Anaerobic Wastewater Treatment
UASB

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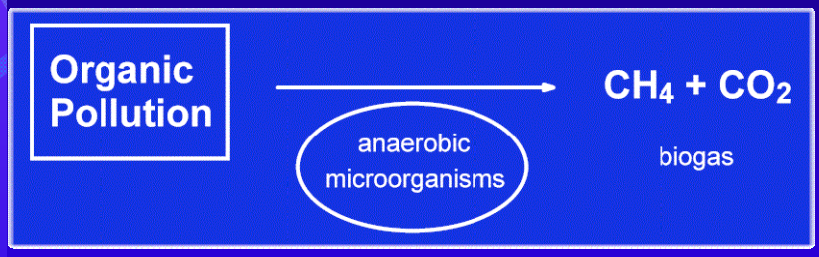
Maj 2020

What is Anaerobic Biodegradation?



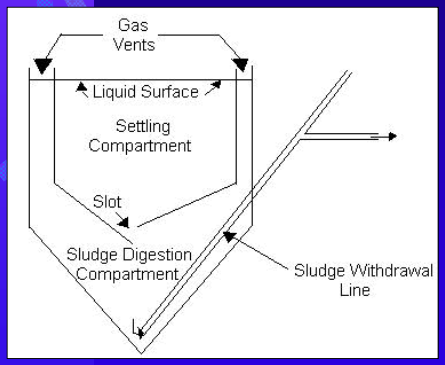
Marsh Gas

UASB

- Developed by Professor Gatze Lettinga (University of Wageningen, The Netherlands)
- They are really just the latest development of septic tanks:

  1. The septic tank (1885)
  2. The Imhoff tank (1906) →
  3. **UASBs (1977)** − see

Imhoff Tanks

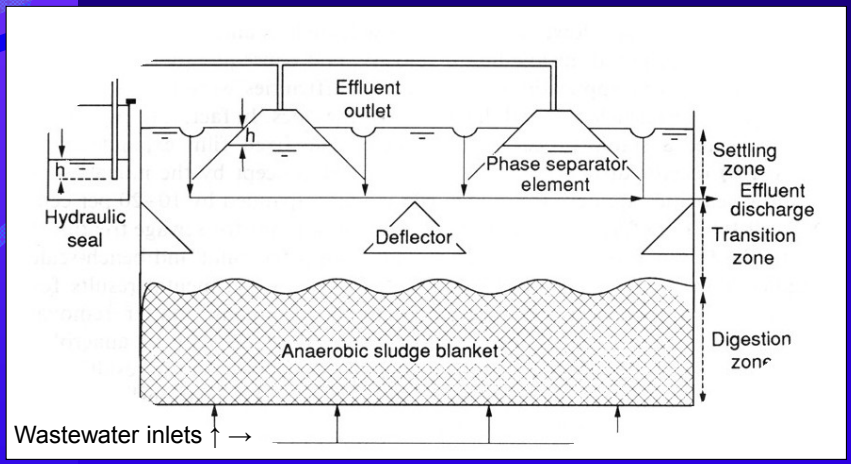


Separation of sedimentation and digestion zones

USA, 1936

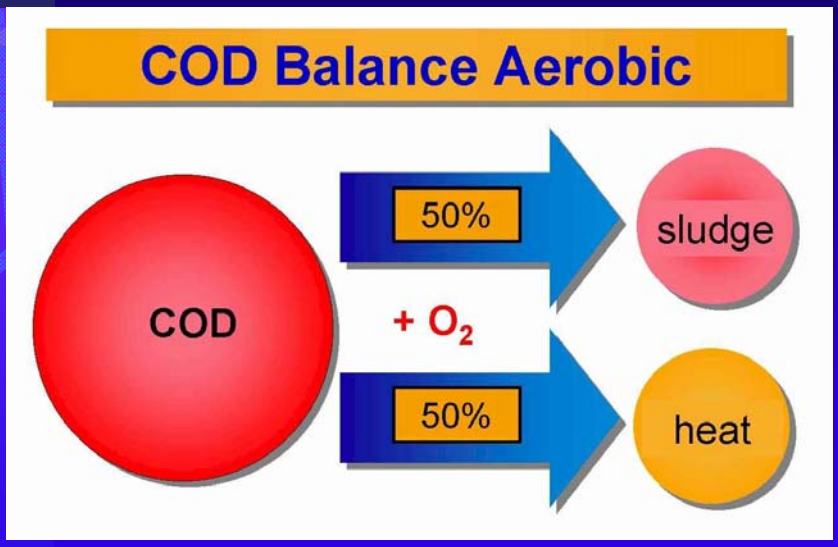
Italy, 2010

UASBs:
more efficient but much more complicated:

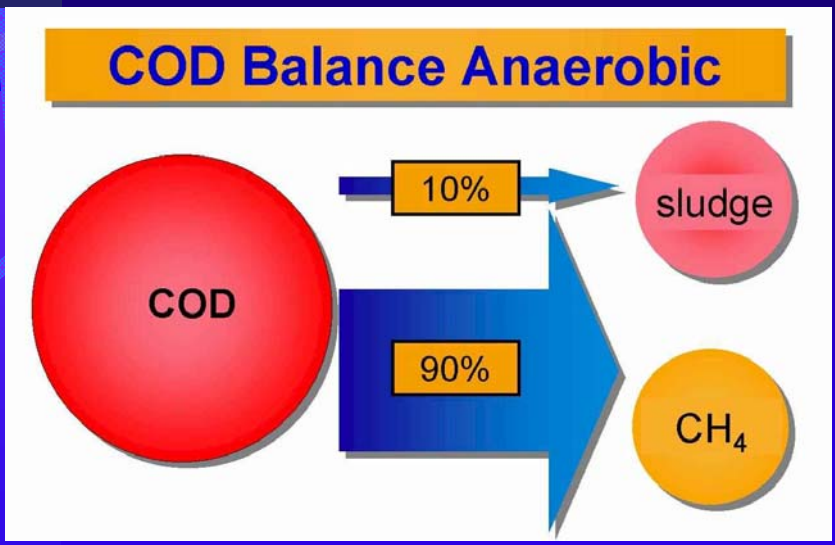


Screened wastewater inlets at base of reactor

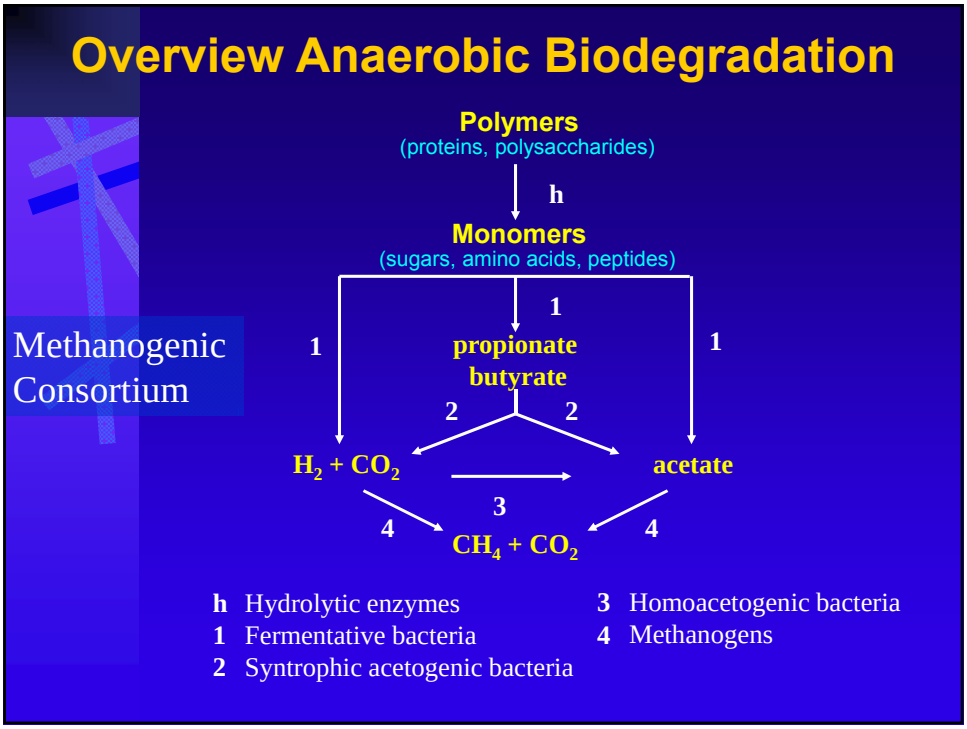
COD Balance Aerobic Biodegradation



COD Balance Anaerobic Biodegradation



Overview Anaerobic Biodegradation



h Hydrolytic enzymes
1 Fermentative bacteria
2 Syntrophic acetogenic bacteria
3 Homoacetogenic bacteria
4 Methanogens

