CIE4485
Wastewater Treatment

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10. Anaerobic Reactor Technologies

TU Delft

CT4485 Wastewater Treatment

Lecture 4c: Anaerobic Reactor Technologies

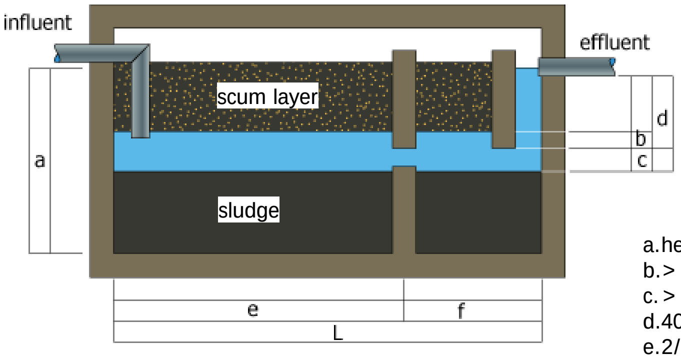
Prof.dr.ir. Jules van Lier

6 December 2012

Sludge digestion

Donald Cameron, 1895 (UK)

1. septic tank

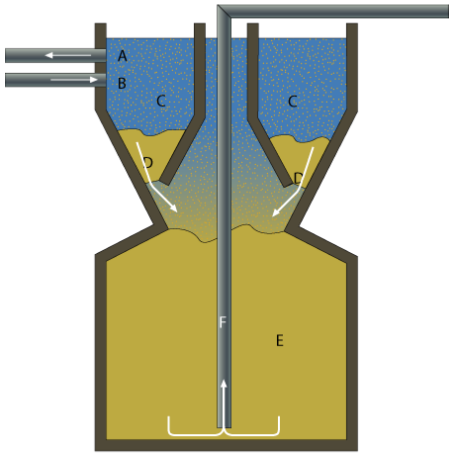


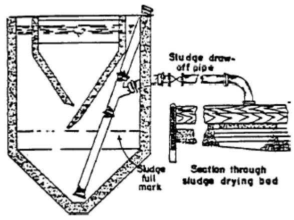
a. height of liquid
b. > 7.5 cm
c. > 30 cm
d. 40% of liquid height
e. 2/3 of L
f. 1/3 of L

Sludge digestion

Karl Imhoff, 1905 (Germany)

2. Imhoff tank



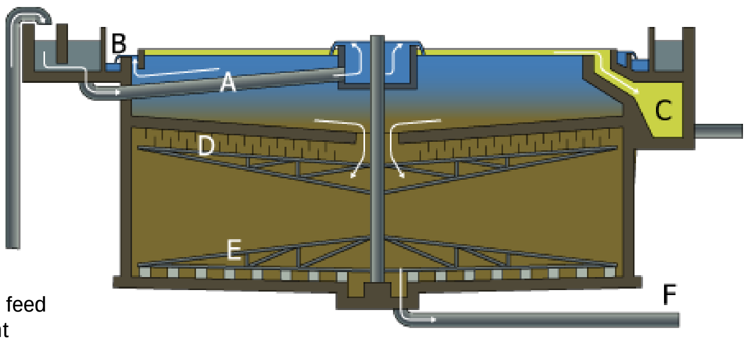


A. effluent
B. sludge feed
C. settling
D. settled sludge
E. sludge digesting
F. sludge discharge pipe

Sludge digestion & Wastewater treatment

3. Clarigester

Stander, 1950 (South Africa)



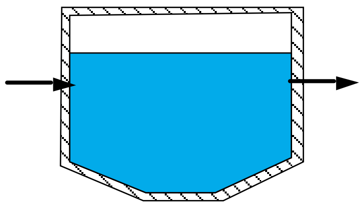
A. sludge feed
B. effluent
C. scum discharge
D. scum break off
E. bottom scraper
F. sludge discharge pipe

