

# Slides that can be used during the final exam (2025)

Applied wastewater engineering

Michael Jon MATTLE

# Specific (design) loading rates per population equivalent (PE)

item	specific (design) loading rates (g/PE·d)
COD	120
BOD <sub>5</sub>	60
TSS	70
TKN	11
P <sub>tot</sub>	1.8

values from DWA (ATV-A 131)

# How will the installations for oMP removal be financed?

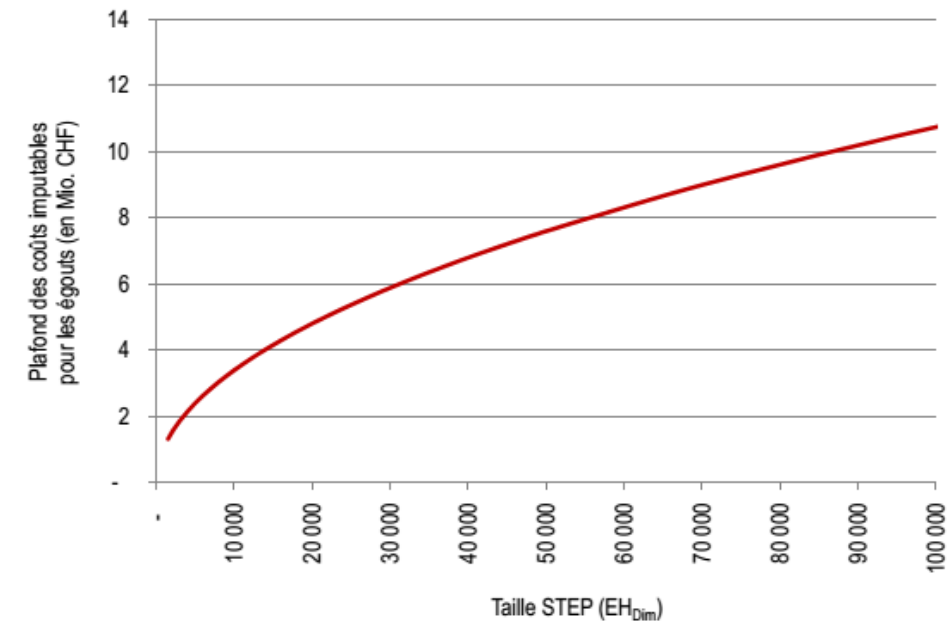
- maximum creditable costs for a sewer system are:

$$= 34'000 \sqrt{\text{size of WWTP}(PE)}$$

Fig. 3 > Plafond des coûts imputables des égouts en fonction de la taille de la STEP

coûts arrondis mathématiquement en milliers de francs.

$$\text{Plafond des coûts imputables des égouts} \\ = 34\,000 \cdot \sqrt{\text{taille STEP (EH}_{DIM})}$$



FOEN: Elimination des composés traces organiques dans les stations d'épuration : Financement des mesures

# Current choice of substances to monitor the 80 % removal of oMP

- removal efficiency is computed based on at least six substances
- proportion of substances of group 1 and group 2 has to be 2:1
- total removal efficiency (RE) corresponds to the average of the removal efficiency of each selected substance expressed in percent

	Substance	type of substance
<b>group 1:</b> very easy to remove with advanced oMP treatment	amisulpride	pharmaceutical psychiatric
	carbamazepine	pharmaceutical anticonvulsant
	citalopram	pharmaceutical antidepressant
	clarithromycin	pharmaceutical antibiotic
	diclofenac	pharmaceutical analgesic
	hydrochlorothiazide	pharmaceutical diuretic
	metoprolol	pharmaceutical beta blockers
	venlafaxine	pharmaceutical psychiatric
<b>group 2:</b> easy to remove with advanced oMP treatment	benzotriazole	anti-corrosive agent
	candesartan	pharmaceutical antihypertensive
	irbesartan	pharmaceutical antihypertensive
	4-methylbenzotriazole/ 5-methylbenzotriazole	anti-corrosive agent

