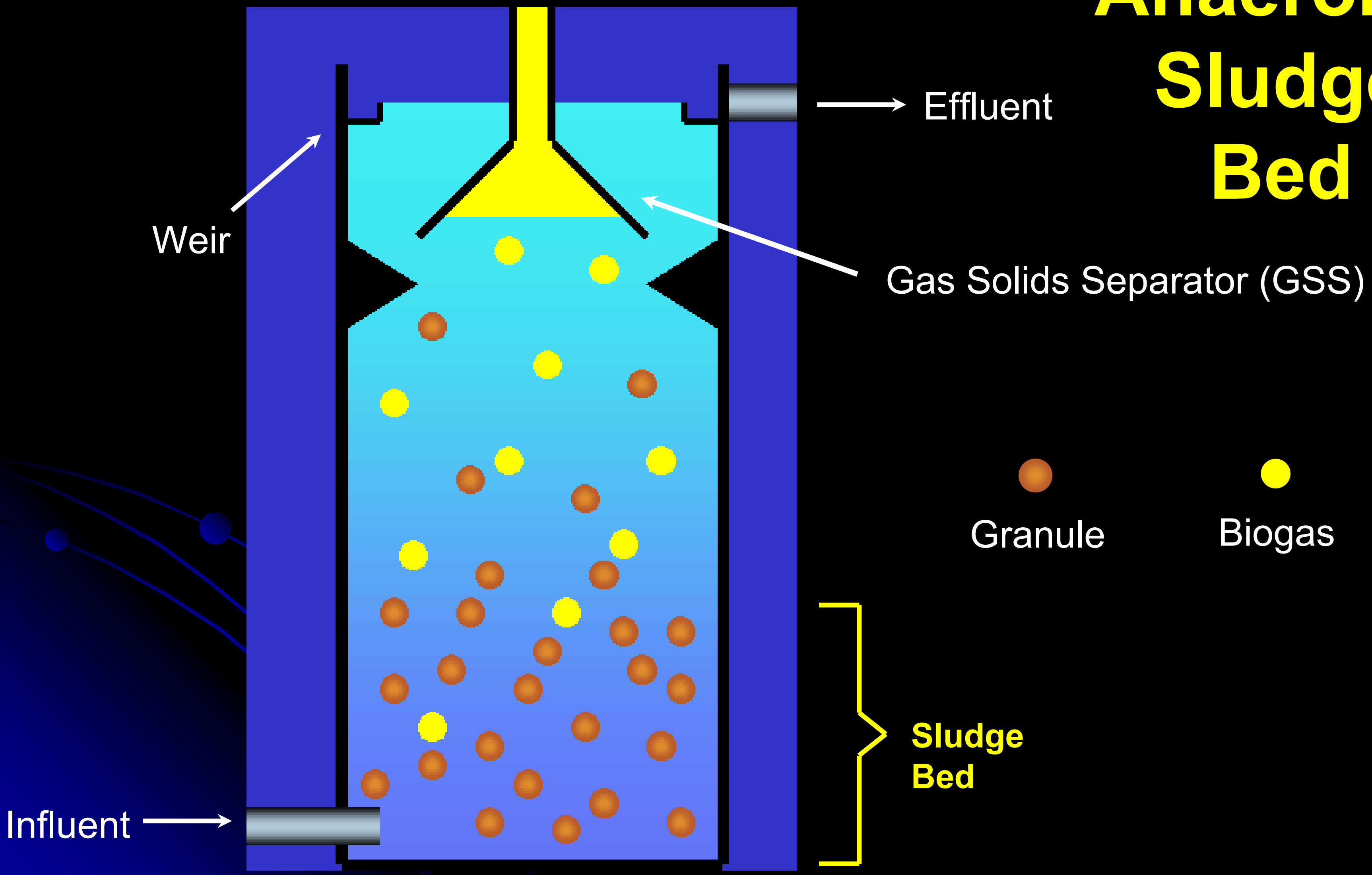
Acetate as Substrate
(*Methanosaeta*)

Sucrose as Substrate
(Mixed culture)

Granulation: structure of granules



Upflow Anaerobic Sludge Bed



Upflow Anaerobic Sludge Blanket (UASB):

Characteristics.

- Developed at Wageningen University in late 1970s
- Typical upflow velocity is 0.5 ~ 1.0 m/h, the height to depth is 0.2 ~ 0.5.
- Dividing gas into solids in terms of Gas/Liquid/Solids Separator (GSS) device
- 1215 full-scale reactors (UASB + EGSB) were operated in the world (2001)
- The flow is between completed mixed and plug flow

Application and development trends.

- aliphatic wastewater
- dairy wastewater
- degrading biocides
- domestic wastewater
- adding natural or artificial materials

Gatze Lettinga

Upflow Anaerobic Sludge Blanket (UASB):

UASB Design.