Methanogenic Reactions

acetoclastic methanogenesis

$CH_3COOH \rightarrow CH_4 + CO_2$

acetate — methane — carbon dioxide

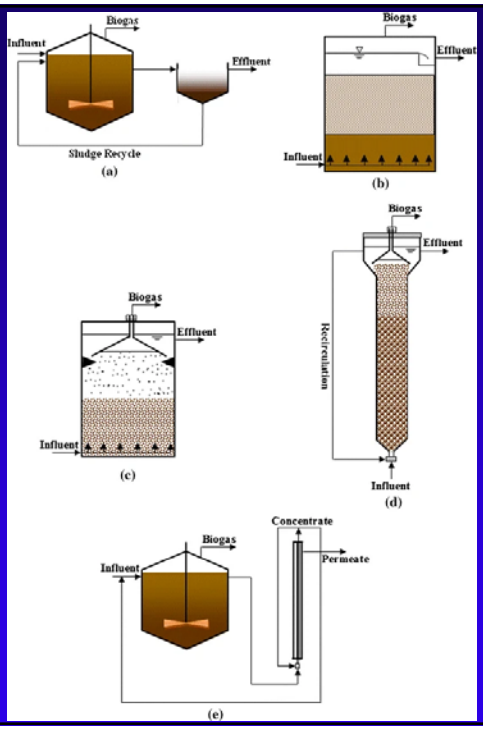
autotrophic methanogenesis

$CO_2 + H_2 \rightarrow CH_4$

carbon dioxide — hydrogen — methane

Kinetic Parameters Anaerobes

	Doubling Time days	Cell Yield g VSS g-1 COD	Cell Activity g COD g-1 VSS d-1	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 (H2)	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