- $$RE(\%) = \frac{RE_{substances\_1}(\%) + RE_{substances\_2}(\%) + \dots + RE_{substances\_n}(\%)}{n}$$

# oxidation processes

$$\frac{dc_{compound}}{dt} = -k_{compound,oxidant} c_{compound} c_{oxidant}$$

reaction rate constant [M<sup>-1</sup>s<sup>-1</sup>]

$$\ln \left( \frac{c_{compound,i}}{c_{compound,f}} \right) = k_{compound,oxidant} \underbrace{c_{oxidant} t}_{\text{oxidant dose}}$$

oxidant dose

# Ozone injection required

- ozone quantity necessary to achieve the required yield:

$$x \left[ \frac{kg_{O_3}}{kg_{DOC,sec. clarified wastewater}} \right] kg_{DOC,sec. clarified wastewater}$$

$$+ 3.43 \left[ \frac{kg_{O_3}}{kg_{NO_2^- - N, sec. clarified wastewater}} \right] kg_{NO_2^- - N, sec. clarified wastewater}$$

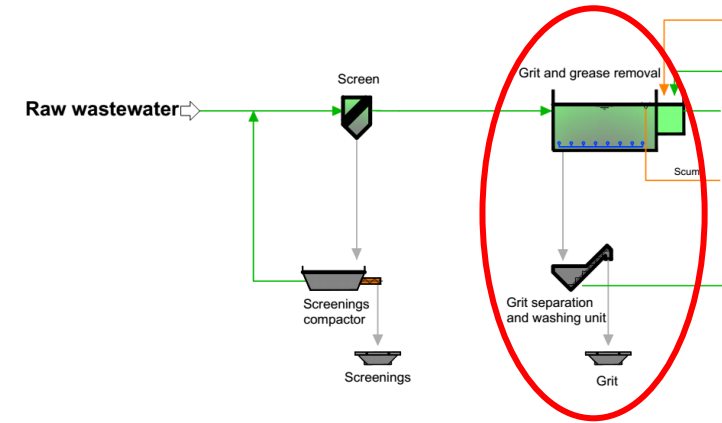
# Handling of screenings

Parameter	unit	range	typical
TS	% [kg TS/kg]	8 – 54	30
calorific value	MJ/kg	2 – 10	4.7 (35 % TS)
TVS	%	73 – 98	87
AOX	mg/kg	3 – 250	80
lead	mg/kg	1 – 63	22
copper	mg/kg	13 – 220	56
zinc	mg/kg	47 – 940	246
...			

# Screenings production

- practical computation of screenings production (TS between 8 and 15 %):
  - size opening  $> 3$  mm:
    - 30 – 300 L/1'000 m<sup>3</sup>
  - size opening  $< 3$  mm
    - static wedgewire screens: 200 – 400 L/1'000 m<sup>3</sup>
    - drum screens: 400 – 800 L/1'000 m<sup>3</sup>
- at the beginning of a heavy rain event (flushing of the sewer system), the volumes of screenings may increase substantially especially for combined sewer systems (up to 10 times) as compared to normal flow
  - additionally a security factor for rain should be added: 2 - 6