H (m) the height of tank can be calculated by: $H = H_s + H_{se}$

The height of sludge layer Hs is: $H_s = V \times HRT$

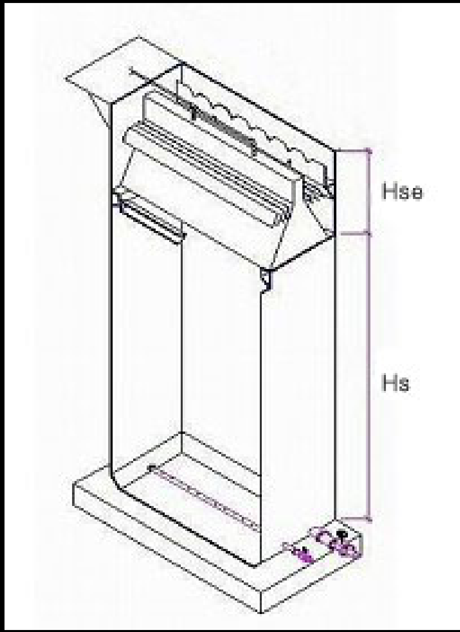
where H_s: the height of sludge layer area (main reactor),
H_{se}: the height of sedimentation area
V: Velocity of flow 0.6 to 0.9 (m/h)
HRT: Hydraulic retention time (h)

In general, the height of sludge layer will be chosen as follow:

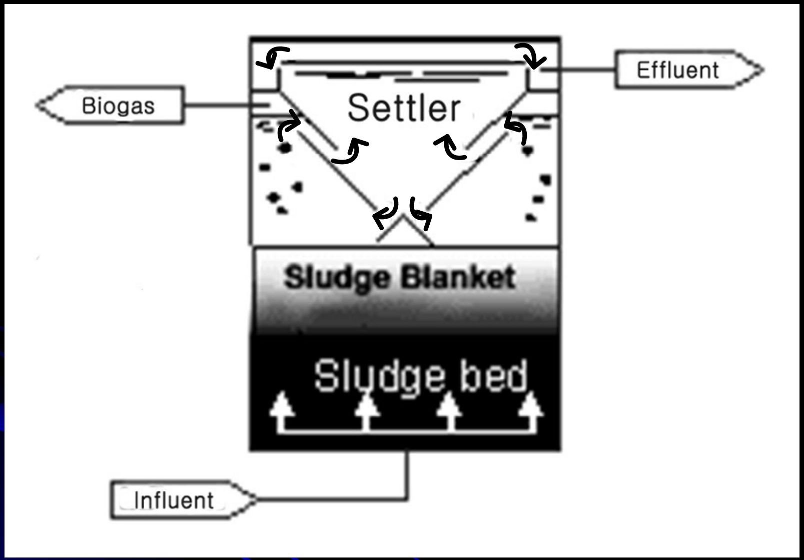
Sludge Layer Height Selection

COD input	Sludge layer height
< 3000 mg/L	3 ~ 5 m
> 3000 mg/L	5 ~ 7 m

Note: Sludge layer is longer than sludge bed layer

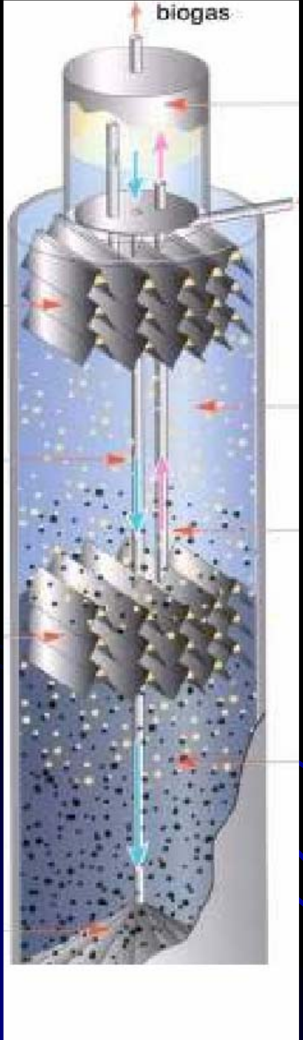


UASB (Biothane®)



