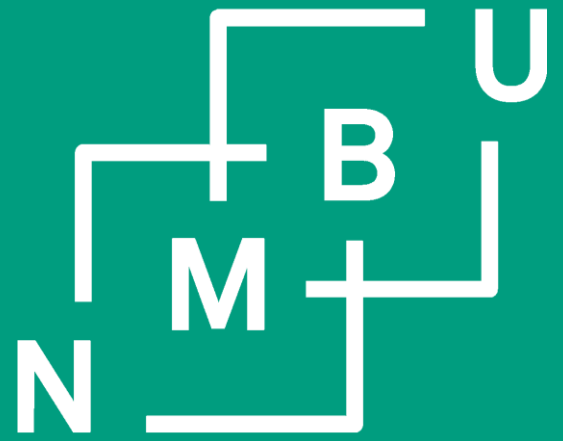
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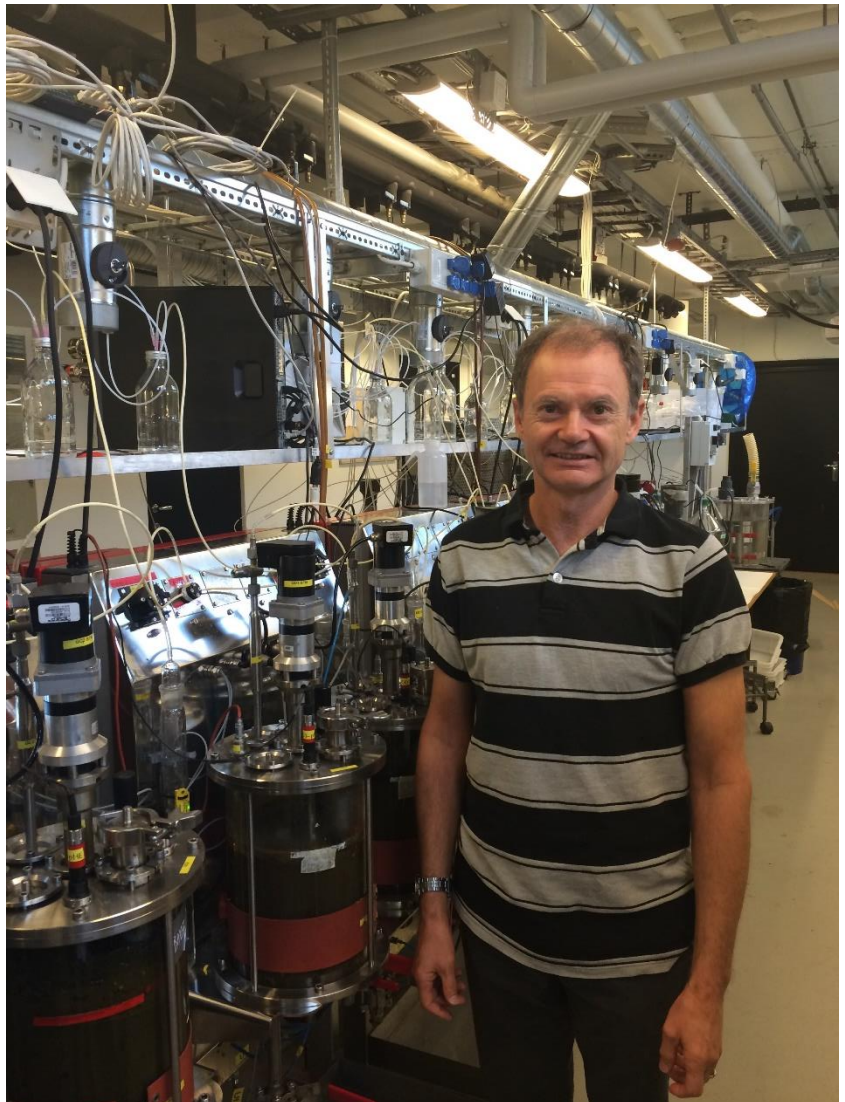
Norwegian University of Life Sciences

Name: John Morken, section architecture and environment, water and environment group

Research/teaching: Anaerobic digestion, modeling GHG emission and ammonia emission, solid waste management, Life cycle assessment

Goals for the lecture

- Basics of the process
  - Sub-processes
  - Process parameters
- Plant design
- Use of gas
- Use of digestate
- Recovery
- Resource-/environmental challenges, Life cycle assessment



Literature

- MANG, H.-P.; LI, Z. (2010): Technology Review of Biogas Sanitation. (can be found on SSWM
- Jönsson et al. (2004): Guidelines on the Use of Urine and Faeces in Crop Production. (can be downloaded from http://www.ecosanres.org/publications.htm#2010-1:_Practical_Guidance_on_the_Use_of_Urine_in_Crop_Production_by_Anna_Richert,_Robert_Gensch,_Håkan_Jönsson,_Thor-Axel_Stenström_and_Linus_Dagerskog.
- H. Kjerstadius, S. Haghighatafshar & Å. Davidsson, 2015: *Potential for nutrient recovery and biogas production from blackwater, food waste and greywater in urban source control systems.*

Practical plan

- 10.30 – 11.00 Introduction
  - Basics
  - Reactors and equipment.
  - Nutrients
- 11.00 – 12.00 Principles
  - Microbiology
  - Potentials
- 13.00 – 14.00 Calculations
  - Design of plants
  - Energy calculations

Problem statement

- **“the greatest challenge in the water and sanitation sector over few decades will be the implementation of low-cost sewage treatment that will at the same time permit selective reuse of treated effluents for agricultural and industrial purpose”. (**the World Bank)

- First plant built in 1859 at Leper colony in India
- Used in 1897 to power streetlights in Britain
- Thousands of 'backyard' digesters throughout China, India other Asian countries
- Most sewage treatment works in Europe stabilize their sludge using AD
- Increasingly being used in Europe to manage municipal waste and to create heat and power

Goals for the treatment

Energy

Hygiene

Recovery of nutrients

Reactor technology - principles

Liquid feedstock: Two principles for reactors (< 10 -15 % d.m.):

1. Micro org. living on particles in substrate (CSTR)
2. Micro org. living permanent in the reactor (d.m. < 1 %)
   a) Granules (i.g. USAB, ABR)
   b) Biofilm
3. High dry matter feedstock:
   1. percolation
   2. Plug-flow