# Grit and grease removal



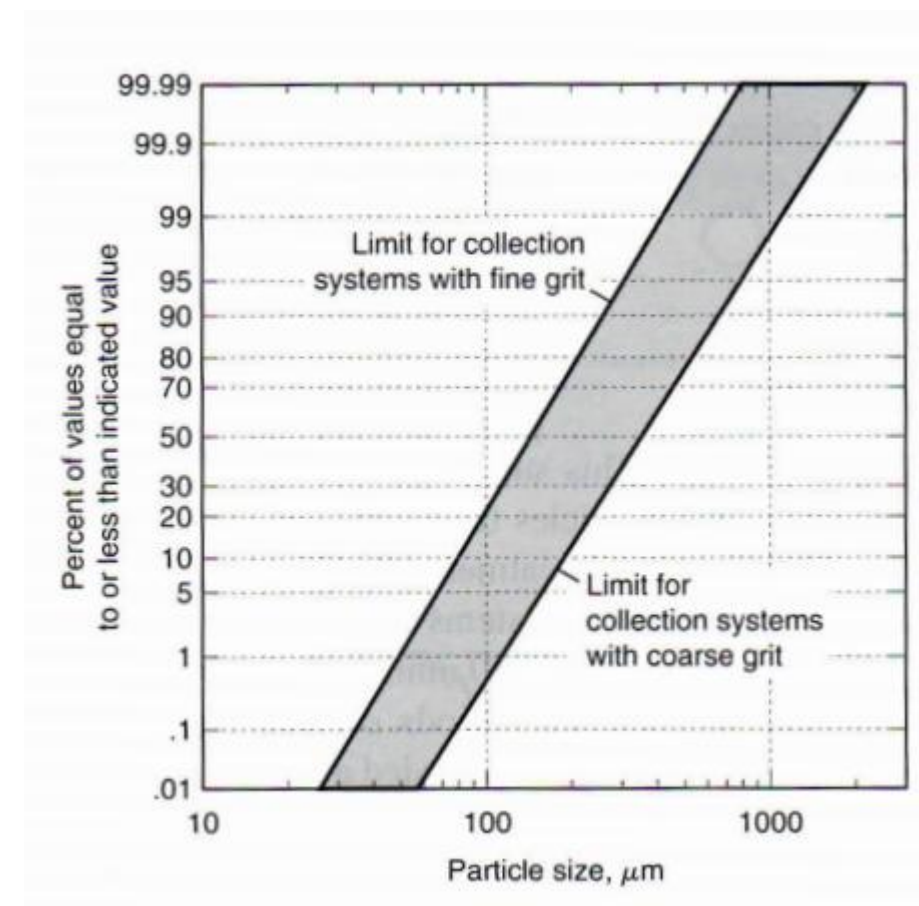
parameter	unit	range
specific volume	L/(PE·year)	2 - 5
specific weight	kg TS /(PE·year)	3 – 7.5
total solids	% [kg TS/kg]	40 - 70
total volatile solids (TVS)	% of TS	10 - 50

- all values depend highly on the site
- may contain considerable amount of organic material

# Grit removal

grit diameter	removal efficiency
0.3 mm	95 %
0.2 mm	85 %
0.15 mm	75 %
0.1 mm	50 %
< 0.07 mm	< 10 %

average achievable removal efficiencies of aerated grit removal (depends on hydraulic retention time and design)



typical particle size distribution range



# Typical sludge composition

parameter	untreated primary sludge (PS)		waste activated sludge (WAS)	
	range	typical	range	typical
total solids (TS) % [kg TS/kg]	1-6	3	0.4-1.2	0.8
total volatile solids TVS (% of TS)	60-85	75	60-85	70
grease and fats (% of TS)	5-8	6	5-12	8
protein (% of TS)	20-30	25	32-41	36
nitrogen (N, % of TS)	1.5-4	2.5	2.4-5	3.8
phosphorous (P <sub>2</sub> O <sub>5</sub> , % of TS)	0.8-2.8	1.6	2.8-11	5.5
cellulose (% of TS)	8-15	10	-	
iron (not as sulphide)	2-4	2.5	*	
silica (SiO <sub>2</sub> , % of TS)	15-20	-		
pH	5-8	6	6.5-8	7.1
alkalinity (mg/L as CaCO <sub>3</sub> )	500-1'500	600	580-1'100	790
organic acids (mg/L as HAc)	200-2'000	500	1'100-1'700	1'350
energy content, kJ/kg TVS	23'000-29'000	25'000	19'000-23'000	20'000

