Increased efficiency for biogas production and nutrient recycling

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Gravitational settling of pig slurry – a cheap separation method

1. Settling method
2. Laboratory settling demonstrations
3. Farm settling demonstrations
4. Anaerobic digestion of settled solids
5. Simple settling model
6. Concept for a centralised biogas plant
7. Pig slurry & digestate settling examples
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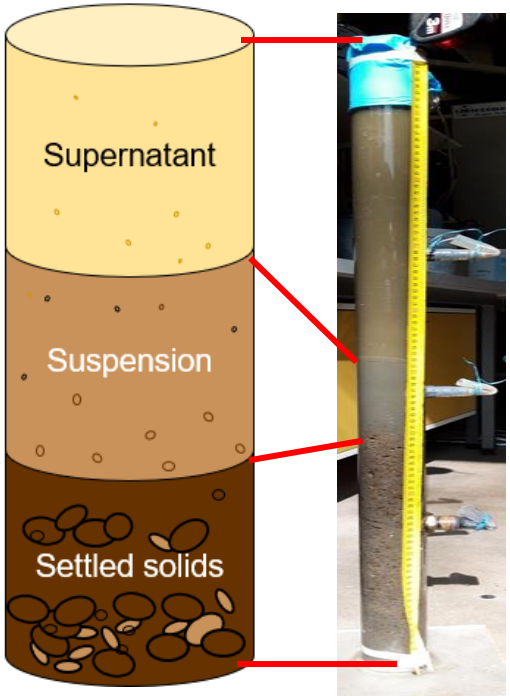
Gravitational settling of slurry

- Settling of particles in a liquid
- Small and less dense particles sink slowly (or float)
- After settling:

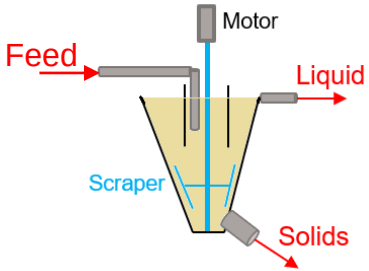
Supernatant zone:
”clear” liquid (smallest and/or least dense particles)

Suspension zone:
smaller and/or less dense particles

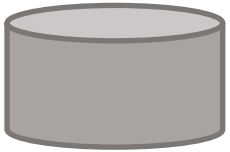
Thickening zone (settled solids):
largest and/or densest particles, compression of solids



Continuous clarifier:

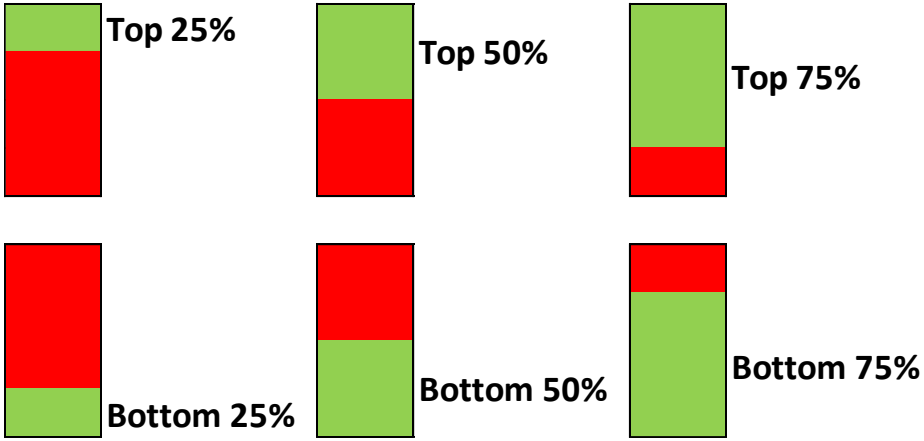


Batch or (semi-)continuous settling tank



Circwaste settling columns

- **Batch** settling in acrylic settling columns (1 m height)
- 3 tubes → **4 fractions** could be obtained (by draining one at a time)
- Analyses from each 4 fractions
- By calculation: properties of bottom half, bottom 3/4, top half…