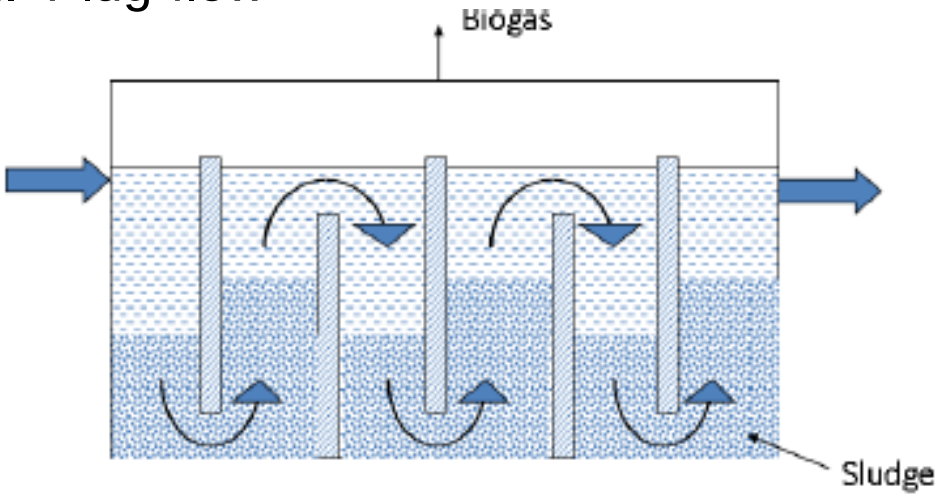
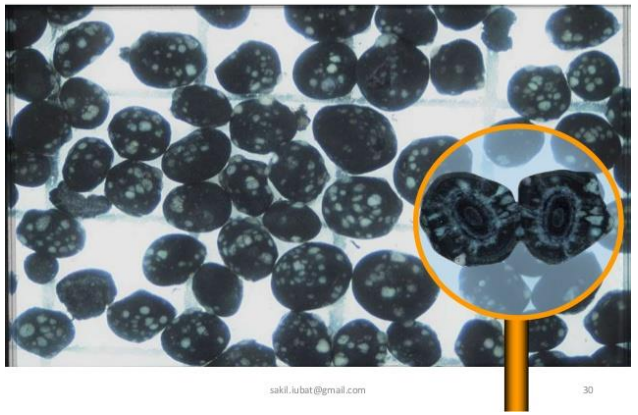
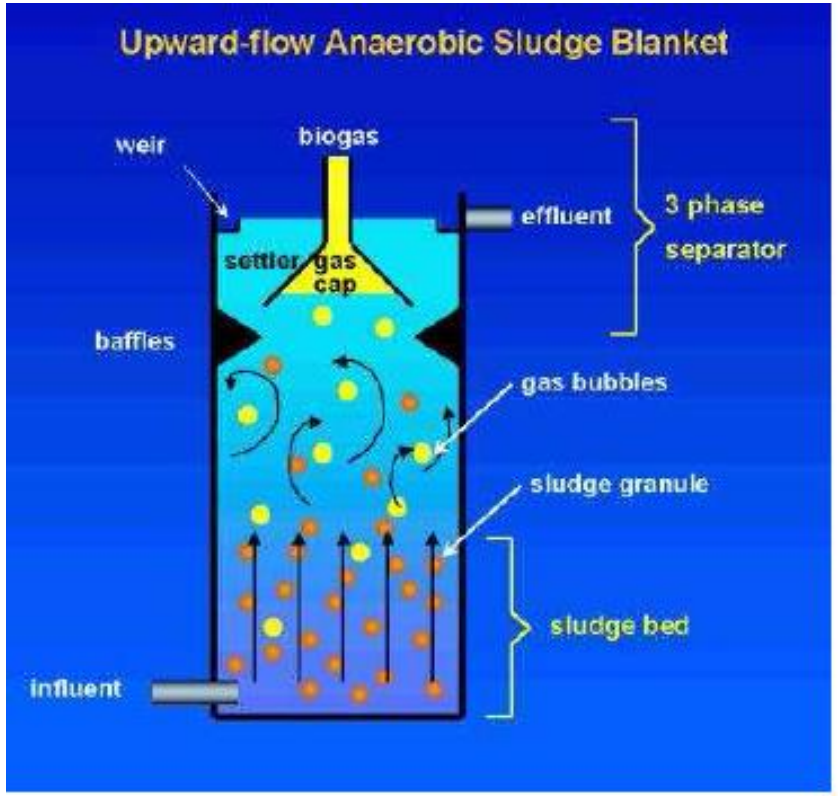


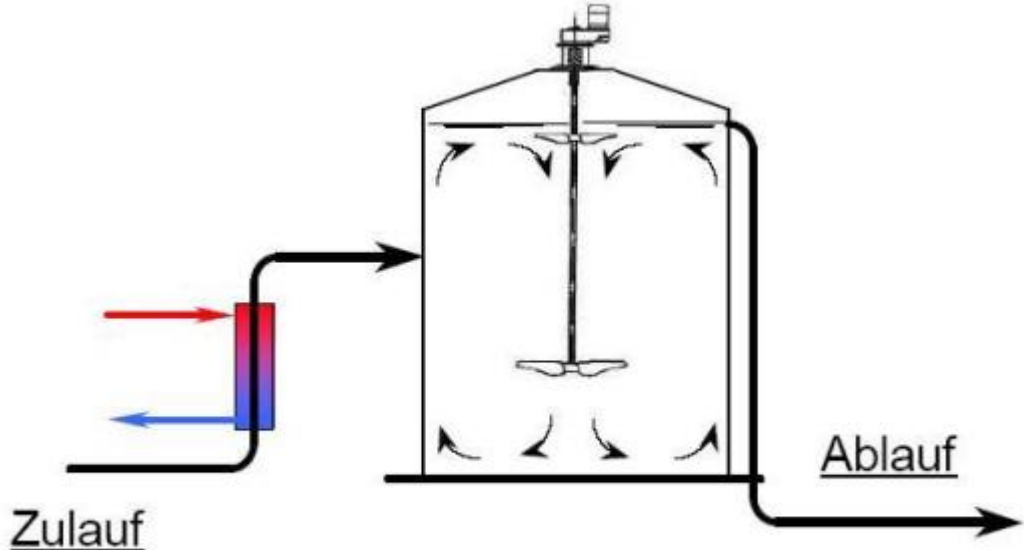
Figure 11: ABR design (Source: Paradigm Environmental Strategies, Bangalore, website: www.ecoparadigm.com)





Design – Components CSTR

- Reactor
  - Concrete (Steel, Glassfiber)
- Stirring equipment
- Heat exchanger (CSTR)
  - Normally not (UASB and ABR))
- Storage of gas



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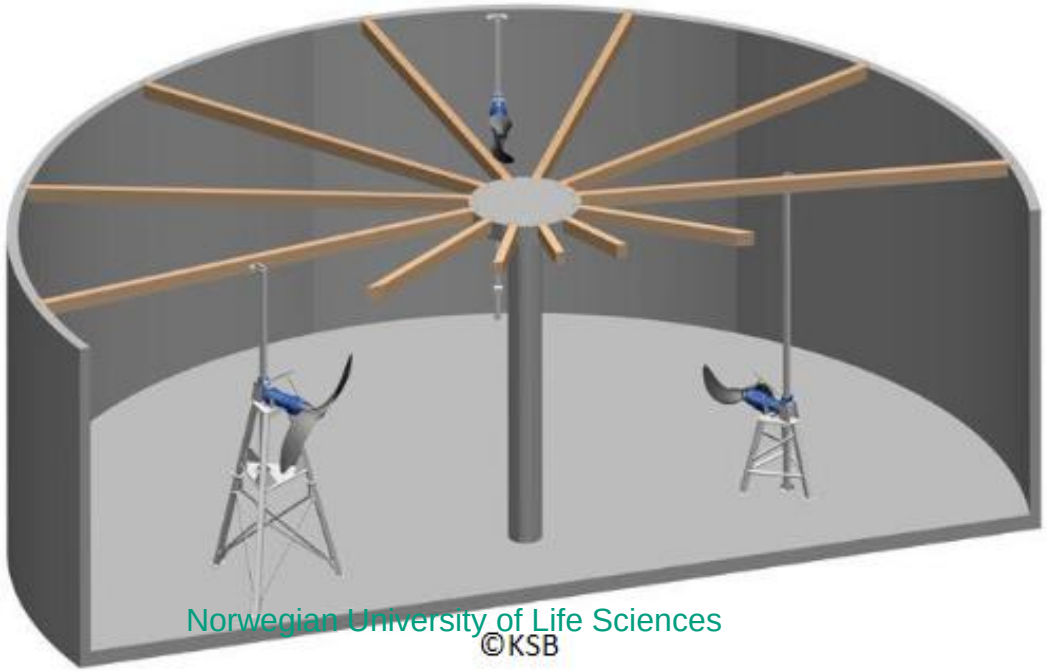