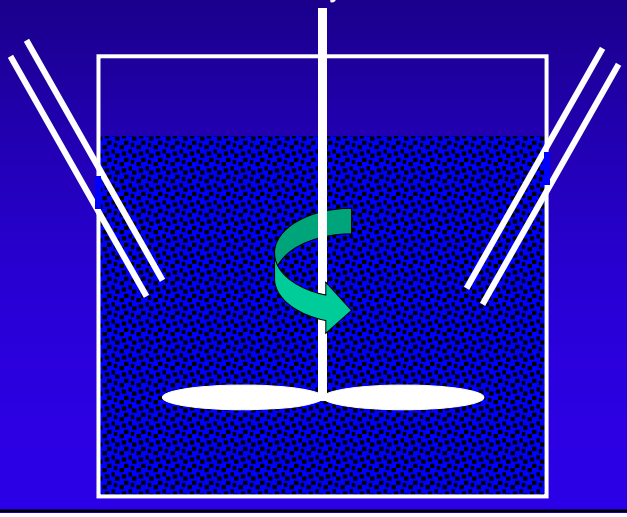


CSTR

Dilution Rate (1/HRT) Time < Growth Rate

Methanosaete (t_d =7 d), growth rate = ln(2)/t_d = 0.1 d^{-1}

so minimum HRT = 10 days

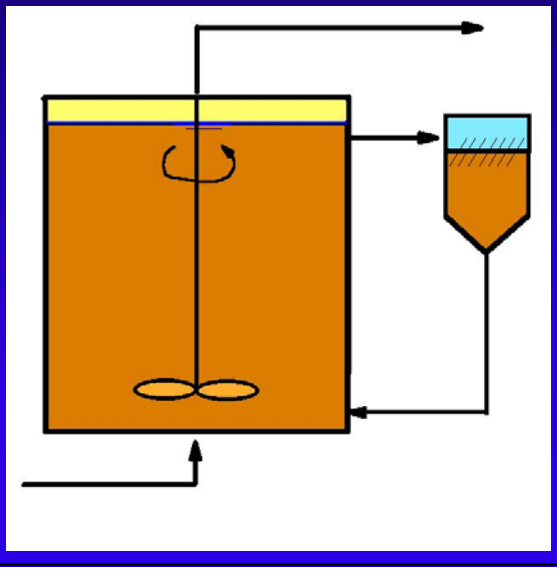


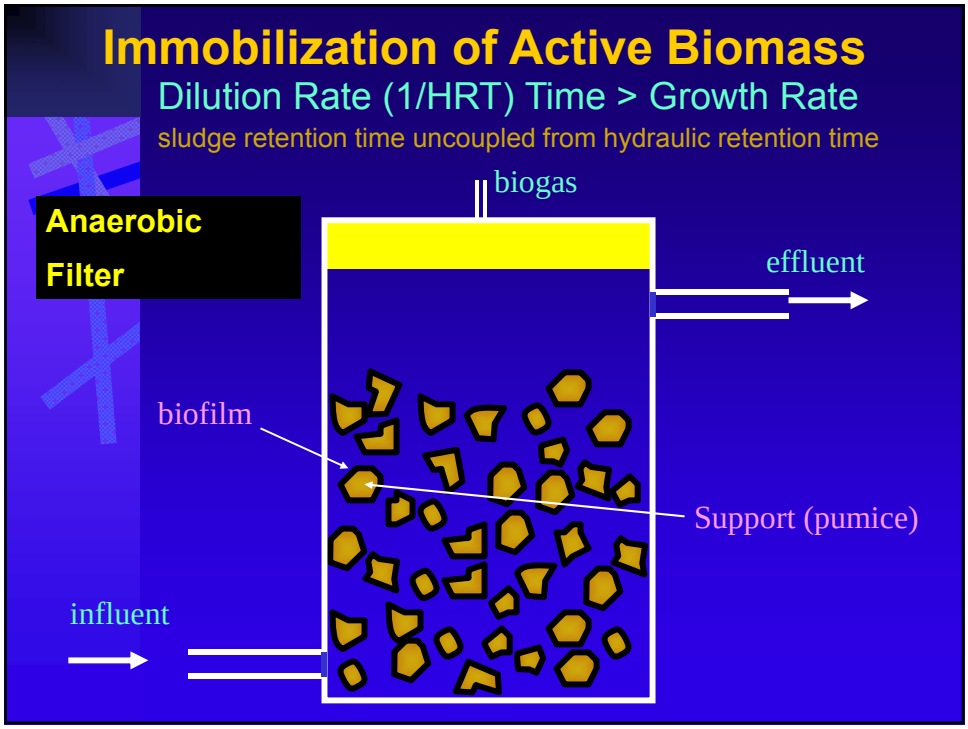
Recycle of Active Biomass

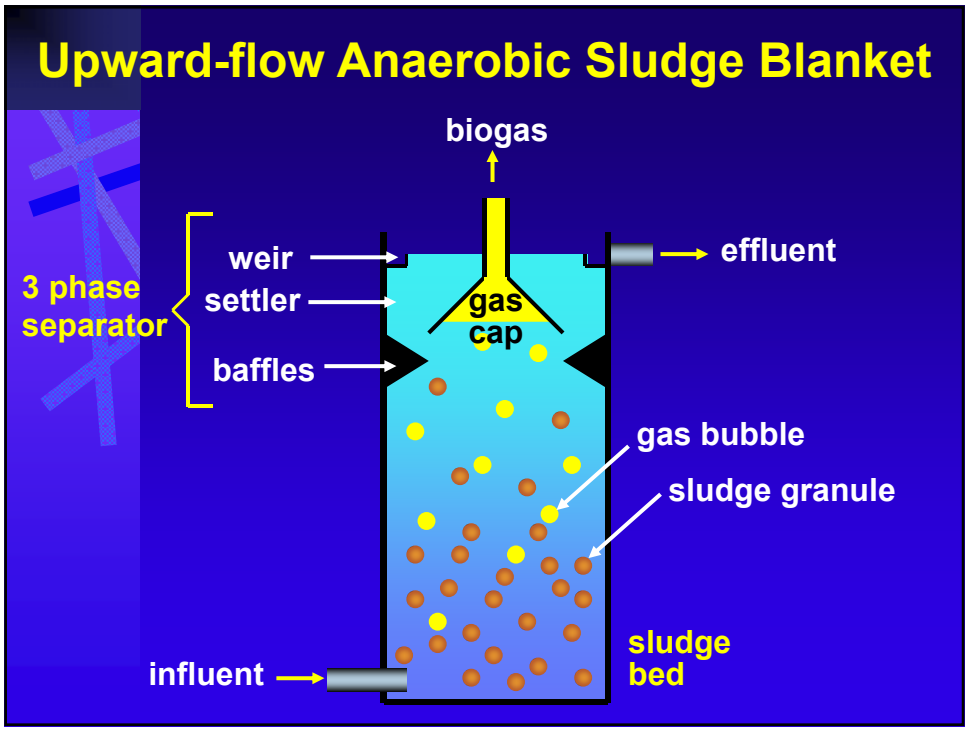
Dilution Rate (1/HRT) Time > Growth Rate