# Typical sludge composition



metal	range of dry solids, mg/kg TS
arsenic	1.18 – 49.2
cadmium	0.21 – 11.8
chromium	6.74 – 1160
cobalt	0.87 – 290
copper	115 – 2580
iron	1575 – 299'000
lead	5.81 – 450
manganese	34.8 – 14'900
mercury	0.17 – 8.3
molybdenum	2.51 – 132
nickel	7.44 – 526
selenium	1.1 – 24.7
tin	7.5 – 522
zinc	216 - 8550

Table: typical metal content in wastewater solids

# Quantities of primary sludge total solids (TS)

Primary sludge production				
minimal 2h- residence time (dry weather)	85 <sup>th</sup> percentile	50 <sup>th</sup> percentile	yield	TVS fraction
[h]	[g TS/(PE·d)]	[g TS/(PE·d)]	[%]	[%]
0.5	30	24	43	75
1.0	35	28	50	75
2.0	40	32	57	75

# Quantities of waste activated sludge (only C-treatment)

only carbon removing activated sludge plant (minimal sludge age 5 days)					
residence time in primary clarifier	temperature	sludge production		total volatile solids (TVS) fraction	
		85 <sup>th</sup> percentile	50 <sup>th</sup> percentile	85 <sup>th</sup> percentile	50 <sup>th</sup> percentile
[h]	[°C]	[g TS/(PE·d)]	[g TS/(PE·d)]	[%]	[%]
0.5	10	56	43	77	76
0.5	15	52	40	75	75
0.5	20	49	38	74	73
1.0	10	50	38	76	76
1.0	15	47	36	75	74
1.0	20	44	34	73	73
2.0	10	44	34	76	75
2.0	15	41	32	74	74
2.0	20	39	30	73	72

# Quantities of waste activated sludge (C- + N-treatment)

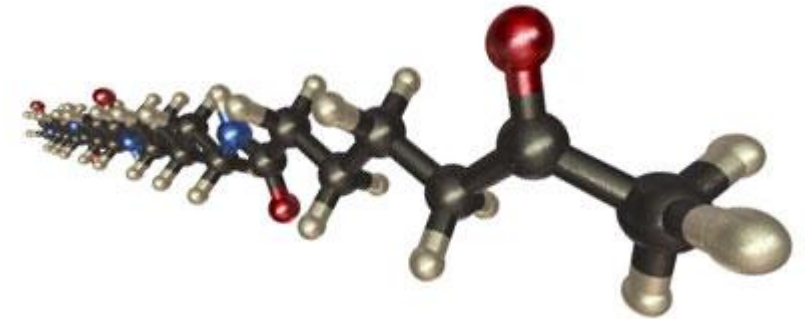
nitrifying activated sludge plant (minimal sludge age 10 days)					
residence time in primary clarifier	temperature	sludge production		total volatile solids (TVS) fraction	
		85 <sup>th</sup> percentile	50 <sup>th</sup> percentile	85 <sup>th</sup> percentile	50 <sup>th</sup> percentile
[h]	[°C]	[g TS/(PE·d)]	[g TS/(PE·d)]	[%]	[%]
0.5	10	49	37	73	73
0.5	20	43	34	70	70
1.0	10	43	33	73	72
1.0	20	39	31	70	70
2.0	10	29	29	72	71
2.0	20	28	28	69	71

# Sludge characteristics (total solids (TS) content)

operation or process application	total solids (TS) concentration (%) [kg TS/kg in %]	
	range	typical
primary sludge	1 - 6	3
primary and waste activated sludge	0.5 – 3	1.5
primary sludge and trickling filter humus	4 – 10	2
primary sludge with iron addition for phosphorous removal	0.5 – 3	2
waste activated sludge with primary settling	0.5 – 1.5	0.8
waste activated sludge without primary settling	0.8 – 2.5	1.3
trickling filter humus	1 – 3	1.5
rotating biological contactor waste sludge	1 -3	1.5