Wastewater Treatment

1930's

Buswell

Industrial Wastes

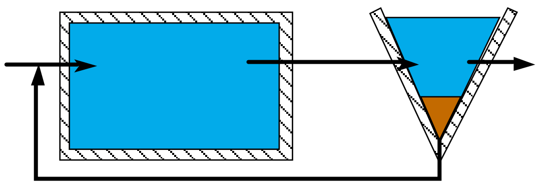


Wastewater Treatment

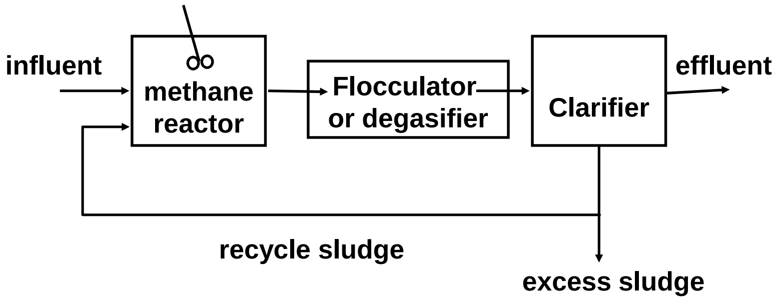
1955, Shroepfer, USA

Schroepfer

Contact process



Contact Process (CP)



The Anaerobic Contact Process

basic principles:

- complete mixing in the digester in order to achieve good contact between sludge and wastewater
- sludge recycling (flow rate generally 80-100 % of the influent flow rate) in order to maintain a high sludge content in the digester

=> high organic removal efficiency stable operation

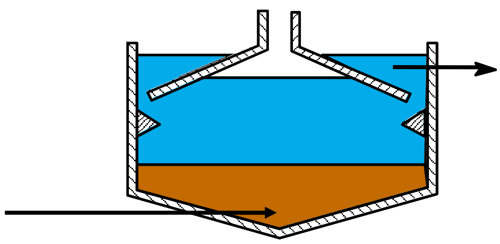
The anaerobic contact process

type of waste water	sludge loading (kg COD · kg^{-1} VSS · d^{-1})	load (kg COD · m^{-3} · d^{-1})	reactor volume(m^3)	COD removal efficiency (%)
sugar factory	1.3 - 2.0	0.6 - 12.9	2100 - 16000	90 - 95
distillery	0.17 - 0.24	1.5 - 2.5	300 - 1890	90 - 98
citric acid	0.16 - 0.29	1.3 - 4.0	10000	75 - 83
yeast factory	0.24 - 0.37	2.8 - 3.9	1900	77 - 82
dairy	0.13	0.88	84	-
green vegetable cannery	0.11 - 0.28	2.0 - 4.2	5000	90 - 95
pectin factory	0.03 - 0.22	1.7 - 5.3	3000 - 3618	88 - 93
starch factory	1.4	3.6	900	65
meat processing works	0.5 - 1.1	0.8 - 4.8	2670 - 7117	88 - 95