sludge retention time uncoupled from hydraulic retention time

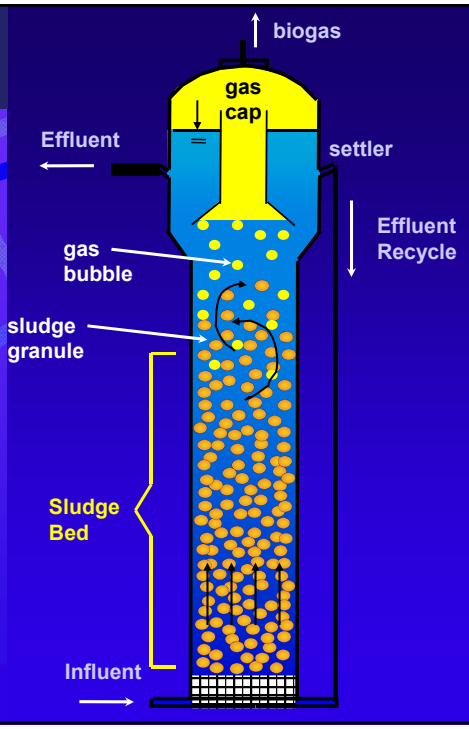
Contact Process




Immobilization of Active Biomass
Dilution Rate (1/HRT) Time > Growth Rate
sludge retention time uncoupled from hydraulic retention time
Anaerobic
Filter
biogas
effluent
biofilm
Support (pumice)
influent


Upward-flow Anaerobic Sludge Blanket
biogas
3 phase
separator
weir
settler
baffles
effluent
gas
cap
gas bubble
sludge granule
sludge
bed
influent

Expanded Granular Sludge Bed



Anaerobic Sludge Granules

Physical:

dense compact biofilms

high settleability (30-80 m/h)

high mechanical strength

Microbial:

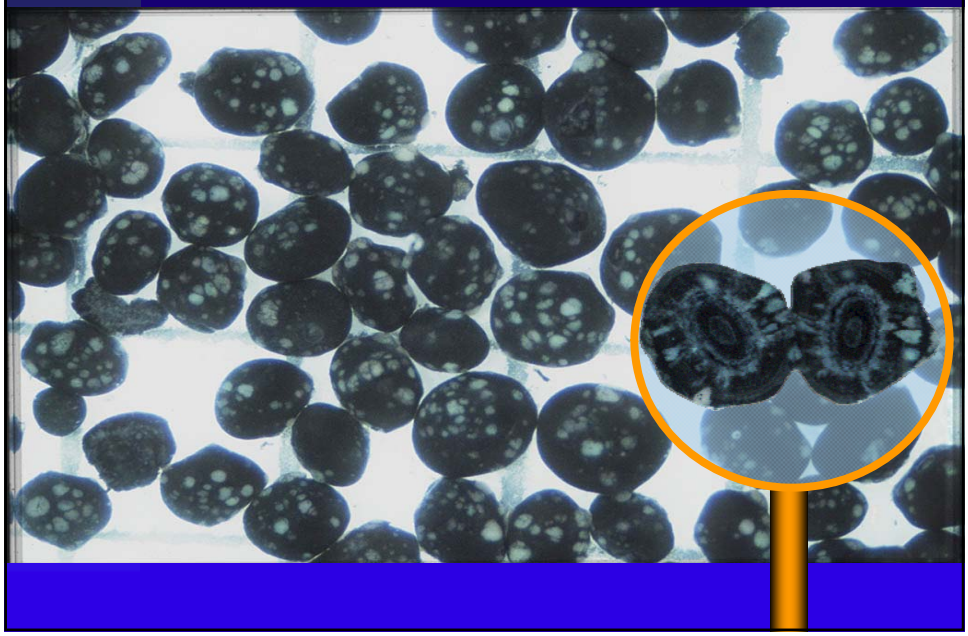
balanced microbial community

syntrophic partners closely associated

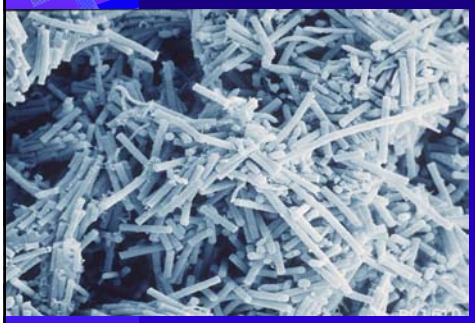
high methanogenic activity (0.5 to 2.0 g COD/g VSS.d)

protection from toxic shock

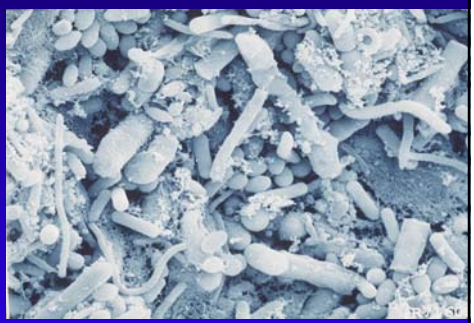
Anaerobic Sludge Granules (close up)



Anaerobic Sludge Granules (SEM)



Acetate as Substrate
(*Methanosaeta*)



Sucrose as Substrate
(mixed culture)

Anaerobic Sludge Granules (settling)

granular flocculent dispersed

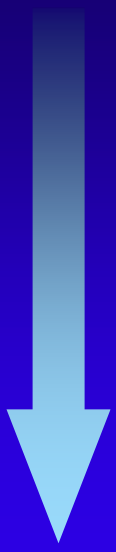
Design Loads Full Scale UASB & EGSB

reactor	n	average design load
UASB	682	10 kg COD/m^3.d
EGSB	198	20 kg COD/m^3.d

Removal Efficiency of Biodegradable COD 85 to >90%

History Anaerobic Treatment Technology

- **Originally: Slurry Digestion**
  Manures, Sludges
- **60 to 80's: Agroindustrial Effluents**
  Brewery, Distillery, Food Processing
- **80 to 90's: Pulp/Paper Effluents**
  Condensates, (C)TMP, Bleachery
- **90's: Chemical/Petrochem. Effluents**
  Terephthalate, phenols
- **90 to 00's: Anaerobic Bioremediation**
  PCE, BTEX

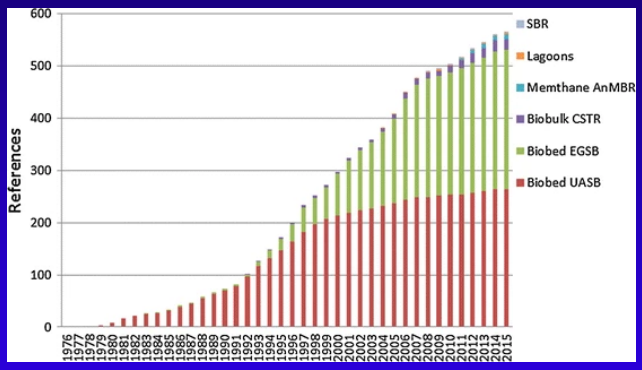


Most Important Markets for High Rate Anaerobic Treatment

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

These four wastewater types account for 87% market

Evolution of the market



Sales of anaerobic high rate reactors by Biothane-Veolia since the company's start-up (1976)

UASB Technology for Removal and Recovery of Metals

SO_4^{2-} + COD → HS^- + CO_2

sulfate | organic substrate | sulfate reducing bacteria | sulfide | carbon dioxide

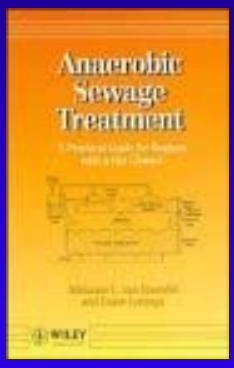
S^{2-} + M^{2+} → MS ↓

sulfide | heavy metal [*soluble*] | metal sulfide [*insoluble*]

UASB performance

- Lettinga's equation for COD removal:

$$R = 100(1 - \theta^{-0.68})$$



R = percentage COD removal

θ = retention time, hours

So, for θ = 8 h, R = 70%

❑ Temperature − ??