# Chemical conditioning

molecular weight	relative molecular weight
very high	> 6'000'000 – 18'000'000
high	1'000'000 – 6'000'000
medium	200'000 – 1'000'000
low	< 200'000

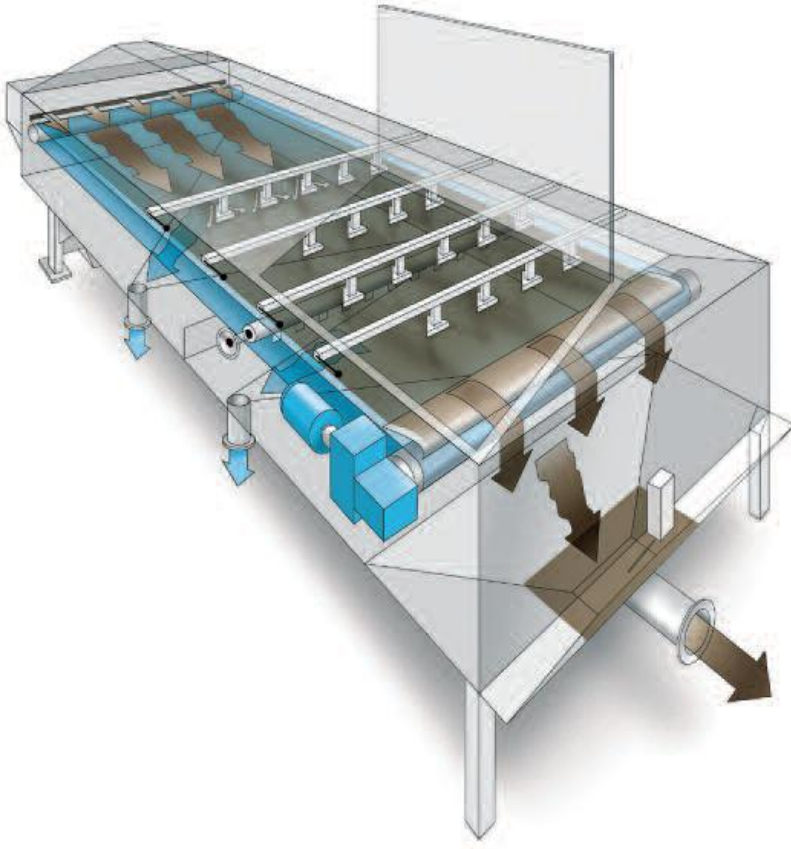


# Typical design parameters for gravity thickening

sludge sedimentation characteristics	sludge type	solids loading rate	maximum hydraulic overflow	solids concentration, % TS [kg TS/kg]	
		[kg TS/m <sup>2</sup> ·d]	[m <sup>3</sup> /m <sup>2</sup> ·d]	unthickened	thickened
bad	waste activated sludge	20 -50	4 - 8	0.5 – 1.5	2 – 3
intermediate	primary and waste activated sludge digested sludge	40 – 80	6 - 12	0.5 – 4	2 - 7
good	primary sludge	up to 100	15 – 31	1 – 6	3 - 10

# Mechanical thickening using natural gravity force

- hydraulic loading rates for gravity-belt thickeners (influent sludge at 0.5 – 1 %)



belt size (effective dewatering width)	hydraulic loading range
[m]	[l/s]
1.0	6.7 – 16
1.5	9.6 – 24
2.0	12.7 – 32
3.0	18 - 47

# Flotation thickening

- capture rate improved when using polymer (from 85 to 98 or 99 %)

type of sludge	surface loading rate [kg/m <sup>2</sup> ·h]	
	without chemicals	with polymers
mixed liquor (no clarification) waste activated sludge	1.2 – 3	up to 10
settled waste activated sludge	2.4 – 4	up to 10
primary and waste activated sludge	3 – 6	up to 10
primary sludge only	4 – 4	up to 12