The Netherlands

UASB - IC

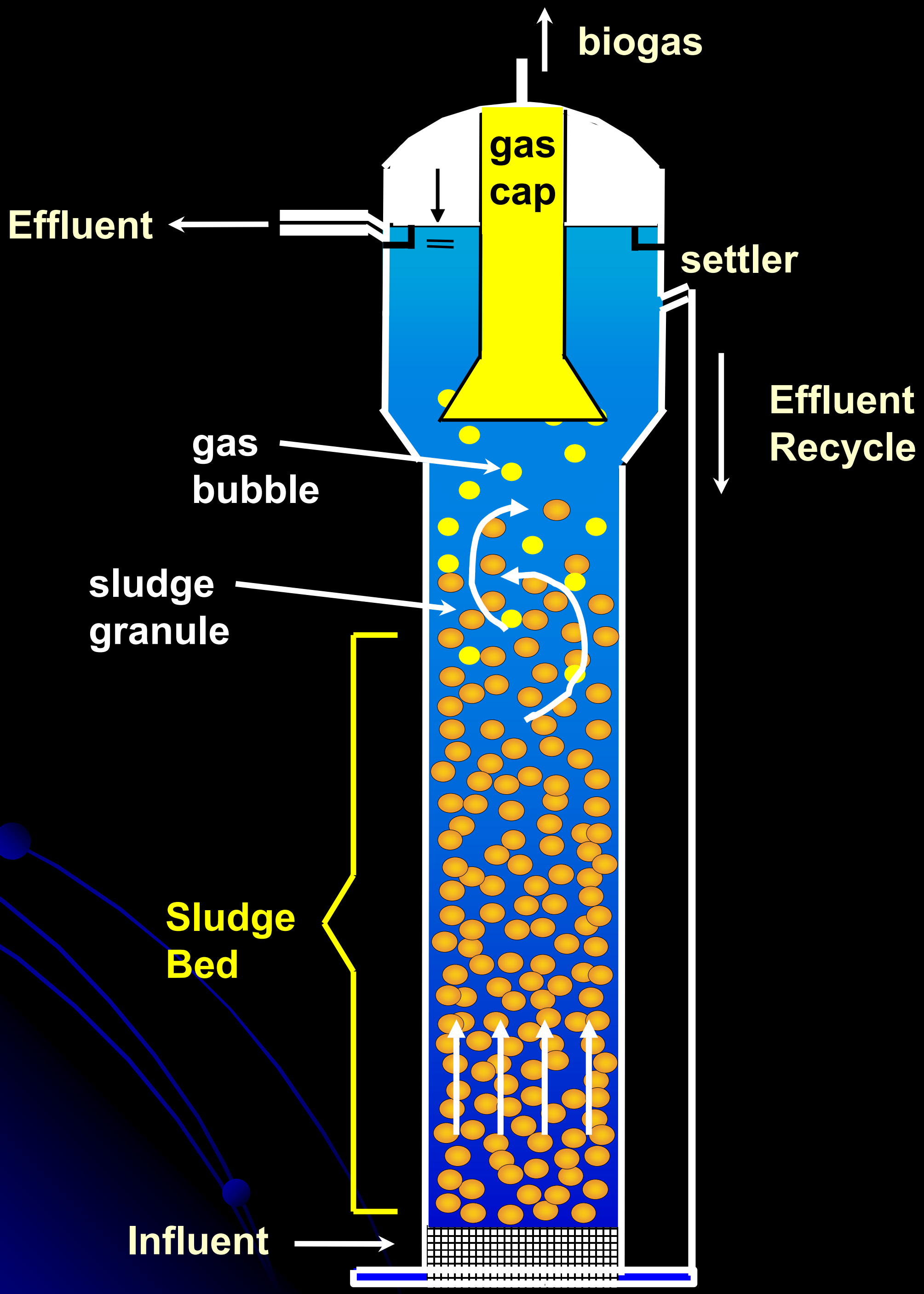


Brewery (Switzerland), 20 m height

UASB - IC

Kraft Paper Mill Foul Condensates, Alabama

Expended Granule Sludge Bed



Expended Granule Sludge Blanket (EGSB):

Characteristics.

- Typical upflow velocity is higher than 6.0 m/h, the height to depth is 4.0 ~ 5.0.
- Enable granules to mix with wastewater enough in the EGSB
- Suitable for very high-strength wastewater (30 kg COD/m^3·day) or low-strength water (<1000 mg COD/L), especially cold temperature
- The flow is expected between completed mixed and dispersed plug flow.

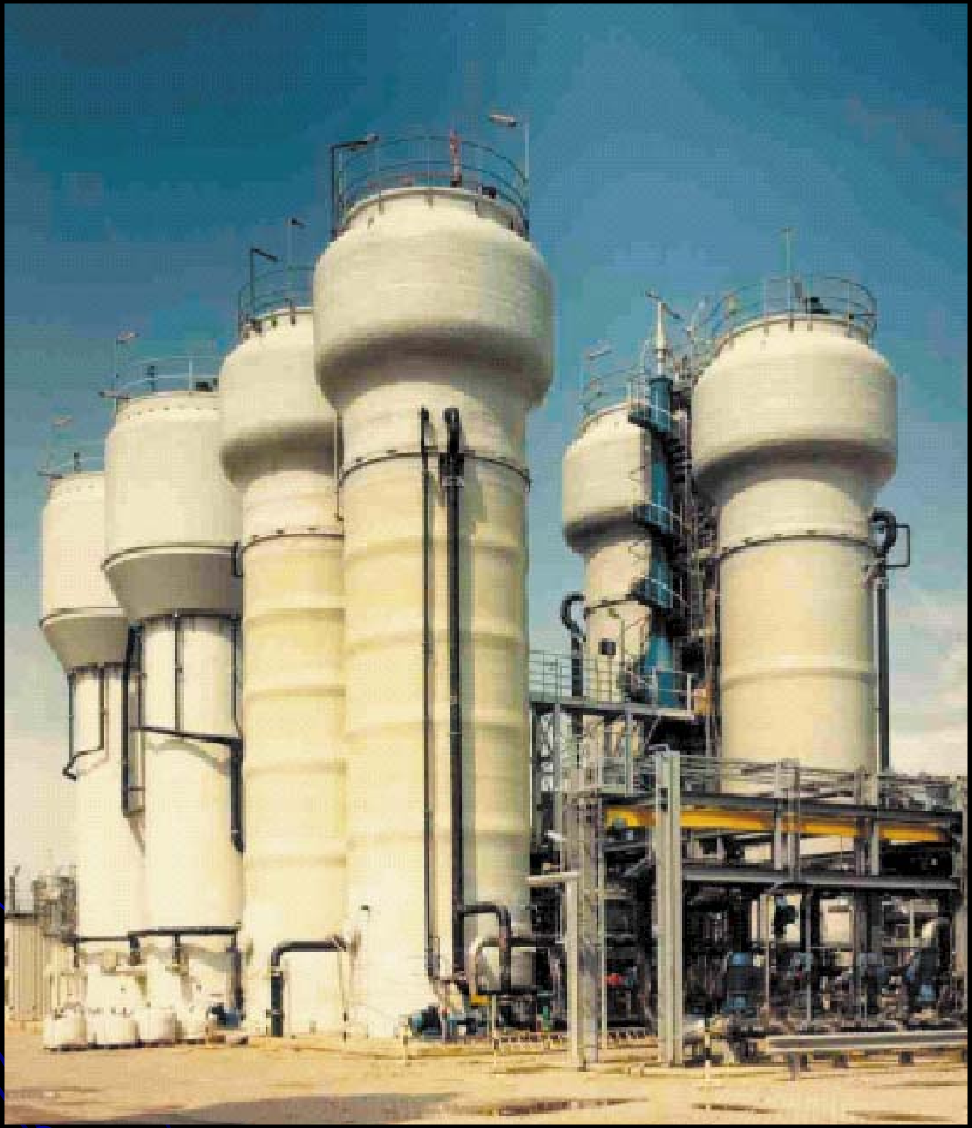
Besides, it depends on the recycle ratio.