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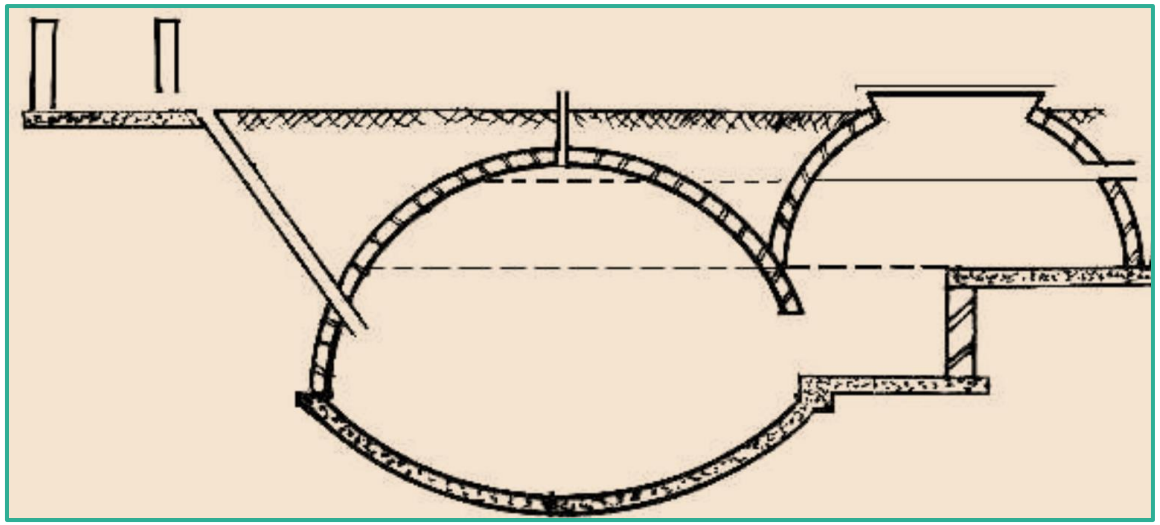
Anaerobic digester – Biogas settler (BS)



Anaerobic baffled reactor (ABR)

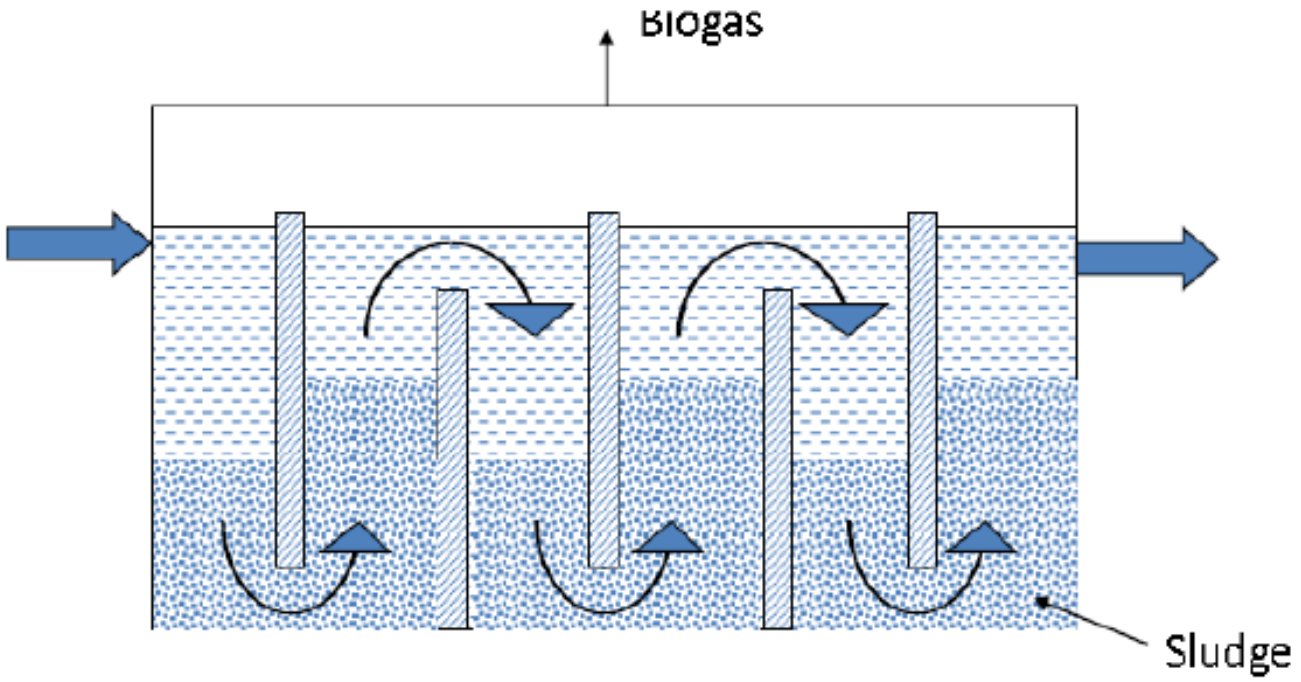
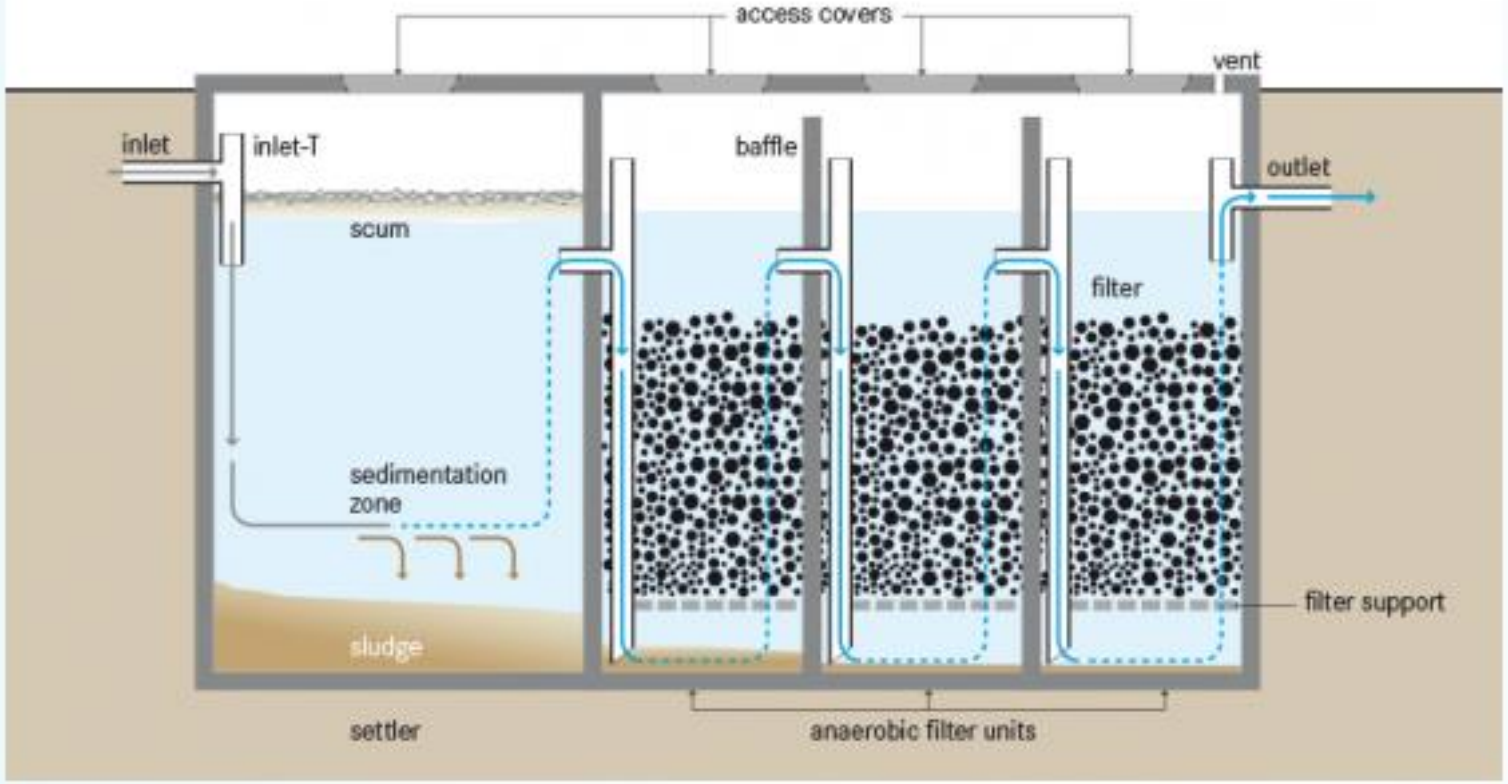