# Summary of sludge thickening

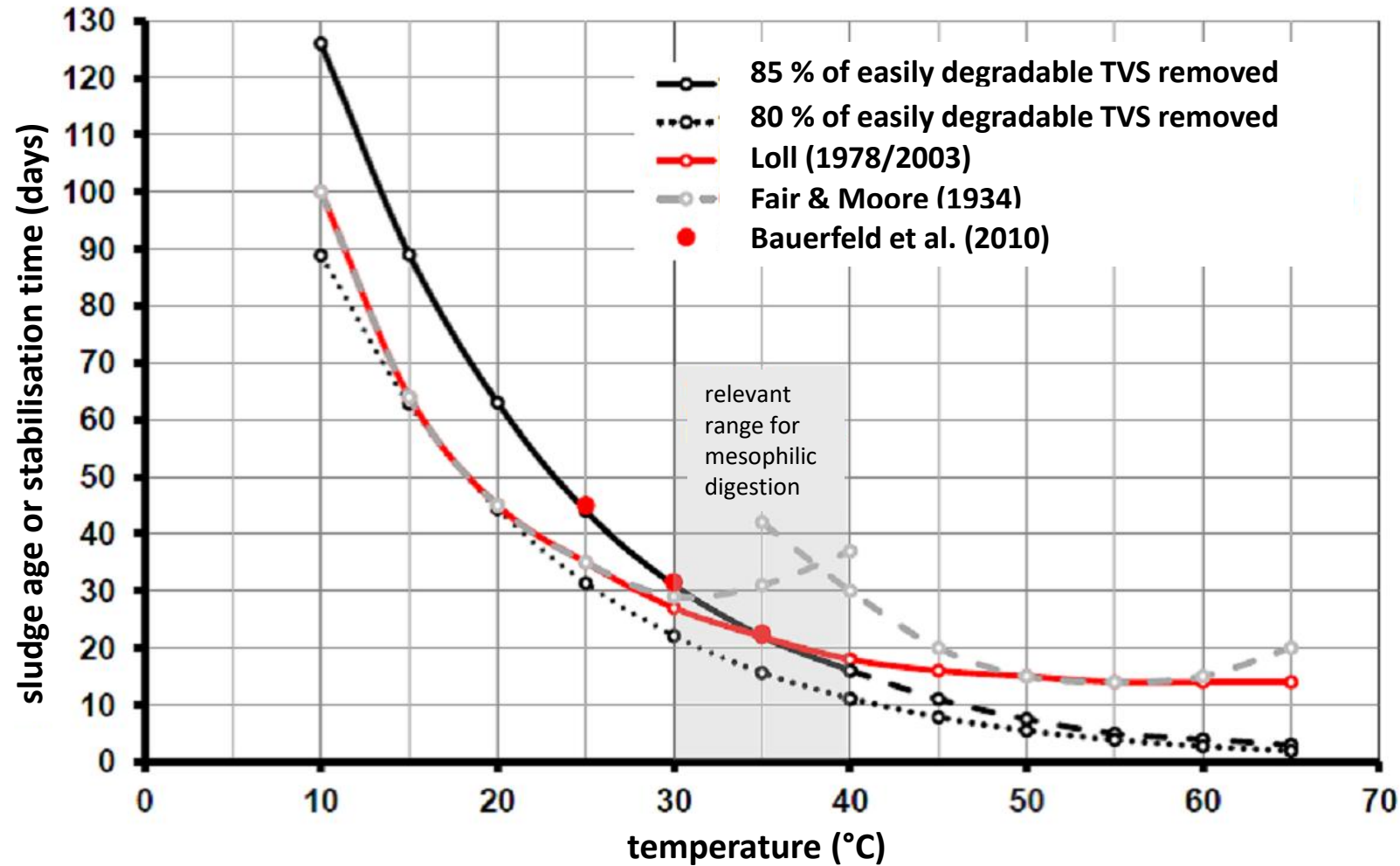
		gravity thickening		flotation	mechanical thickening	
		without polymers	with polymers		using natural gravity force	centrifuge
primary sludge	% TS [kg TS/kg]	5 – 10	-			
mixed sludge	% TS [kg TS/kg]	4- 6	5 – 8		5 – 8	5 – 8
waste activated sludge	% TS [kg TS/kg]	2 – 3	3 – 4	3 – 5	5 – 7	5 – 8
polymer use	kg/t TS	0	0.5 – 3	0	3 – 7	0 – 1.5
specific energy use	kWh/m <sup>3</sup>	< 0.1	< 0.1	0.6 – 1.2	< 0.2	1 – 1.4
specific energy use	kWh/t TS	< 20	< 20	100 – 140	< 30	180 -220