Application and development trends.

- slaughterhouse wastewater
- dairy wastewater
- ANAMMOX process application
- domestic wastewater
- dye wastewater

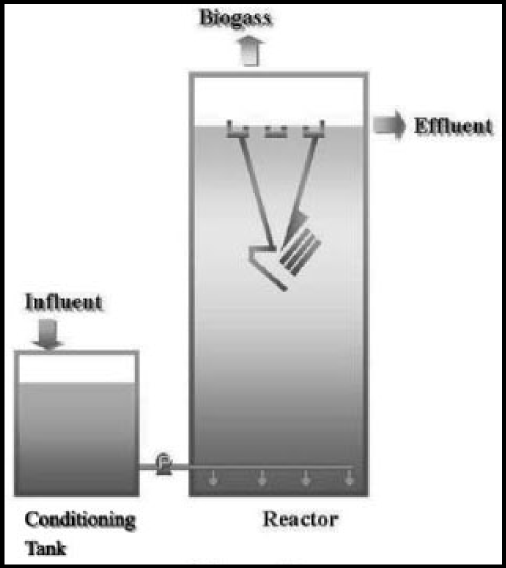
Gatze Lettinga

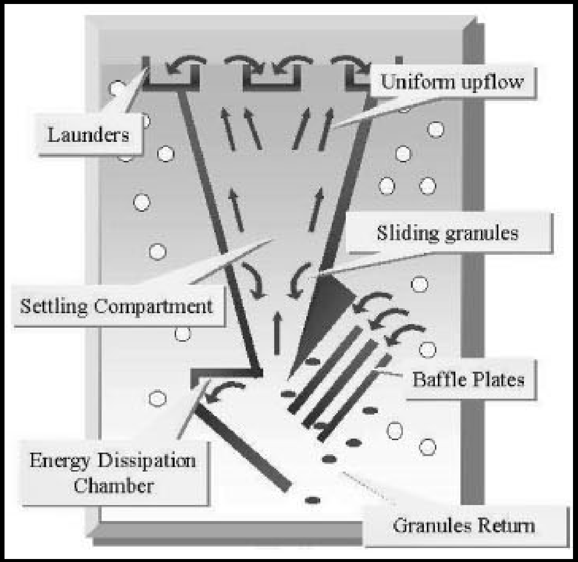
EGSB



The Netherlands - Gist Brocades (yeast, pharmaceuticals)

EGSB (Biobed®)





Citrus Plant in the Netherlands

Chemical installation in Turkey

Comparisons between UASB and EGSB:

Comparison between Biothane® UASB and Biobed® EGSB.

Comparison between the main characteristics parameters of Biothane® UASB and Biobed® EGSB

	Biothane® UASB	Biobed® EGSB
Loading (kg COD/m^3·day)	10	30
Height (m)	5.5 ~ 6.5	12 ~ 18
Toxic	+/-	++
Components		
V_{liquid} Settler (m/h)	1.0	10
V_{liquid} Reactor (m/h)	<1.0	<6.0
V_{gas} Reactor (m/h)	<1.0	<7.0

- Biobed® EGSB: formaldehyde producing factory

  (COD & methanol removal efficiency: 99%)

Comparisons between UASB and EGSB:

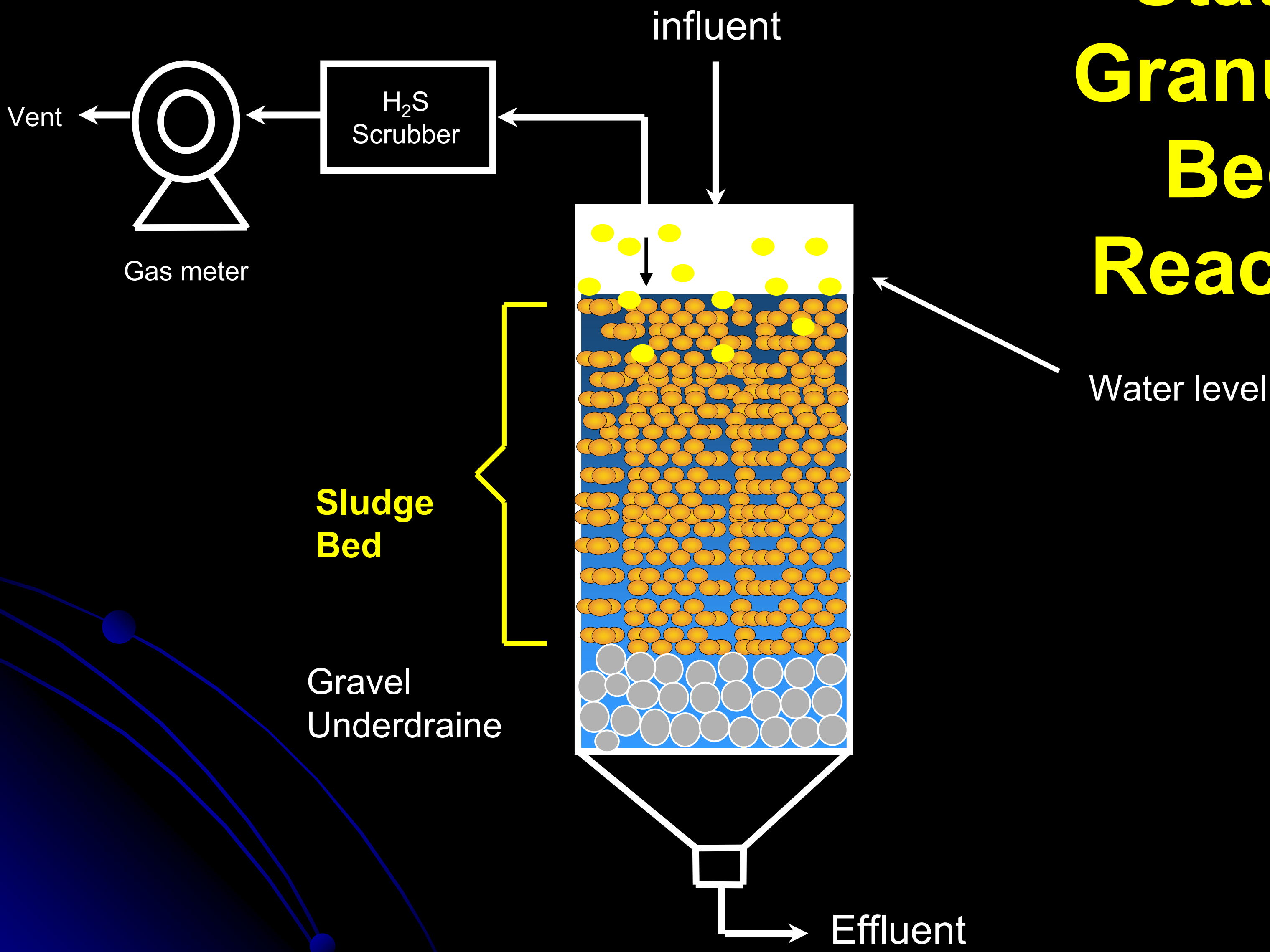
Other research results.

- Granule sizes are so similar between UASB and EGSB with various strength.
- Removal efficiencies also are not hard to differentiate (good results).
- Even sludge activity and sludge ash content is are the same.