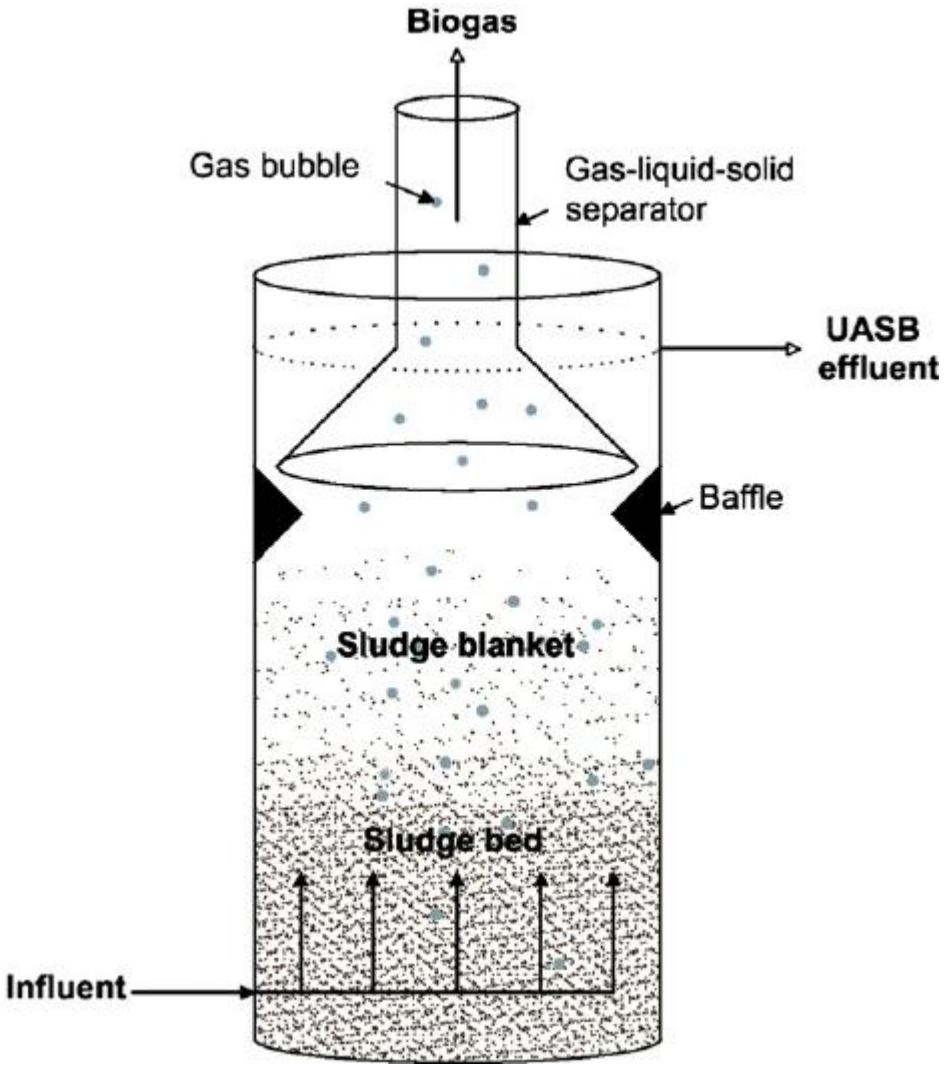
Figure 11: ABR design (Source: Paradigm Environmental Strategies, Bangalore, website: www.ecoparadigm.com)

Anaerobic filter

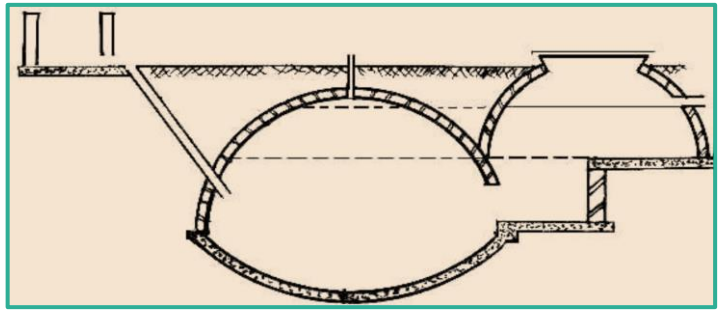


Schematic of an anaerobic filter. Gas is evacuated by the venting opening at the upper right. Source: TILLEY et al. (2014)

Upflow Anaerobic Sludge Blanket (UASB) reactor



Chose the reactor type according to



- Temperature and investments
  - Need of external heating?
- Dry matter of the feedstock
  - < 1 % BS, UASB, ABR
  - < ~3 % ABR
  - > 3 % CSTR or PFR