# Sludge stabilisation

process	degree of attenuation		
	pathogens	putrefaction	odour potential
anaerobic digestion	fair	good	good
advanced anaerobic digestion (higher temperatures)	excellent	good	good
aerobic digestion	fair	good	good
alkaline stabilisation	good	fair	fair
composting	good	good	fair to good

# Anaerobic digestion

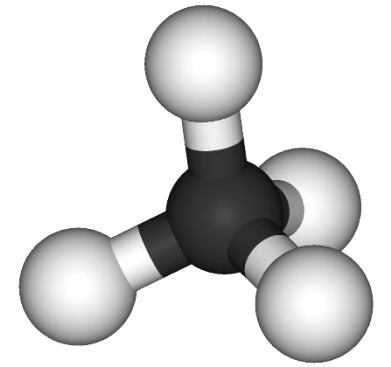
- increased temperatures reduce required sludge age
- temperatures above 40°C have little impact on required sludge age
- mesophilic range is most commonly used (requires heating)
- relatively high sludge age necessary to obtain a stable operation
- about 70 % of primary sludge total volatile solids (TVS) and 45 % of secondary sludge TVS are easily degradable



anaerobic sludge age required for single-staged digester using mixed sludge

# Biogas production

- about 0.95 Nm<sup>3</sup> per kg of TVS removed for primary sludge
- about 0.85 Nm<sup>3</sup> per kg of TVS removed for waste activated sludge
- about 20 Nlitres (normal litres) per population equivalent (PE) and per day



# Design parameters for anaerobic digesters

Size of wastewater treatment plant		< 50'000 PE	50'000 – 100'000 PE	> 100'000 PE
sludge age	days	20 – 28	18 – 25	16 – 22
loading factor with easily degradable volatile solids	kg TVS <sub>easily deg.</sub> /(m <sup>3</sup> ·d)	1.0 – 1.4	1.1 – 1.5	1.2 – 1.7
	kg COD <sub>easily deg.</sub> /(m <sup>3</sup> ·d)	1.7 – 2.3	1.8 – 2.6	2.1 – 2.9

# Summary of mechanical dewatering technologies

sludge type	unit	centrifuge	belt-filer press	filter press	screw press
final solids content % [kg TS/kg]					
primary sludge	%	32 – 40	30 – 35	32 – 40	30 – 40
mixed sludge	%	26 – 32	24 – 30	26 – 32	24 – 30
extended aeration sludge (no primary decantation)	%	18 – 24	15 – 22	18 – 24	18 – 24
anaerobically digested sludge	%	22 – 30	20 – 28	22 – 30	20 – 28

# Summary of mechanical dewatering technologies

sludge type	unit	centrifuge	belt-filer press	filter press	screw press
energy consumption (including conditioning and feed pump)					
specific energy consumption	kWh/m <sup>3</sup>	1.6 – 2.2	1.1 – 1.4	1.5 – 1.8	0.6 – 1.0
specific energy consumption	kWh/t TS	60 – 90	40 – 50	60 – 70	20 – 40
polymer use					
polymer consumption	kg/t TS	8 – 14	6 – 12	6 – 12	6 – 12