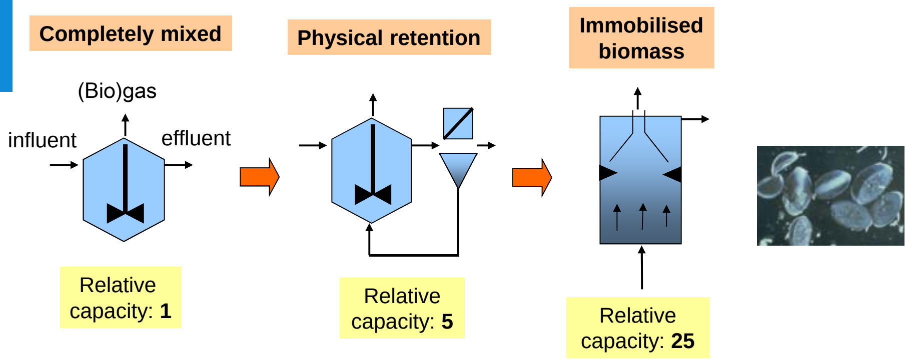
Wastewater Treatment: UASB

1970s, Gatze Lettinga, The Netherlands

Lettinga UASB

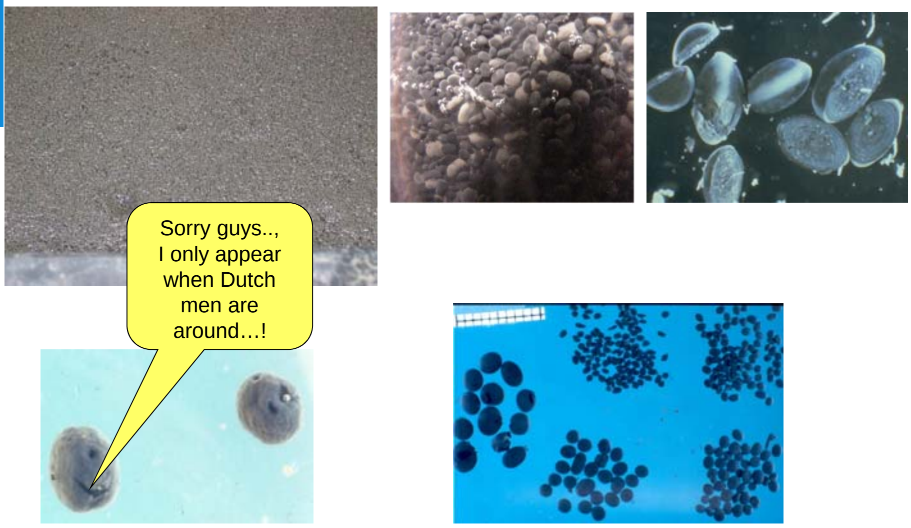


Development of "high-rate" anaerobic treatment systems



Early full-scale UASB for sugar mill effluent (CSM,1976)

Anaerobic Granular Sludge

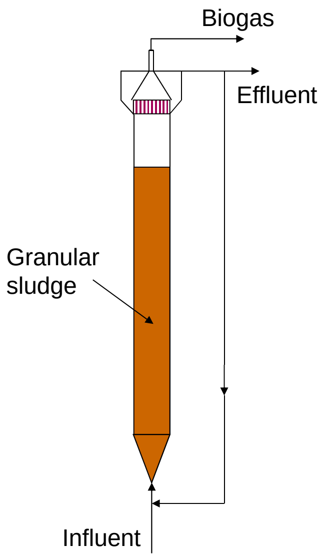


Expanded Granular Sludge Bed (EGSB) Reactors

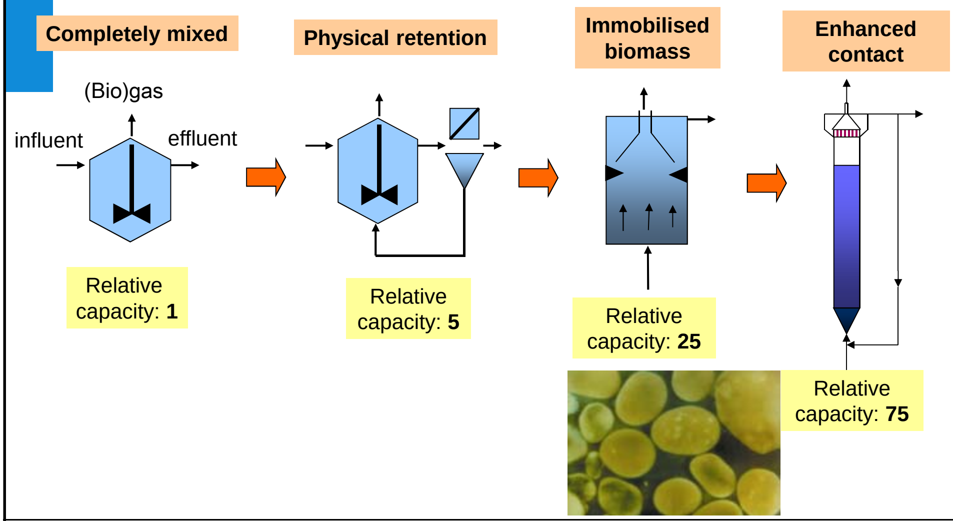
Effective use of granular sludge !!