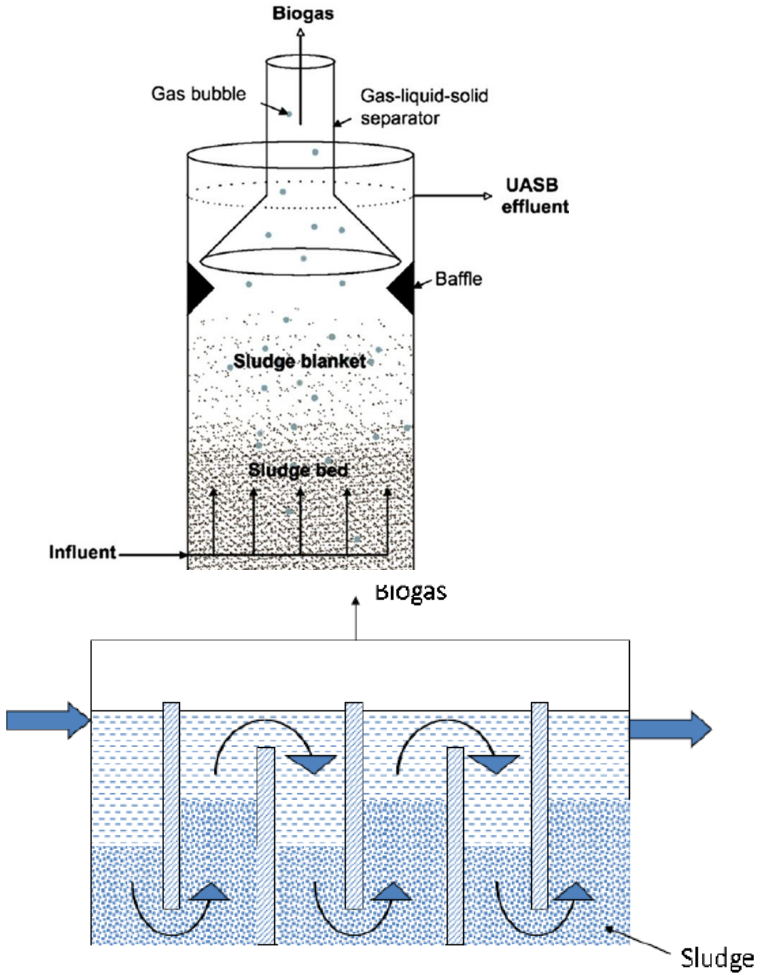


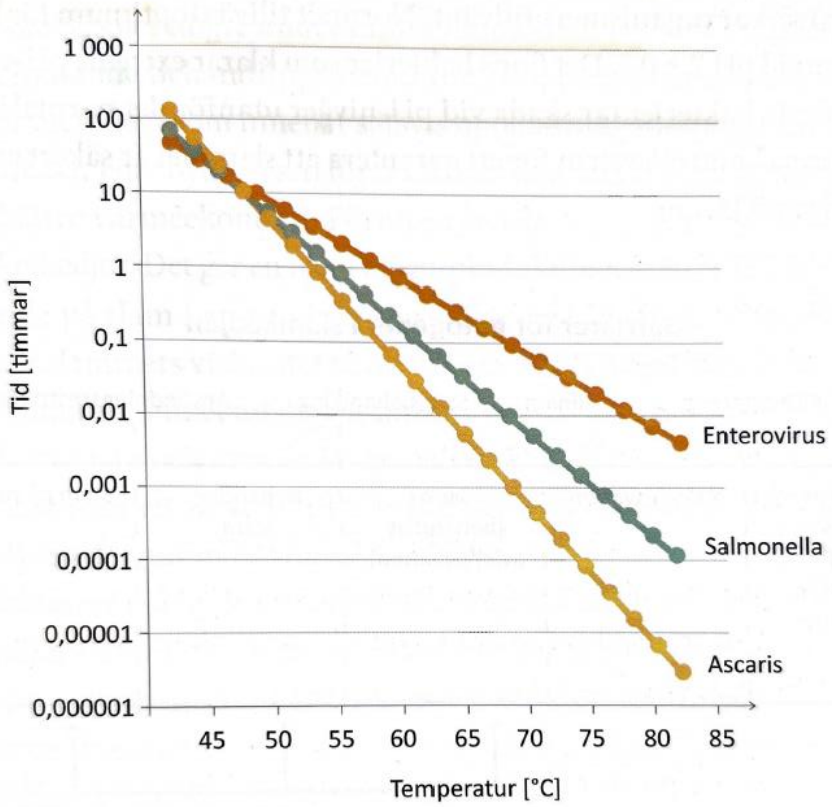
Figure 11: ABR design (Source: Paradigm Environmental Strategies, Bangalore, website: www.ecoparadigm.com)

Simple reactors – performance

Type of digester	Expected BOD reduction	HRT (days)	OLR (kg COD/ m^3)	SRT (days)	optimal application
biogas septic tank (BST) / biogas settler (BS)	25-60%	minimum 20, optimum 60 (limited by construction costs, but longer HRT for sanitization required)	0.5 – 2	miniumum 10 days, maximum 7 years (as higher to lower sludge volume handling challenges)	Pretreatment, energy optimized with organic wast as coferment, baffle in BS required if built as main treatment system with post-composting, post-wetland, or drying bed
Anaerobic baffled reactor (ABR)	70-90%	2 - 4	1 - 12	At least 2 years	Post-treatment after BS (than without bafle)
Anaerobic filter (AF)	70–95%	0.5 - 4	5 - 15	Theorethicall no, but sludge may accumlate at the bottom	Post-treatment after BST or after ABR
Upflow anaerobic sludge blanket (UASB)	55-90%	0.5 - 10	15 - 32	more than 365 days	Main-treatment after grid chamber, energy optimized with organic waste as co-ferement, or post-tretament after BS or BST, with post-wetland, or post-lagoon

(source: H.-P.Mang)

Destruction of pathogens



Figur 5.14 Tid- och temperaturförhållanden för avdödning Enterovirus, Salmonella och Ascaris. Utdrag ur Svensson (2007).

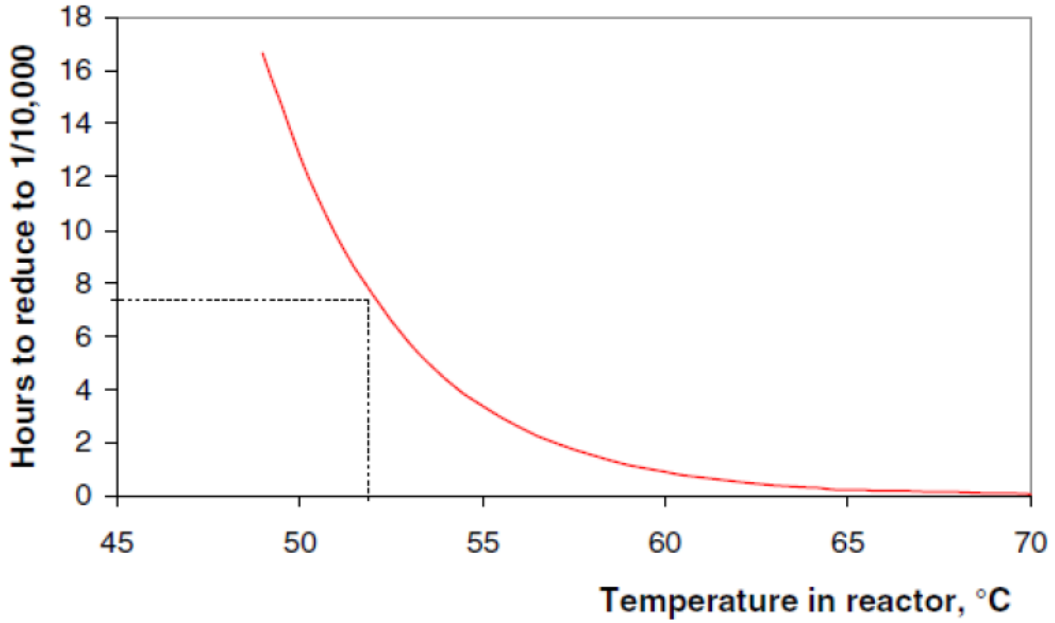


Figure 1.1. Relations between temperature and retention time in order to reduce the number of faecal streptococci to a level of 1/10,000 of the original content. At 52°C this reduction is obtained after 7.5 hours. (Bendixen, 1995).

Hygiene

Table 1. Effects of anaerobic batch sanitisation on selected pathogens and parasitic ova as well as on E. Coli indicator

Pathogens & parasitic ova	Thermophilic fermentation (53-55℃)		Mesophilic fermentation (35-37℃)		Ambient temperature fermentation (8-25℃)	
	Days	Fatality (100%)	Days	Fatality (100%)	Days	Fatality (100%)
Salmonella	1 – 2	100	7	100	44	100
Shigella	1	100	5	100	30	100
Poliviruses			9	100		
E-Coli titre	2	10^{-1} – 10^{-2}	21	10^{-4}	40 - 60	10^{-4} – 10^{-5}
Schistosoma ova	Several hours	100	7	100	7 – 22	100
Hookworm ova	1	100	10	100	30	90
Ascaris ova	2	100	36	98.8	100	53

(source: Yongfu, Y., Yibo, Q., Yunxuan, G., Hui, Z., Yuansheng, X., Chengyong, X., Guoyuan, F., Jiequan, X. and Taiming, Z. (1992), The Biogas Technology in China. Agricultural Publishing House, China, ISBN 7-109-01777-X)

Biogas sanitation system

Biogas sanitation systems are usually designed as:
1. primary treatment for removal of settleable and digestable solids and organic matter (biogas settler, biogas septic tank), the primary treatment could be divided in multiple anaerobic steps i.e. as “biogas settler followed by anaerobic baffled reactor”,
2. secondary treatment for nutrient removal (nitrogen), hygienisation, and reduction of chemical oxygen demand (COD) and biological oxygen demand (BOD) – (anaerobic filter, upflow anaerobic sludge blanket reactor). Secondary treatment could further be carried out in a separate aerobic treatment process with natural aerated trickling filters, constructed wetlands or aerobic polishing pond systems.