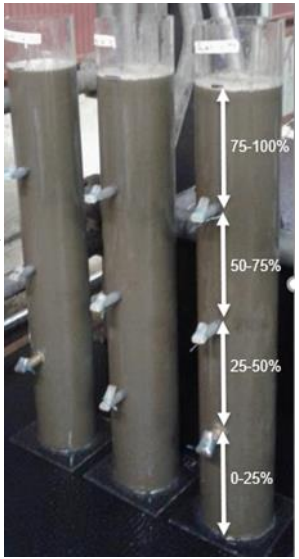


Laboratory demonstrations

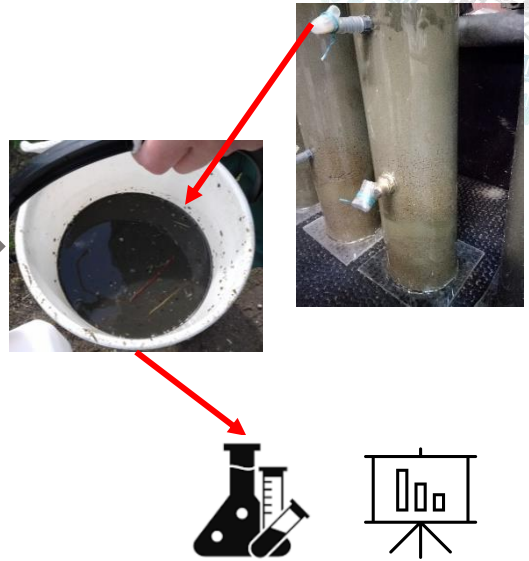
Mixing of slurry

Sampling & analyses of slurry

Settling in columns



Sampling & analyses of fractions



Laboratory settling results

Low dry matter (2-3%) slurry:

- Fast: only 0.3-1.3 days per metre of slurry depth
- High share of slurry dry matter phosphorus to bottom 25% fraction
- Less & wet settled solids (little compaction in the thickening zone)

High dry matter (6-9%) slurry:

- Slow (hindered) settling
  - Most settleable (biogas producing) dry matter settles in 25 days/m
  - Phosphorus settles in 50-60 days/m, because large portion of P is in small particels
- More & drier settled solids (consolidation = compression of solids)

Farm demonstrations

Mixing of slurry

Sampling & analyses of slurry

Settling in a sea container

Pumping & sampling & analyses of fractions

Farm settling results / observations

- ~1 or 2 metre slurry height in sea container, similar results as in 1 m laboratory columns
- After settling 2 m of high DM (8%) slurry (52 days)
  - Loss of water by evaporation & loss of (organic) dry matter by microbial activity
  - Top fractions were removed with a powerful pump
  - The pump could not remove the settled solids (DM 15%) → excavator/scraper needed?

Anaerobic digestion of settled solids

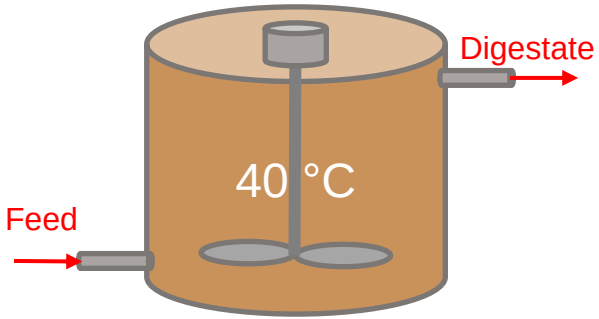
Biochemical Methane **Potential** (BMP)

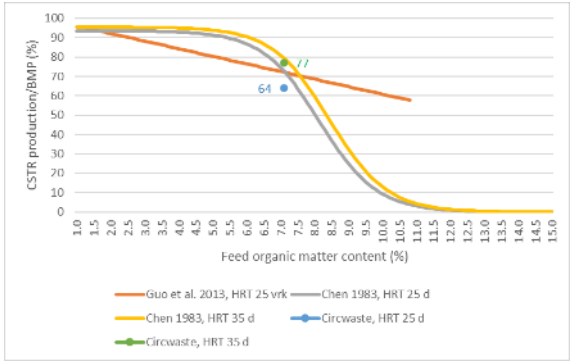
- Feed
- Digestates

Digestion of solids in continuous stirred reactors (CSTR)