Main Features
- High upflow velocities (> 8 m/h)
- High concentration of bio-catalyst
- Extreme loading rates (20-40 kg/m^3.d)
- Virtually no mass transfer limitation
- Very small footprint

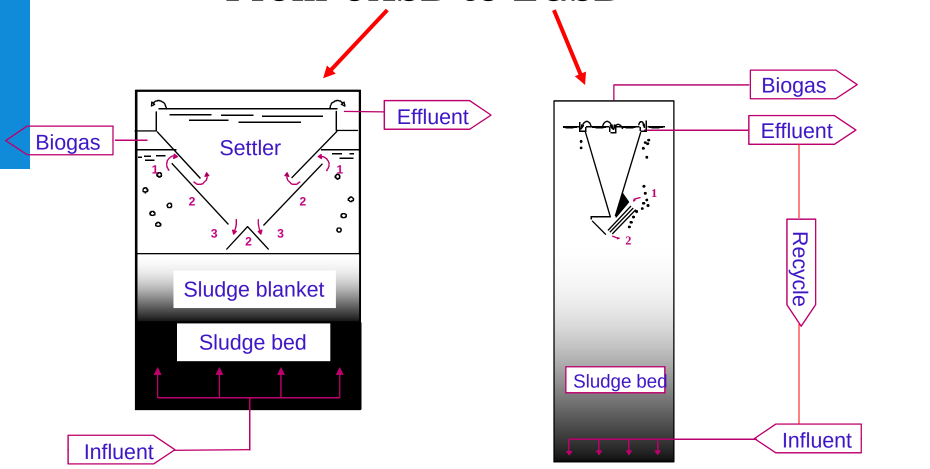
Application:
- cost effective alternative for UASB (2-3 times higher load)
- Cold wastewaters (< 20°C)
- Dilute wastewaters (< 1 g COD/l)
- Presence of degradable toxic compounds
- LCFA containing wastewaters
- Wastewaters with foaming problems in UASB