Organic pollutants in the fractions

- **Urine and faeces:** Hormones and pharmaceutical residues (~1400 active substances, many identical to natural substances)
- **Problems in aquatic environment**
- **Greywater:** Most of the 30.000+ substances in society can occur.

Nutrients

Why do plants need N,P,K?

Plants need seventeen essential nutrients to complete their life cycle (Mahler, 2004). Depending on the quantity of a nutrient needed, these are categorized into macronutrients and micronutrients. Macronutrients are needed in relatively larger amounts, compared to micronutrients. Each nutrient has a vital role in plant growth.

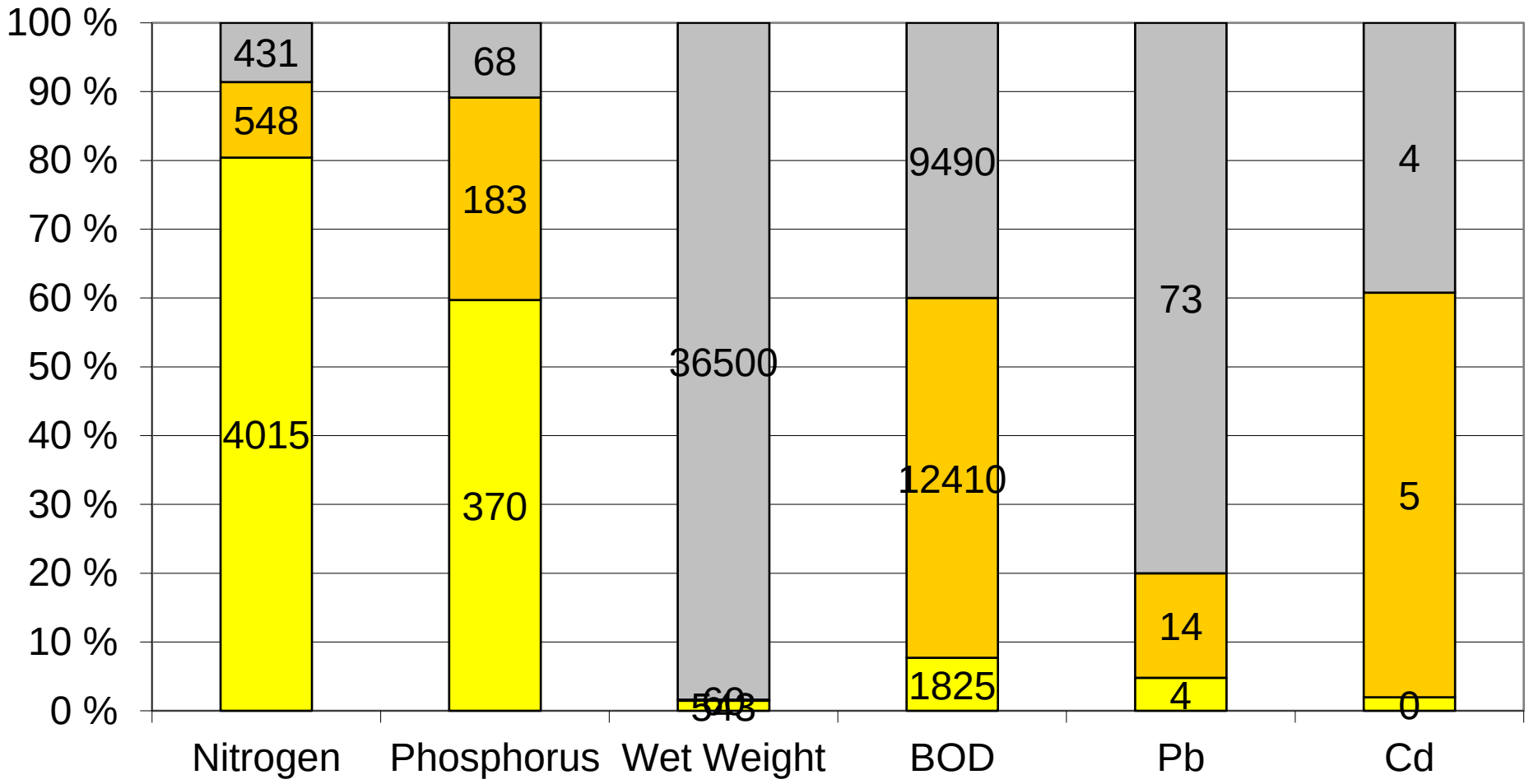
- Nitrogen (N) is an integral part of the plant cells. It constitutes plant proteins, hormones, and chlorophyll.
- Phosphorus (P) plays a vital role in transferring energy from the sunlight to the plant tissues. Specifically, electrons in the molecules of chlorophyll are activated by the sunlight(red and blue light). The excited electrons transfer energy to ADP and NADP (P-containing molecules), which then convert into ATP and NADPH. ATP and NADPH drive many processes in living cells. P also accelerates early root growth and stimulates maturity in plants.
- Potassium (K) stimulates the process of the formation of starches, sugars, and oil in plants. It improves fruit quality. Further, it helps the movements of these elements within the plants. It increases the vigor of plants and helps increase disease resistance.

NUTRIENTS IN BLACKWATER AND ORGANIC WASTE

	Blackwater	Organic waste
Amount	~500 kg/person and year	~100 kg/person and year
Dry matter content (%)	< 1	20 – 35
Volatile solids (% of DM)	45 – 60	85 - 95
Total nitrogen (g/kg)	9.1	0.2
Ammonia nitrogen (g/kg)	8	~0
Nitrate (% of DM)	~0	~0
Phosphorus (g/kg)	1,1	1.4
Potassium (g/kg)	2 – 2.5	2 – 2.5

Contributions to household wastewater, g/p,yr

(kg/p,yr for mass and mg/p,yr for Cd)



Refs: Jönsson et al., 2005. Composition of urine , faeces, greywater and biowaste ;
For P in greywater: Ek et al., 2011. Teknikenkät