- ”Economic” retention time 25 d
- ”Enviro-friendly” retention time 35 d

Calculation of CSTR production/BMP ratio & comparison to literature

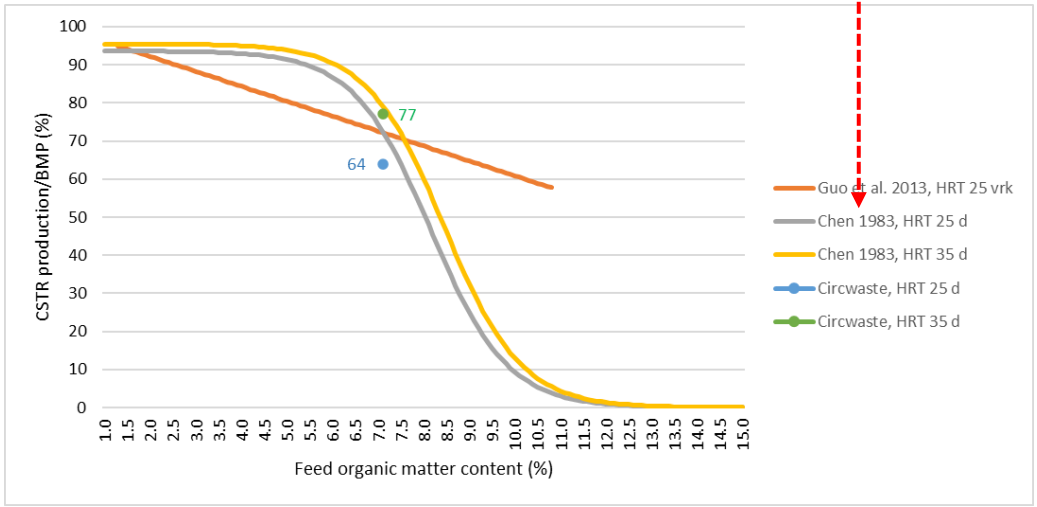




Continuous solids digestion results

- ”Economic” 25 d retention time: 17% higher total methane production per reactor volume (compared to 35 d retention), but production was only 64% of methane potential
- ”Enviro-friendly” 35 d retention time: 77% of methane potential was achieved → less methane emissions from digestate
- Settled solids had 9% dry matter and 7% organic matter
  - Higher organic matter pig slurry solids might be a challenging feedstock for biogas plants without more dilute co-feedstock (according to literature)

Retention time (d)	25	35
Organic loading rate (kgVS/(m^3*d)	2.8	2.0
Feed dry matter (%)	9.3	9.3
Feed organic matter (VS%)	7.1	7.1
Feed BMP (m^3 CH_4/t_{VS})	346	346
CSTR production (m^3 CH_4/t_{VS})	222	265
CSTR production / BMP (%)	64	77
CSTR prod. m^3 $CH_4/m^3_{reactor}$/d	0.63	0.54
Digestate BMP (m^3 CH_4/t_{VS})	226	141



Simple settling model (pig slurry ~5-9% DM)

Separation efficiency (% of mass components of slurry) to BOTTOM fractions:

Fraction	Dry matter	Organic matter	Methane potential	N	Soluble N	P	K
Mixed slurry (100%)	100	100	100	100	100	100	100
Bottom 75%	91	93	90	79	75	94	73
Bottom 50%	79	83	77	56	51	81	49
Bottom 25%	56	61	48	30	25	52	23

*Examples: Whole mixed slurry has 6.7% dry matter content. Dry matter content of Bottom 25% fraction = 6.7% * (56/100) / 0.25 = 15.0%. Dry matter content of Bottom 50% fraction = 6.7% * (79/100) / 0.5 = 10.6%.*

Bottom 25% fraction contains ~50 % of dry matter, methane production potential and phosphorus of the whole mixed slurry (all fractions combined)

Reversed table: separation efficiency to TOP fractions:

Fraction	Dry matter	Organic matter	Methane potential	N	Soluble N	P	K
Top 25%	9	7	10	21	25	6	27
Top 50%	21	17	23	44	49	19	51
Top 75%	44	39	52	70	75	48	77
Mixed slurry (100%)	100	100	100	100	100	100	100

Top 25% fraction contains very little dry matter, methane production potential and phosphorus

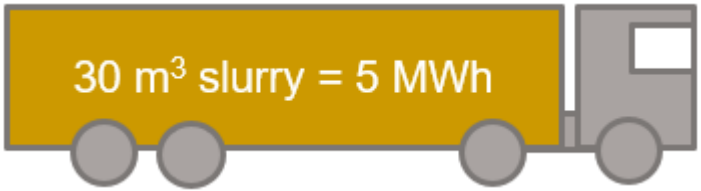
Increased efficiency for biogas production

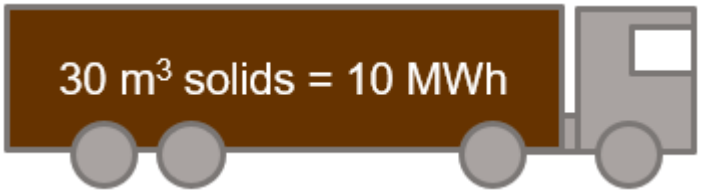
https://jukuri.luke.fi/handle/10024/540238

Bottom fractions have higher energy density per tonne and phosphorus content than slurry