Development of “high-rate” anaerobic treatment systems



From UASB to EGSB

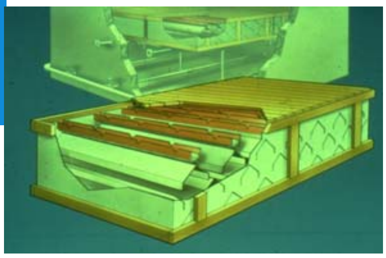


1. Sludge/biomass inlet
2. Gas baffle plates
3. Return settled sludge

1. Sludge/water mixture
2. Settled sludge

Biothane Systems International

Application of Multi-layer settling system

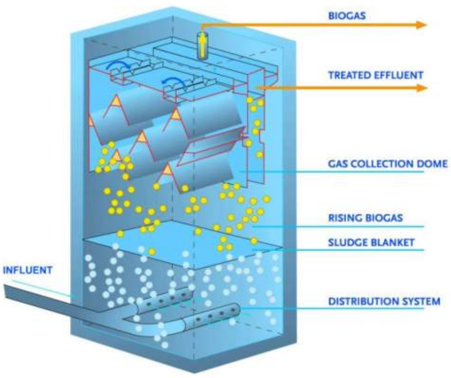


Polypropylene settlers

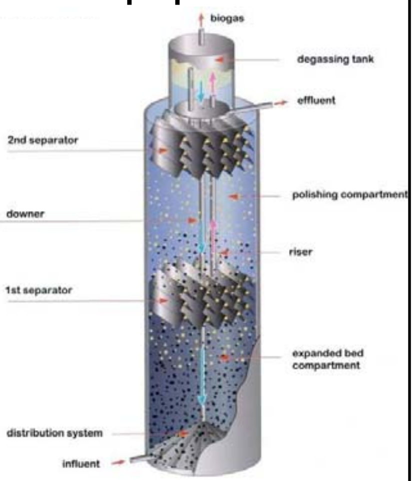
Less PP per m²/ No tropical hardwood

Developments – Technical/Technological

Biopaq® - UASB

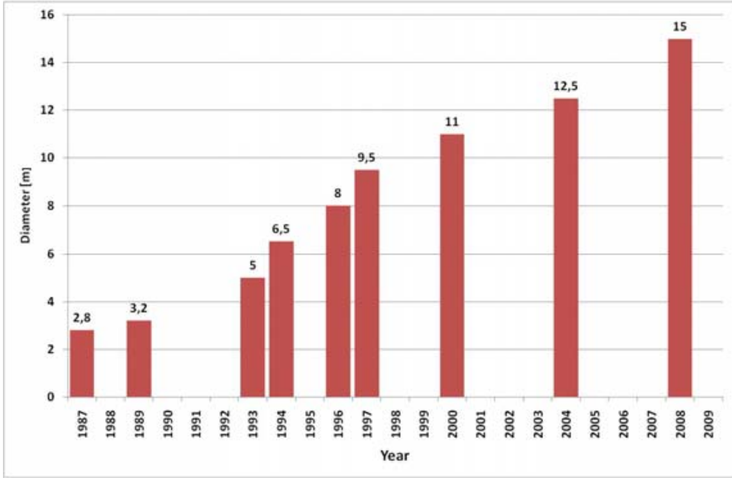


Biopaq® - IC



Developments – Technical/Technological

Increasing diameter of Biopaq® - IC



Developments – Technical/Technological

1987 : 2,8 m

2008 : 15 m

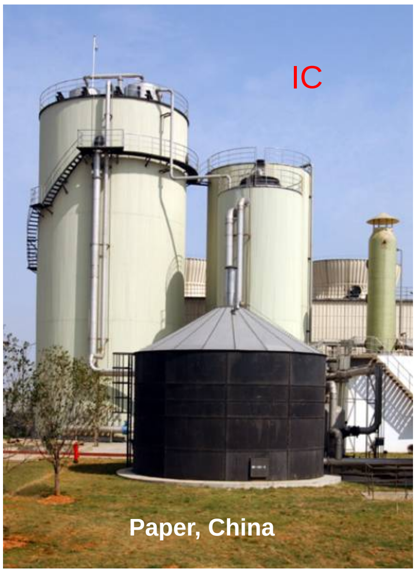
100 tpd COD per reactor

Developments – Technical/Technological

1989 : 6 x Ø 3,2 m

1996 : 1 x Ø 8 m

Full scale AWWT at beer brewery



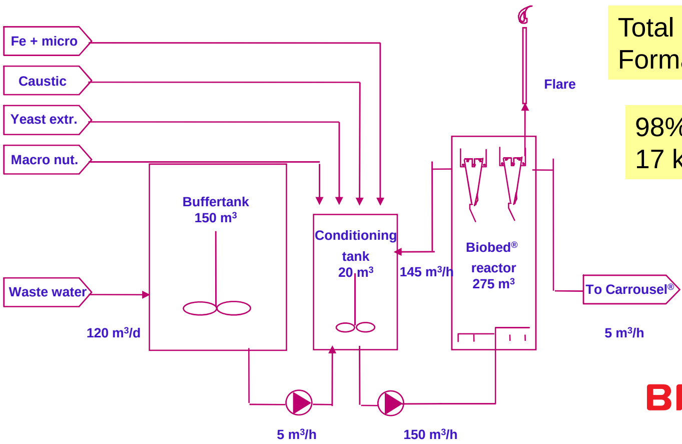
Chemical Wastewater Treatment

COD: 40 kg/m^3, of which:
- Formaldehyde 20 kg/m^3
- Methanol 10 kg/m^3

Possible to treat with a UASB??

Chemical Wastewater Treatment

Amended process design to prevent toxicity in anaerobic stage



Total COD: 40 g/l
Formaldehyde: 20 g/l

98% efficiency
17 kg COD/m^3.day

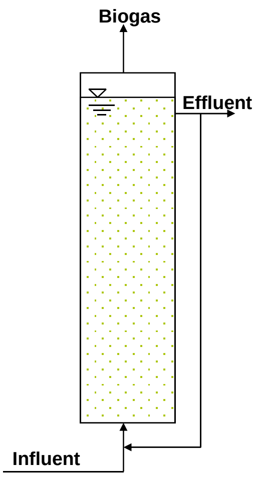
BIOTHANE

Influent : recycle ratio = 1 : 30 !!