The mineralization i biogas reactors

Eng. Life Sci. **2012**, *12*, No. 3, 242–257

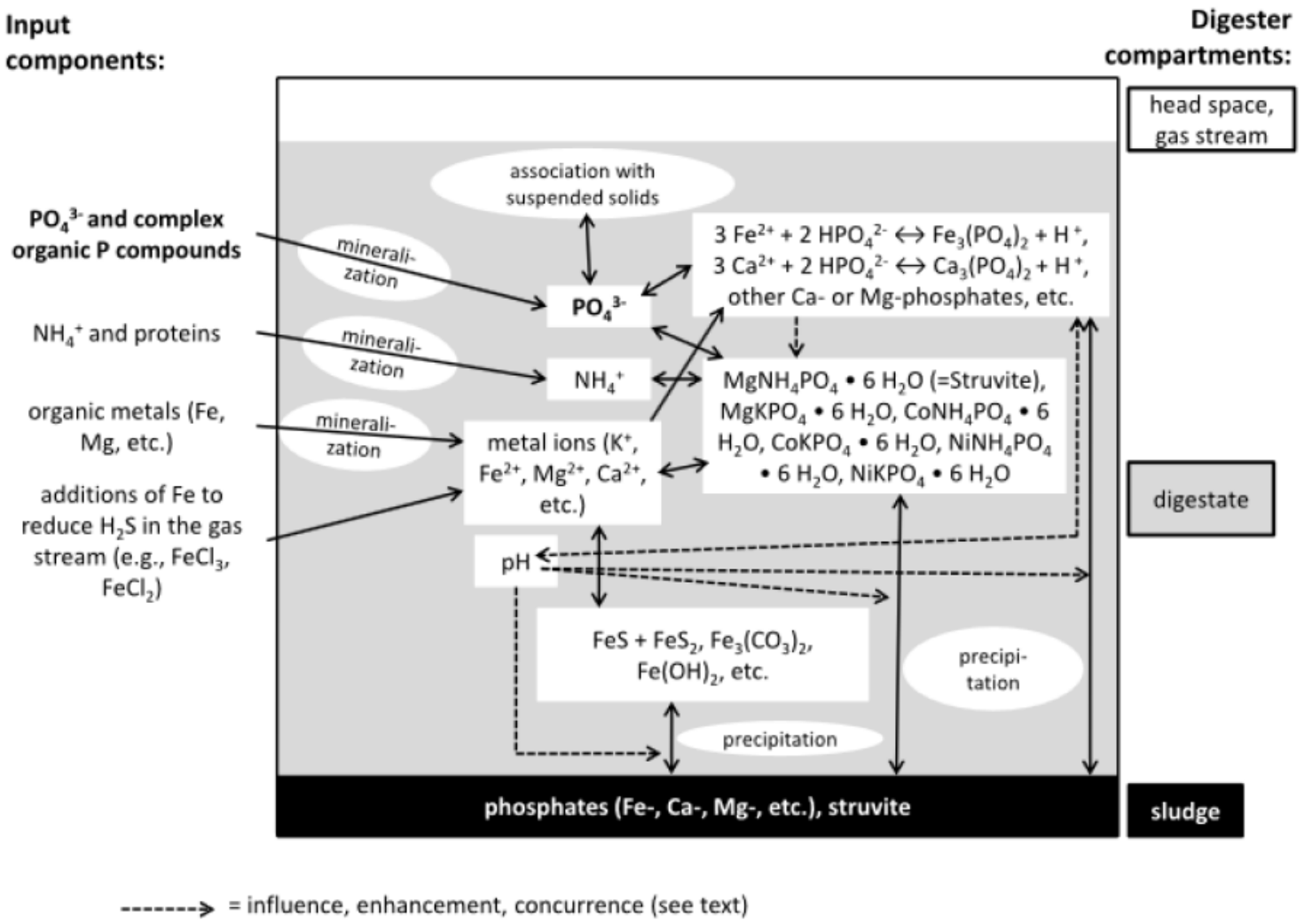
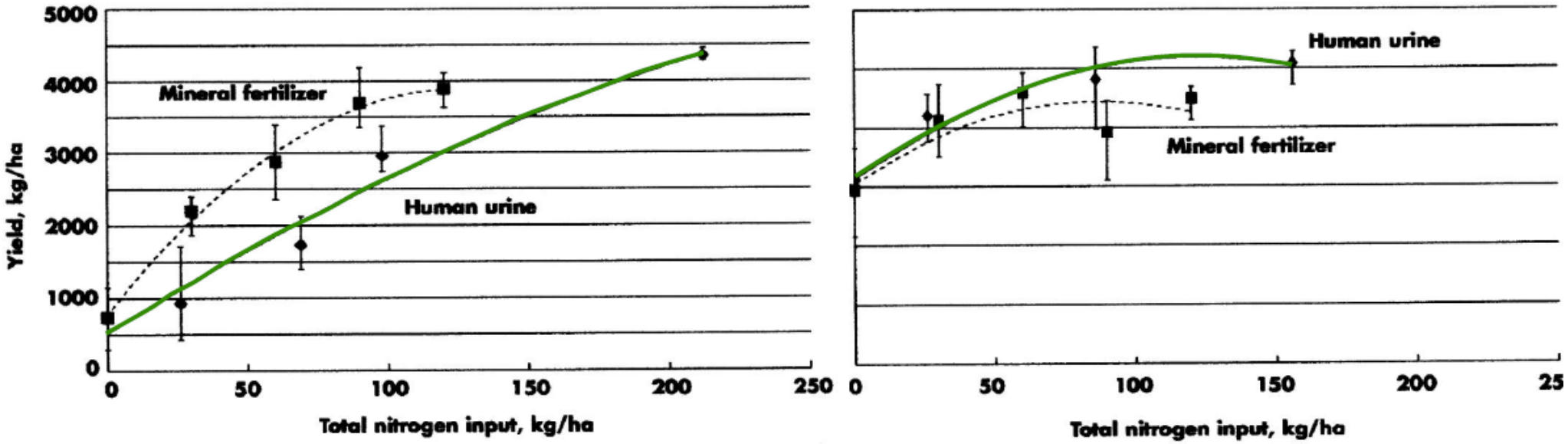


Figure 4. Phosphorus turnover in biogas digesters.

Urine & blackwater as fertilizer



N effect

- **Approx similar to NH_4^+-N fertilzer.**
  In Sweden: ~90% of NH_4NO_3 fertilizer after reduction for NH_3-loss.
  (Johansson et al. 2000)

P effect

- **Similar to mineral P fertilizer** (*Kirchman & Pettersson, 1995)*

- **Blackwater ought to be similar**

Production of biogas,mineralized N and P 120 persons in a block, 8 h working hours

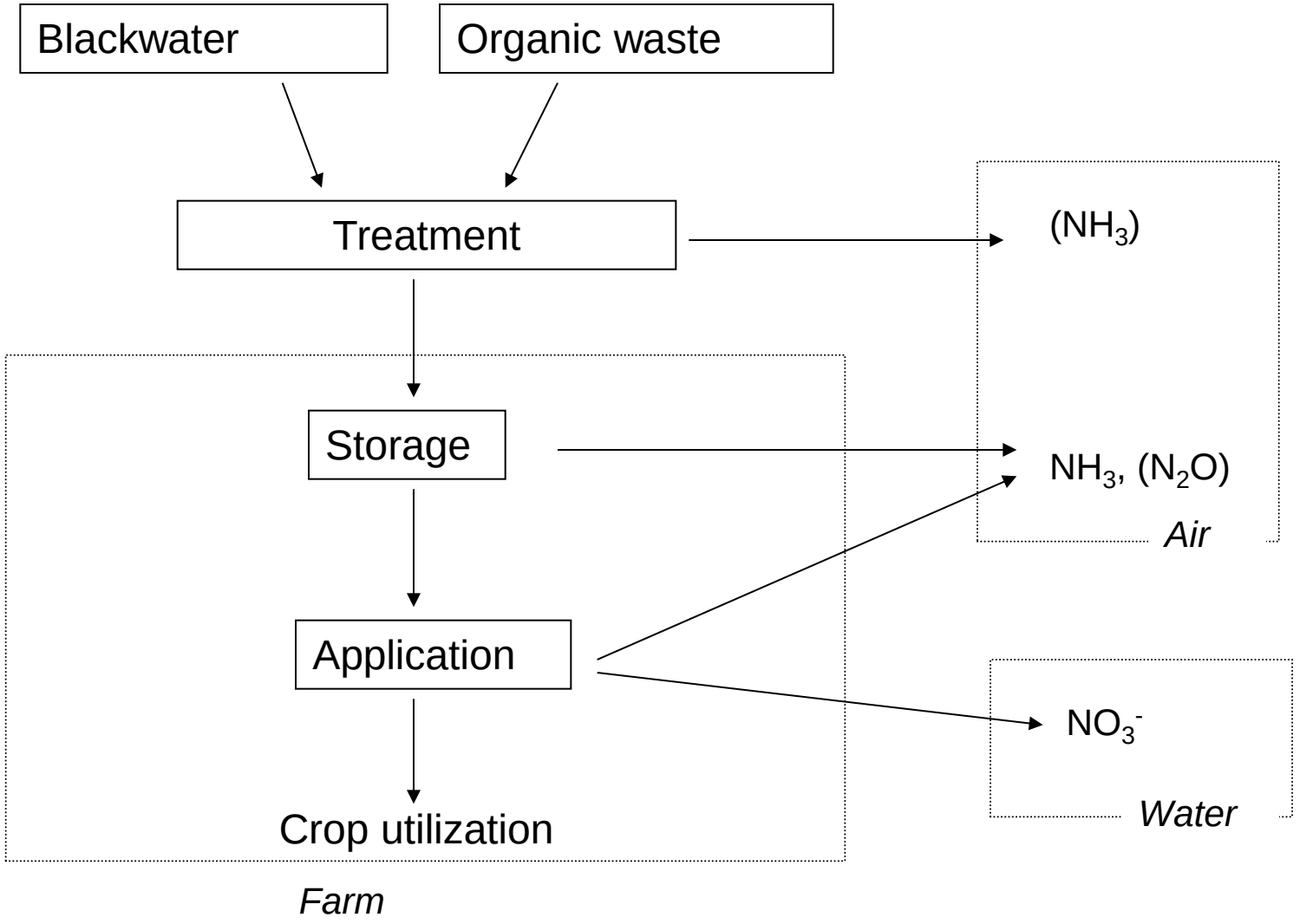
	Mass, kg/ person and day	D.M. (%)	V.S. (%)	Biogas pot. (m3/tonn VS)	Biogas total (m3/day)	N-tot kg/day	NH3 mineral-ization (kg/year)	P tot (kg/year)
Blackwater	5.0	0.6	83	500	1.6	1.092	290.2	10.98
Food waste	1.51	10	80	723	11.36	0.009	1.9	7.78
Garden waste	0.08	40	90	476	1.76	0.148	32.4	1.25
Total	6.59				14.7		324.5	20