# Sources of bad odours

Odorous compound	Chemical formula	Molecular weight	Odor threshold, ppm, <sup>a</sup>	Characteristic odor
Ammonia	NH <sub>3</sub>	17.0	46.8	Pungent, irritating
Crotyl mercaptan	CH <sub>3</sub> -CH=CH-CH <sub>2</sub> -SH	90.19	0.000029	Skunk like
Dimethyl sulfide	CH <sub>3</sub> -S-CH <sub>3</sub>	62	0.0001	Decayed cabbage
Diphenyl sulfide	(C <sub>6</sub> H <sub>5</sub> ) <sub>2</sub> S	186	0.0047	Unpleasant
Ethyl mercaptan	CH <sub>3</sub> CH <sub>2</sub> -SH	62	0.00019	Decayed cabbage
Ethyl sulfide	(C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> SH	91.9	0.000025	Nauseating odor
Hydrogen sulfide	H <sub>2</sub> S	34	0.00047	Rotten eggs
Indole	C <sub>8</sub> H <sub>6</sub> NH	117	0.0001	Fecal, nauseating
Methyl amine	CH <sub>3</sub> NH <sub>2</sub>	31	21.0	Putrid, fishy
Methyl mercaptan	CH <sub>3</sub> SH	48	0.0021	Decayed cabbage
Skatole	C <sub>9</sub> H <sub>9</sub> NH	132	0.019	Fecal odor, nauseating
Sulfur dioxide	SO <sub>2</sub>	64.07	0.009	Pungent, irritating
Thiocresol	CH <sub>3</sub> -C <sub>6</sub> H <sub>4</sub> -SH	124	0.000062	Skunk like, irritating
Trimethyl amine	(CH <sub>3</sub> ) <sub>3</sub> N	59	0.0004	Pungent, fishy

<sup>a</sup> Parts per million by volume.

# How much air should be treated

- as a general simple rule

accessible or not?	workplace or not?	air exchange rates
not accessible	no workplace	3 – 4 times/hour
accessible	no workplace	4 – 6 times/hour
accessible	workplace	6 – 12 times/hour

# Typical design parameters for biological waste air treatment

parameter	units	biofiltres	biotrickling filters
optimum temperature	°C	15 – 35	15 – 35
moisture content	%	50 – 65	50 – 65
pH	unitless	6 – 8	6 – 8
porosity	%	35 – 50	35 – 50
surface loading rate	m <sup>3</sup> /(m <sup>2</sup> ·h)	50 – 100 (up to 200 possible depending on compound)	10 – 100
depth of medium	m	0.6 – 1.25	1 – 1.25
liquid application rate	m <sup>3</sup> /(m <sup>2</sup> ·d)		0.75 – 1.25
elimination capacity (H <sub>2</sub> S)	mg/(m <sup>3</sup> ·h)	80 – 130	80 – 130
elimination capacity (other odorous gases)	mg/(m <sup>3</sup> ·h)	20 – 100	20 – 100

# Efficiency of chemical scrubbing

- typical removal efficiencies for single-stage chemical scrubbers (hypochlorite wet scrubbers)
- higher efficiencies may be achieved with multi-stage scrubbers

gas	expected removal efficiency [%]	
	range	typical
hydrogen sulphide	90 – 99	98
ammonia	90 – 99	98
sulphur dioxide	90 – 96	95
mercaptans	85 – 92	90
other oxidisable compounds	70 – 90	85



# Typical design parameters for chemical scrubbers (with packing)

item	unit	value
packing depth	m	1.8 – 3
waste air residence time in packing	s	1.3 – 2.0
scrubbant flow rate	kg H <sub>2</sub> O/kg waste air flow	1.5 – 2.5
scrubbant flow rate	L/s per m <sup>3</sup> /s air flow	2 – 3
temperature	°C	15 – 40
caustic usage kg NaOH/kg sulphide	kg NaOH/kg sulphide	2 - 3