Fluidized Bed Systems

Upflow Anaerobic Attached Fixed Film Expanded Bed (EB)

Attached Growth Anaerobic Fluidised Bed (FB)



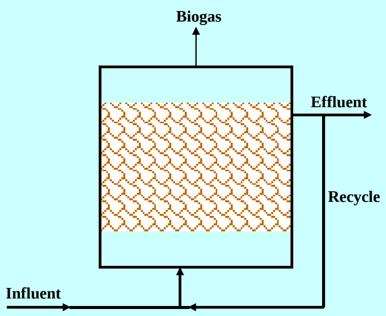
FB reactors rebuilt to EGSB reactors at DSM-yeast factory, Delft

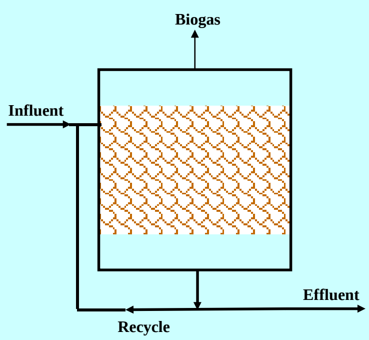
Anaerobic Attached Growth Processes

Anaerobic Filter Systems (1)

Upflow Anaerobic Filters (UAF)

Downflow Stationary Fixed Film (DSFF)





Anaerobic Filter Systems (2)

Upflow Anaerobic Filter (UAF)

based on:

- attachment of a biofilm to a solid (stationary) carrier material
- sedimentation and entrapment of sludge particles between the interstices of the packing material
- formation of well settling sludge aggregates

Major disadvantage

- difficult to realise required contact between sludge and wastewater
- applicable loads are relatively low, I.e. generally below 10 kgCOD/m^3.day

Anaerobic Filter Systems (3)

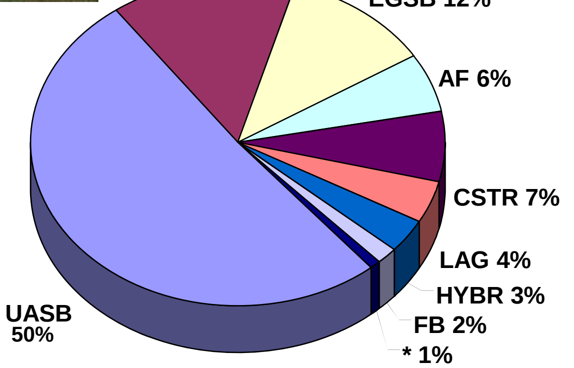
Downflow Stationary Fixed Film (DSFF)
Attached Anaerobic Film (AFF)

Sludge retention based on:

Attachment of biomass to the packing.
(sludge retention is relatively low, because hardly any suspended material retained)

- generally no channelling problems
- low loading potentials

Historically applied anaerobic processes
(1981 – 2007 (Jan.) N= 2266)

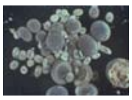


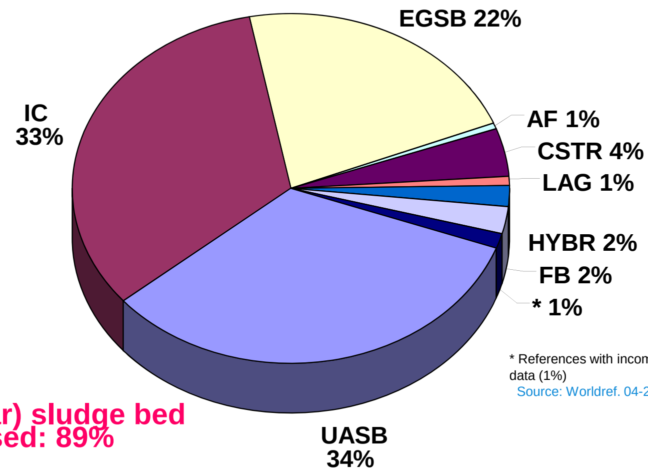
(Granular) sludge bed based: 77%

* References with incomplete data (1%)
Source: Worldref. 04-2007

Currently Applied Anaerobic Processes
(2002 – 2007 (Jan.), N= 610)