Impact of AD on nutrient value and availability in digestate

Table 6 An example from Northern Ireland of the average nutrient composition over 52 weeks of feedstock (dairy cow slurry) and digestate in a mesophilic digester at the Agri-Food and Biosciences Institute (Frost and Gilkison, 2010)

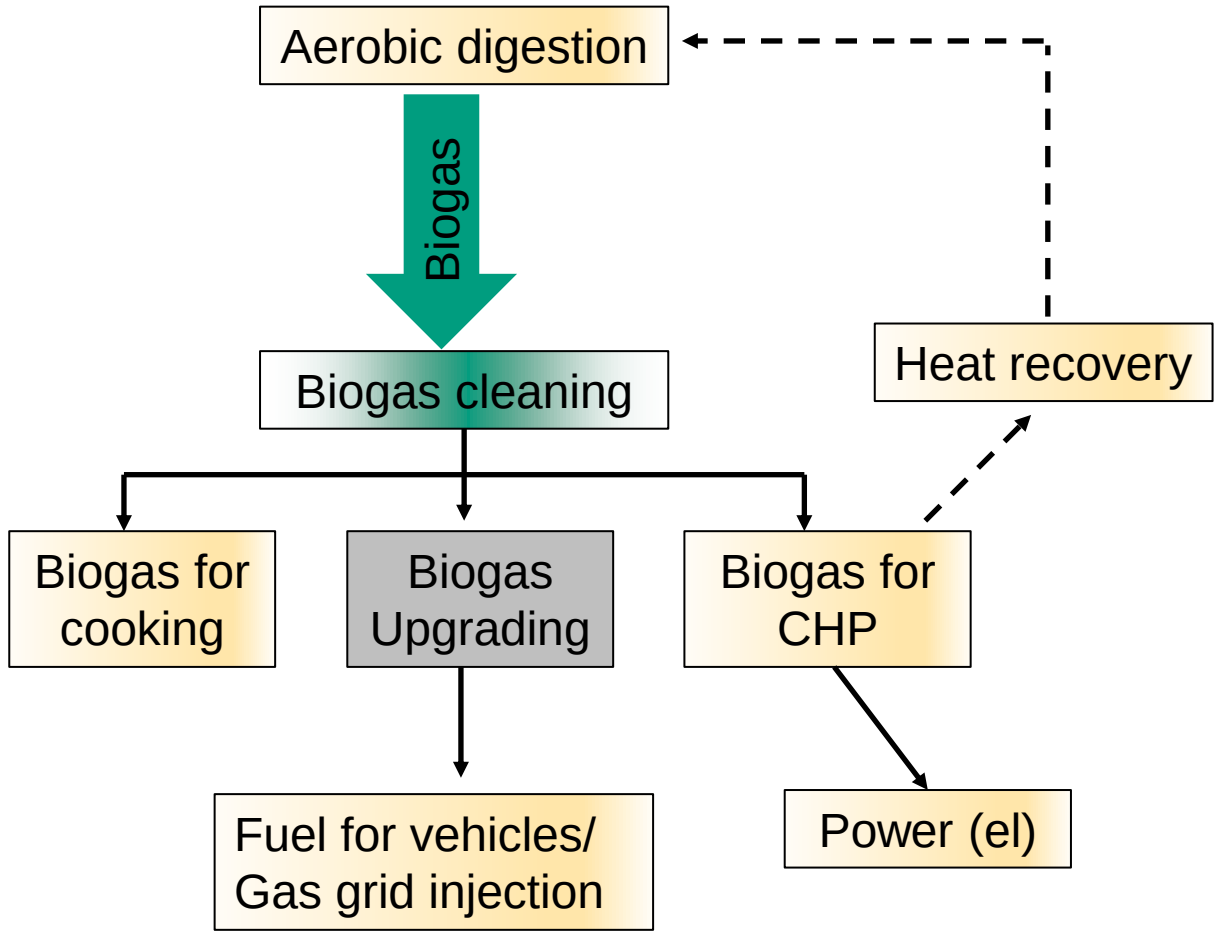
	Dry matter (g/kg)	Total N (g/kg fresh)	NH_4-N (g/kg fresh)	NH_4-N (% Total N)	pH
Feedstock	72.2	3.5	2.0	67.0	7.4
Digestate	59.3	3.6	2.4	80.5	7.9
Change	−17.9%	+2.8%	+20%		
Standard deviation feedstock	8.50	0.52	0.36		0.34
Standard deviation digestate	5.22	0.48	0.43		0.23

N-flux


Blackwater
Organic waste
Treatment
(NH3)
Storage
NH3, (N2O)
Air
Application
NO3-
Water
Crop utilization
Farm

Composition of biogas

Compound	Unit	AD gas
Methane	Vol-%	50-70
Carbon dioxide	Vol-%	30-50
Nitrogen	Vol-%	0-5
Oxygen	Vol-%	1
Hydrogen sulphide	mg/m^3 Ppm Vol-%	100-10000 10-5000 0,5
Ammonia	mg/m^3 Ppm Vol-%	0-100 0-50 0,05
Siloxanes	mg/m^3	0-50
Water vapor	Vol-%	1 – 5



Heat/Cooking

- Heat/cooking:
  - Common in China, India, African countries
  - Suitable for household plants
- District heating (big plants)
  - 75-90 % used energy
  - > 1000 ppm H_2S

CHP

- More common in countries like Denmark, Germany, Italy, France, England, ond others because power from biogas is regarded as renewable and CO2-free energy
  - Internal combustion engine (ICE) (30 – 40 % el)
  - Stirling engines (<30 % el)
  - Micro turbine (~30 % el)
- H_2S
  - ICE/SE < 200 ppm
  - Micro turbine
    < 50 ppm

Summing up

- AD is old technology
- Used for sanitation of sewage sludge
  - Different technology and treatment temperatures determines the reduction potentials of pathogens
- Nutrient recovery
  - P is mineralized and available
  - N – most in urine in the form of ammonia

When planning you want to know

- How much energy will the reactor produce?
- How big should the reactor be?
- What HRT should I use

- The engineer would ask:
  - What feedstock do you have?
  - What is the mass/volume of the feedstocks?

What to do

1. Calculate the total t.s. and VS
2. Decide if you have to add water (t.s. should be max. 15 % for pumps and pipes in heat exchanger)
3. Choose OLR and calculate HRT or choose HRT and decide if OLR is OK.
4. According to chosen HRT how much should BMP be reduced?
5. Calculate methane production multiplied with % of BMP
6. Mulitiply the answer with heat energy needed if you cannot use external energy.