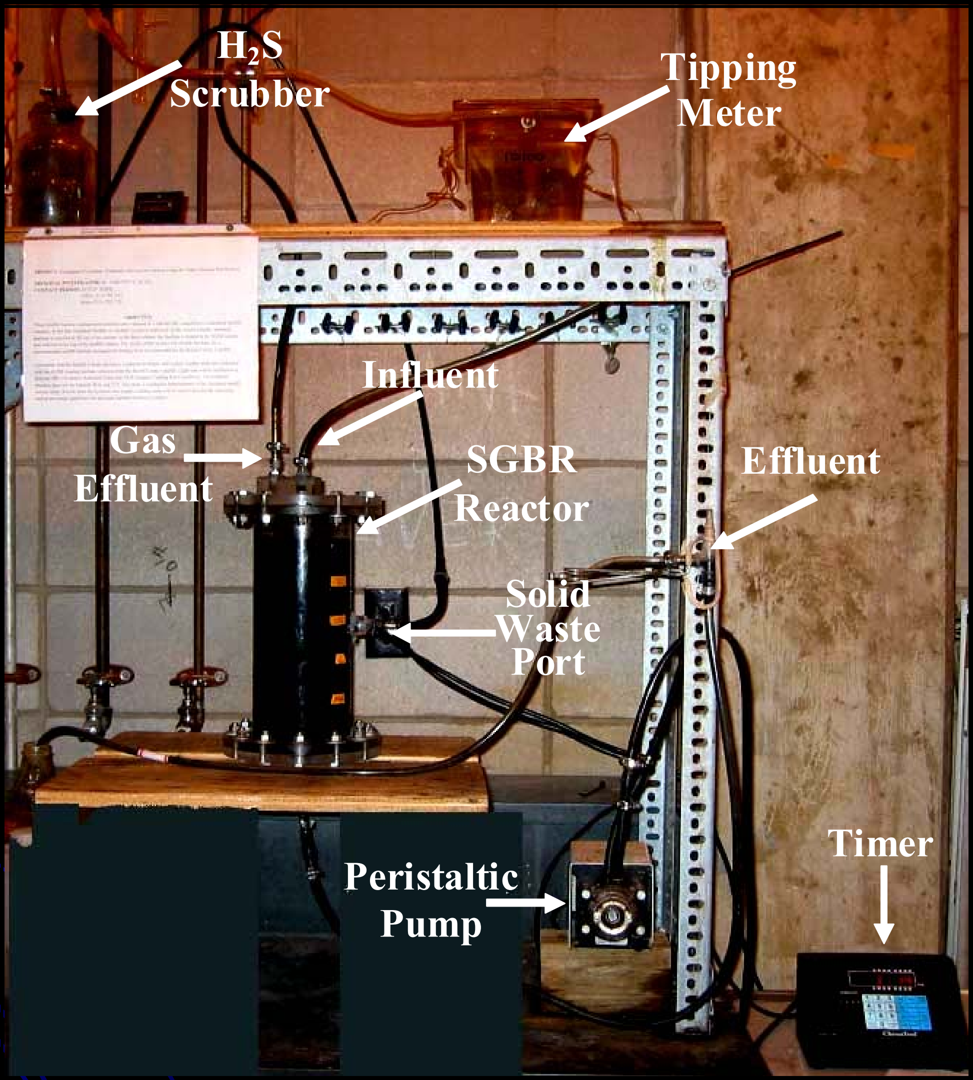
In conclusion,

- The UASB is designed up to 10 ~ 20 $kg/m^3 \cdot d$ high-strength organic wastewater.
- The EGSB is able to treat high-strength organic wastewater up to (20 ~ 30 $kg/m^3 \cdot d$) as well as low strength wastewater.
- Especially, the EGSB is suitable for treating domestic wastewater without heat.
- The EGSB shows great COD removal efficiency and high biogas production in psychrophilic condition.

Static Granular Bed Reactor



SGBR



SGBR Pilot Unit – Lab. test

SGBR

SGBR Pilot Unit – Hormel Foods

Static Granular Bed Reactor (SGBR):

Characteristics.

- Innovated at IOWA State University ('2000)
- very simple and no need power without feeding
- performance is better at (height to width = 7) than at (height to width = 2)
- good for low to mid-strength wastewater treatment
- long SRT (greater than 300 days)

Application and development trends.

- slaughterhouse wastewater
- leachates management
- non-fat day milk wastewater
- high-strength sulfate stream
- domestic wastewater

Timothy Ellis

Static Granular Bed Reactor (SGBR):

Some operation results of the SGBR process for various wastewaters

Wastewater	HRT (hr)	Organic Loading Rate (kg COD/m^3·d)	COD Removal Efficiency (%)
Non-fat dry milk	5 ~ 36	0.7 ~ 4.8	91.7 ~ 97.3
Non-fat dry milk	5 ~ 36	0.7 ~ 4.0	93.9 ~ 96.6
Sucrose + non-fat dry milk	18 ~ 48	2.5 ~ 5.0	93.5 ~ 95.3
Slaughterhouse (lab.)	8 ~ 48	0.4 ~ 7.1	83.7 ~ 95.7
Slaughterhouse (pilot)	16 ~ 48	1.3 ~ 4.6	91.8 ~ 94.2
High sulfate waste stream	18	4.0	97.3
Domestic wastewater	12 ~ 48	0.08 ~ 0.8	56.5 ~ 81.6

Anaerobic Treatment: Most important market

- Breweries and beverage industry
- Distilleries and fermentation industry
- Food Industry
- Pulp and paper