Expanded Bed Reactors: 55%

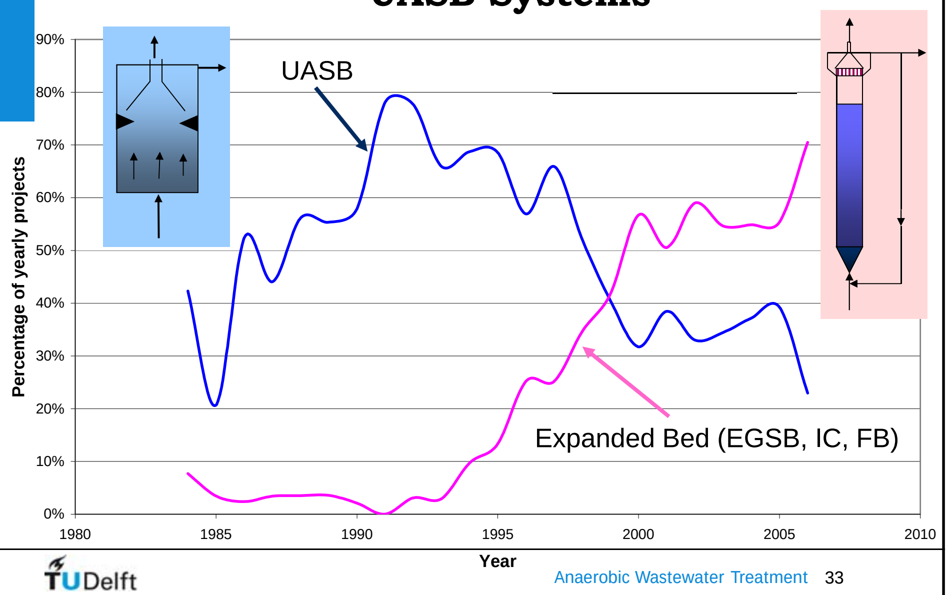




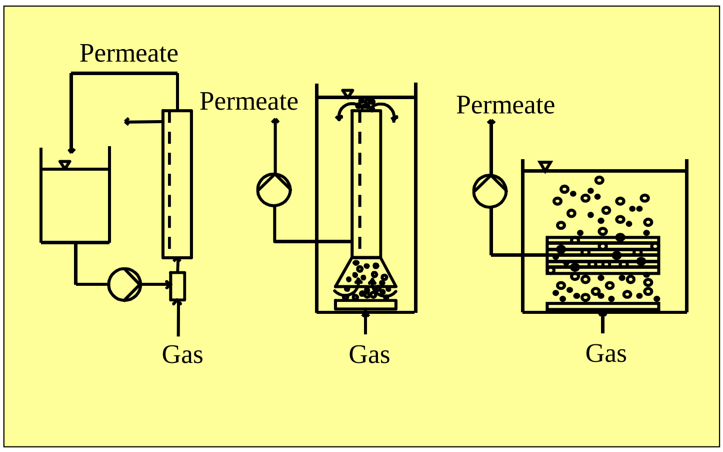
* References with incomplete data (1%)
Source: Worldref. 04-2007

(Granular) sludge bed based: 89%

Full Scale Expanded Bed versus UASB Systems



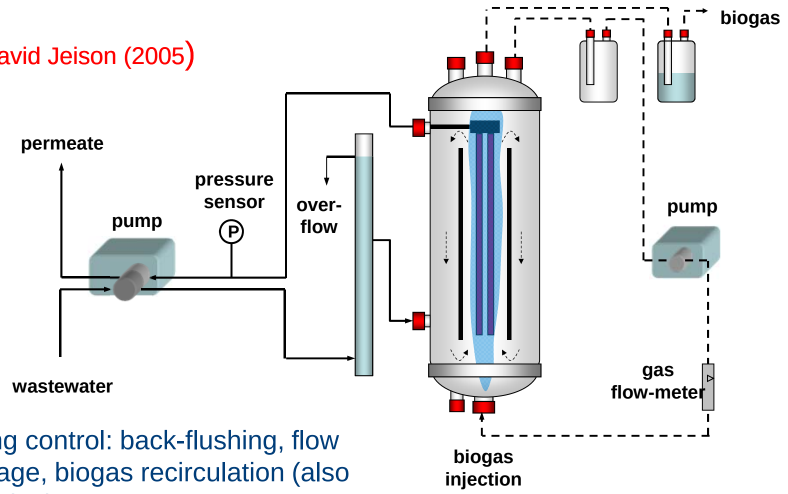
Novel development: Aerobic MBR applications / potential Anaerobic homologues