UASBs or Anaerobic Ponds?

❑ **UASBs**: retention time ~6−12 hours, but:

- constructed in reinforced concrete
- comparatively complex design

❑ **Anaerobic ponds**: retention time ~1−2 days

- simple to construct
- desludging less frequently needed

Removal of different compounds by anaerobic digestion

Compound	Removal
Organic matter	High level of removal (but not good enough for direct discharge to surface waters; would need aerobic post-treatment)
Nitrogen and phosphorus	No removal
Pathogens	Not much removal unless operated at thermophilic* temperatures and very long retention times →multi-barrier approach for reuse
Heavy metals	No removal

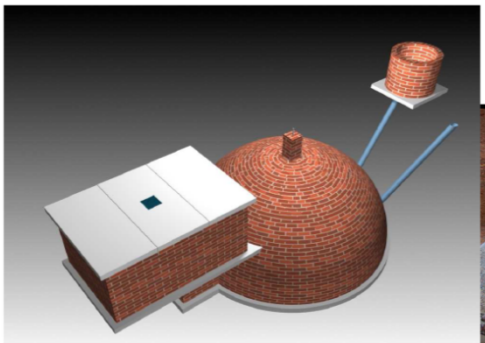
* Thermophilic (~55°C) anaerobic digestion will achieve more pathogen removal than mesophilic (~ 35°C) anaerobic digestion

Overview of commonly used anaerobic treatment technologies

#	Process name	Optimised mixing	Covered reactor	Biogas collection	Scale
1, 2	Septic tanks, anaerobic baffled reactors (ABR)	No / somewhat (for ABRs)	Yes	No / rarely	Household or neighbourhood
3	Household biogas plants*	No / somewhat (round shape)	Yes	Yes	Households, neighbourhoods, institutions, farms
4	Anaerobic ponds	No	No / sometimes	No / sometimes	Community
5	Upflow anaerobic sludge blanket reactor (UASB)	Yes	Yes	Yes	Neighbourhood, community, industries

* Also called household biogas digesters or decentralised biogas plants (i.e. not just limited to households) – currently less well-known than the other technologies

Household biogas plants
(here: fixed dome type)



Household biogas plant
Source: Jan Lam, SNV (at NBP Dhaka, March 2007)

Widespread use e.g. in China, Nepal (SNV program)

Source: Mantopi Lebofa, Lesotho, 2006

Photo 13: Cooking with biogas in a home in Chauhanas Vas, near Ranthambhore, India. (Wright, 2004)

	Aerobic	Anaerobic
Application example	Trickling filters, oxidation ponds	Anaerobic reactor
Carbon balance	50 % - CO_2 50 % - Biomass	95 % - CH_4+CO_2 (Biogas) 5 % - Biomass
Energy balance	40 % - Heat production 60 % - Biomass	5 % - Heat production 5 % - Biomass 90 % - Retained in CH_4
Biomass production	Fast	Slow

Table 6: Characteristics of anaerobic vs aerobic digestion. (Source: unknown)

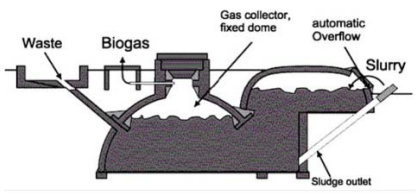


Figure 16: Illustration of a CAMARTEC biogas unit consisting of a FS-fed anaerobic digester (fixed-dome) with biogas collection. (TBW GmbH, Frankfurt)


Ginebra, Colombia
Design flow: 10 l/s


Outlet weirs

Centralized Biogas Plant

Lintrup Biogas plant (Denmark)

animal manures

EGSB

Gist Brocades (yeast, pharmaceuticals) The Netherlands