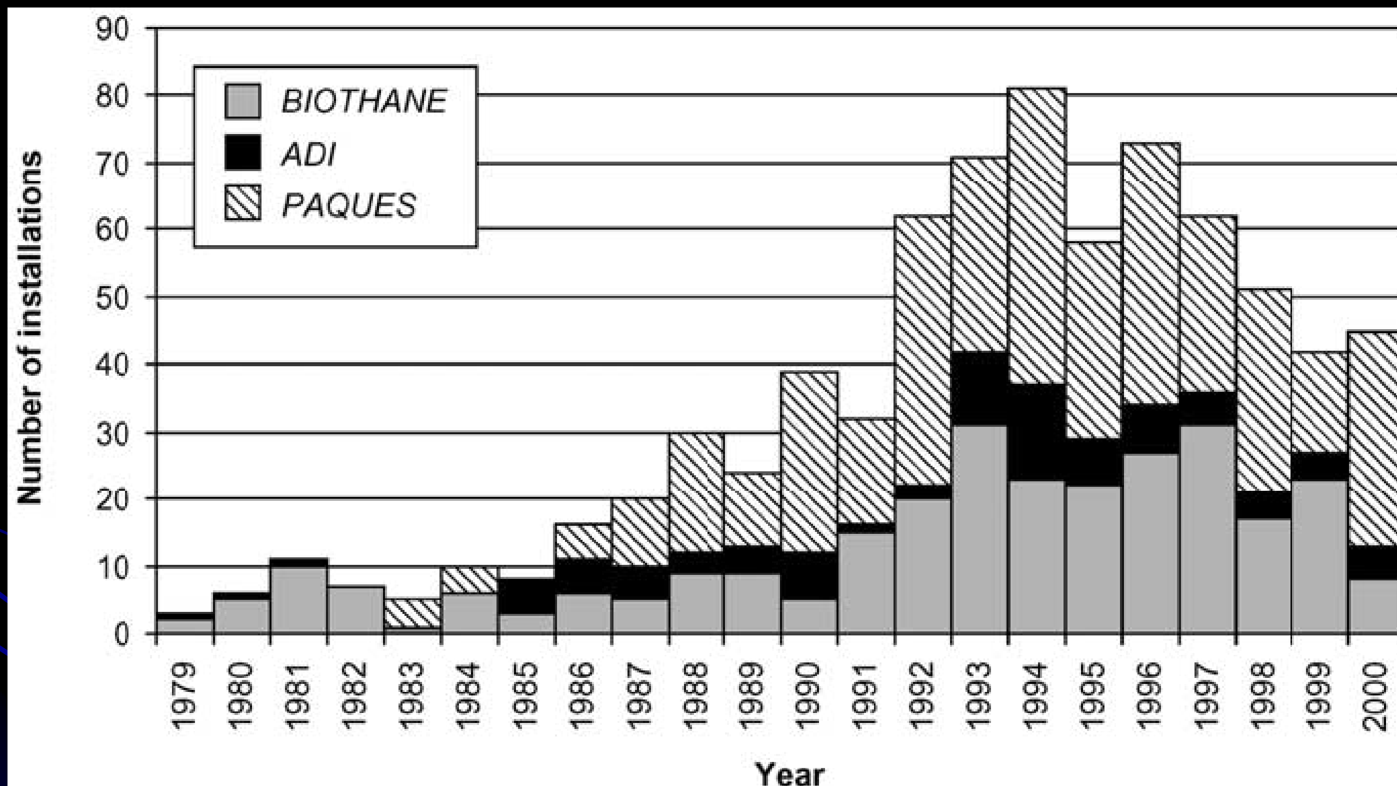
These four wastewater types account for 90% market

Anaerobic Treatment: Challenging market

- Chemical and Petrochemical
- Textile Industry Effluents
- Landfill Leachates
- Sulfate reduction coupled to sulfur removal
- Sulfate reduction coupled metal recovery