Anaerobic Membrane Bioreactor (AMBR)

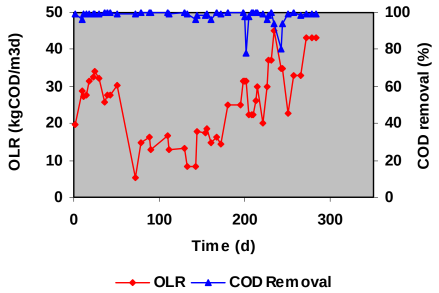
AD under Extreme Conditions

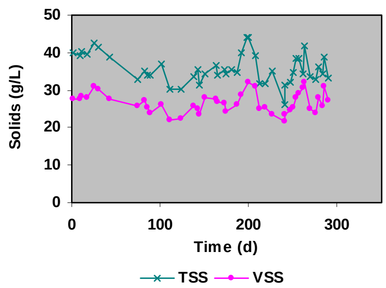
David Jeison (2005)



Fouling control: back-flushing, flow stoppage, biogas recirculation (also for mixing).

Operational performance submerged AnMBR

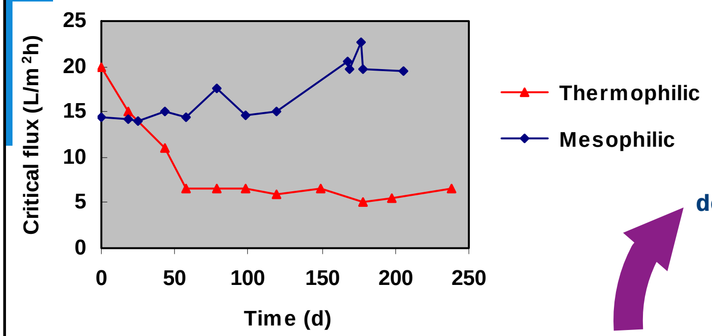


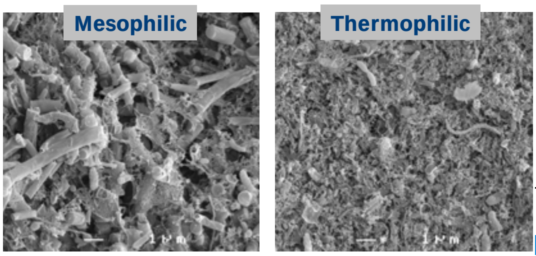


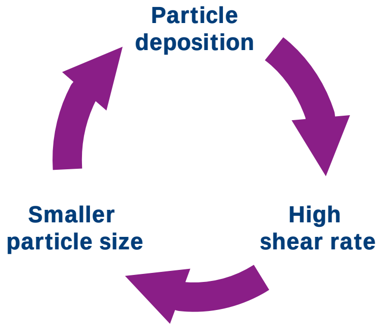
Mesophilic conditions, VFA-fed reactor

Flux determining factors in anaerobic MBRs

(Jeison and van Lier, 2008)







The shear rate dilemma...

High Rate Anaerobic Reactor Systems

- high retention of viable sludge in the reactor
- sufficient contact between viable biomass and waste water
- high reaction rates and absence of serious transport limitations of substrate and metabolic end products
- sufficiently adapted and/or acclimatised viable biomass
- prevalence of favourable environmental conditions for all required organisms inside the reactor under all imposed operational conditions

Principles of Sludge Retention in High-Rate Reactors

Bacterial attachment on non-fixed carriers

e.g. FB (Fluidised Bed) reactors

Bacterial attachment on fixed support materials

e.g. Anaerobic filters

→ Attached Film

Auto immobilisation / granulation

e.g. UASB (Upflow Anaerobic Sludge Bed) reactors

→ Sludge Bed

Sludge settling and membrane filtration

e.g. CP (Contact Process) reactors

AMBR (Anaerobic membrane bioreactors)

→ Separation