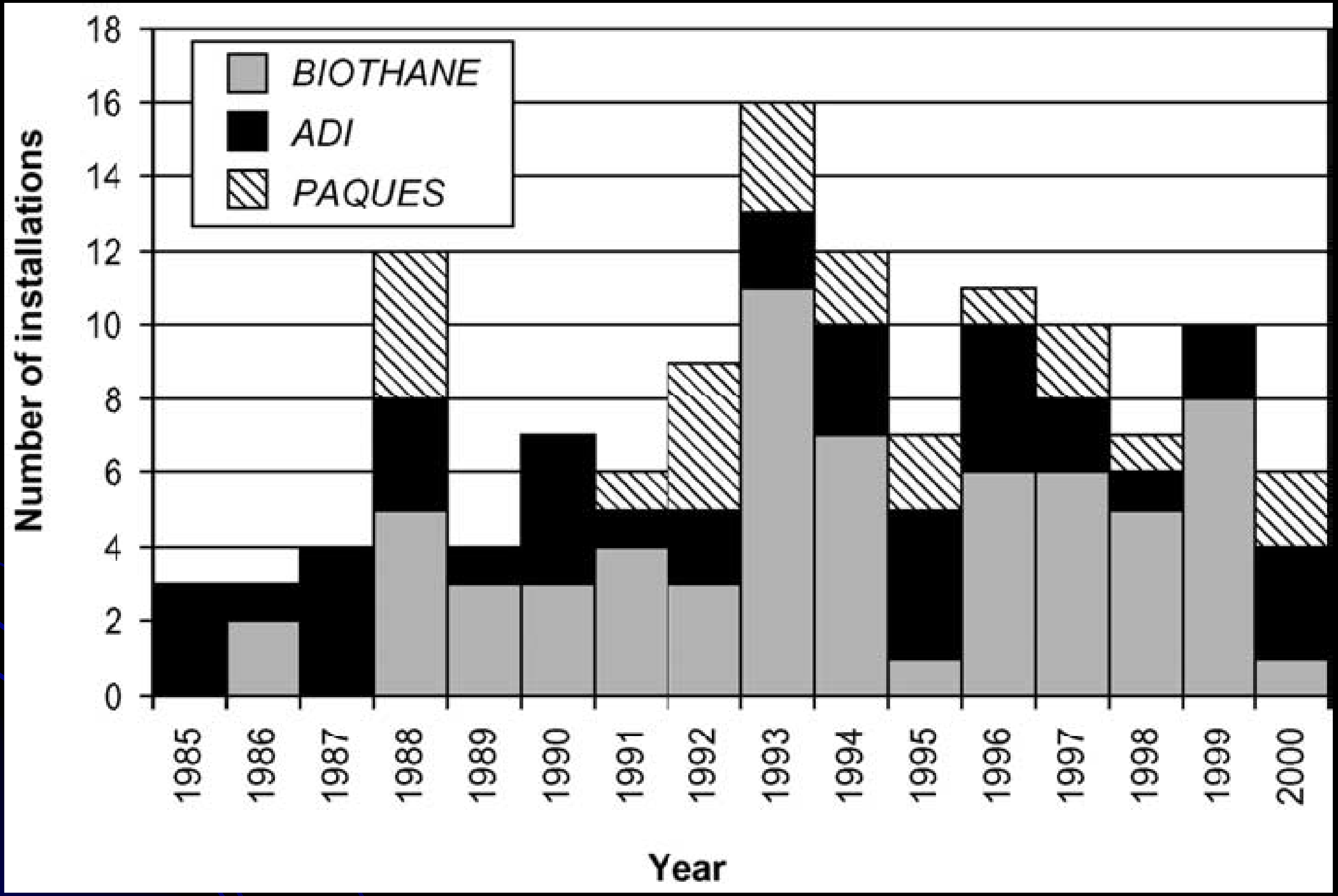
Thank You

Anaerobic Treatment: Market share



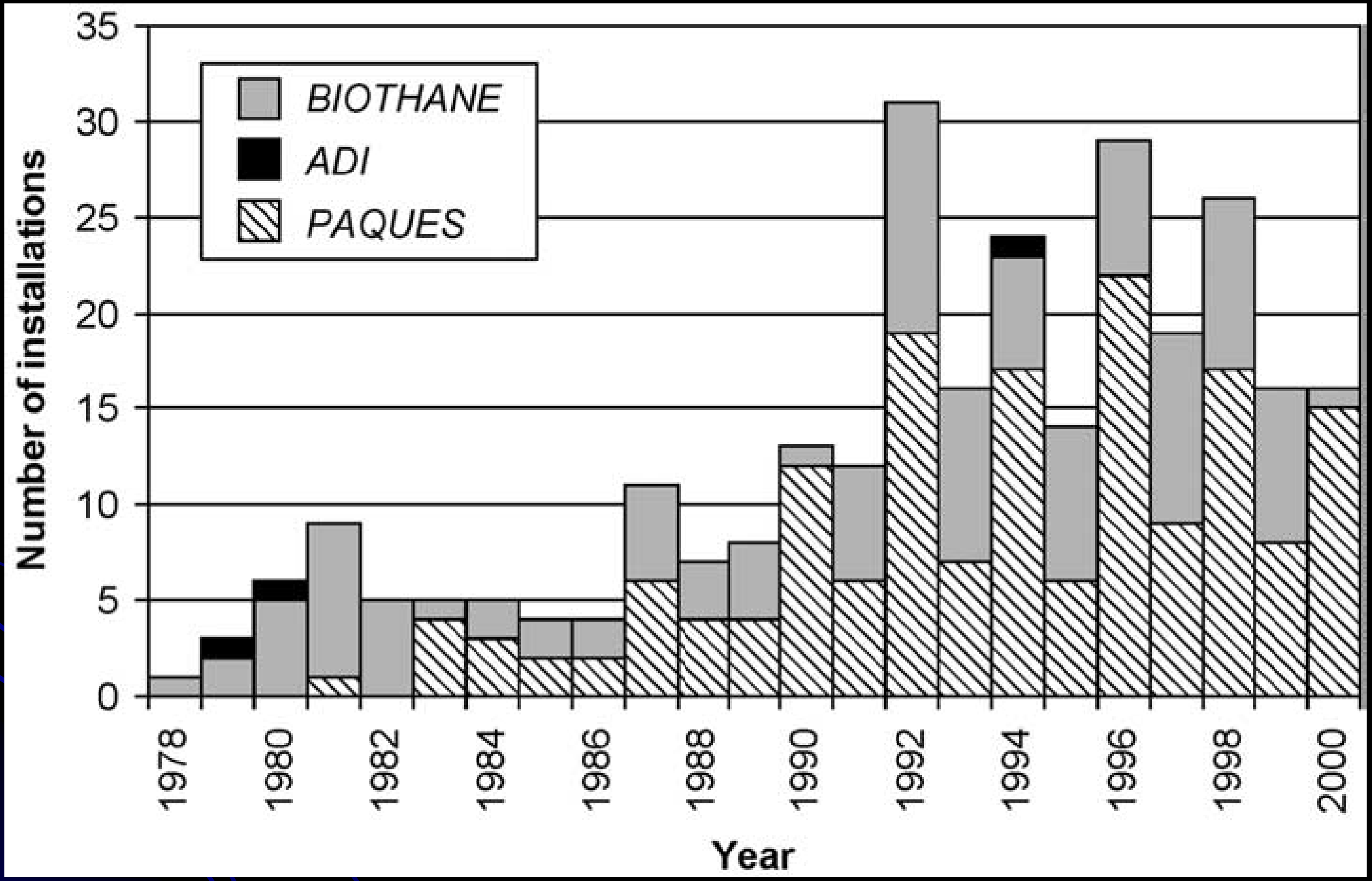
International installations of anaerobic treatment systems by the three major suppliers.

Anaerobic Treatment: Market share



North American installations of anaerobic treatment systems by the three major suppliers.

Anaerobic Treatment: Market share



European installations of anaerobic treatment systems by the three major suppliers.