- More economic transportation
- Higher net energy production in a biogas plant

Fraction	DM (%)	Total N (kg/t)	Soluble N (kg/t)	P (kg/t)	CH_4 pot. (kWh/t)	Bottom fraction compared to slurry
Slurry	6.7	4.0	2.6	0.92	171	-
Bottom 75%	8.1	4.2	2.6	1.15	205	20% more CH_4 per tonne, 25% higher P content
Bottom 50%	10.6	4.5	2.6	1.49	263	54% more CH_4 per tonne, 62% higher P content
Bottom 25%	15.0	4.8	2.6	1.91	328	92% more CH_4 per tonne, 108% higher P content



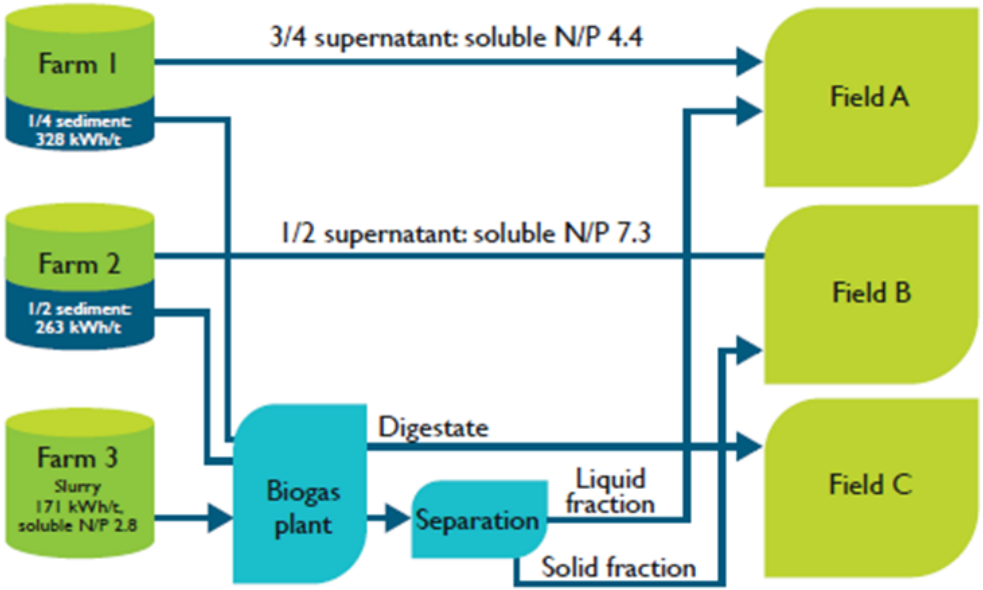


Increased efficiency for nutrient recycling / fertilisation

Top fractions have lower phosphorus but similar soluble nitrogen content as slurry → when using top fractions as fertiliser instead of slurry, more soluble N can be applied on a field when phosphorus fertilisation is restricted

Fraction	DM (%)	Total N (kg/t)	Soluble N (kg/t)	P (kg/t)	Sol. N/ P ratio	Fertiliser application rate when max 5 kg P/ha is allowed
Top 25%	2.4	3.4	2.59	0.22	11.8	22.7 t/ha = 59 kg sol. N/ha (320% more than slurry)
Top 50%	2.8	3.5	2.54	0.35	7.3	14.3 t/ha = 36 kg sol. N/ha (160% more than slurry)
Top 75%	3.9	3.7	2.59	0.59	4.4	8.5 t/ha = 22 kg sol. N/ha (60% more than slurry)
Slurry (100%)	6.7	4.0	2.59	0.92	2.8	5.4 t/ha = 14 kg sol. N/ha

Concept for a centralised biogas plant



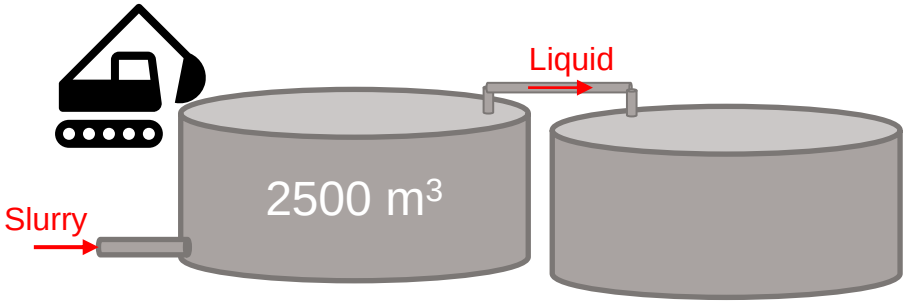
- Unseparated slurry from nearby farms to biogas plant
- Settled solids transported to biogas plant from further away
  - The low-phosphorus supernatant is used as a nitrogen fertiliser on farms
- Digestate can also be separated by settling or by other, more efficient methods (decanter centrifuge, ammonia stripping, drying etc.)

Pig slurry & digestate settling examples

Pig slurry settling

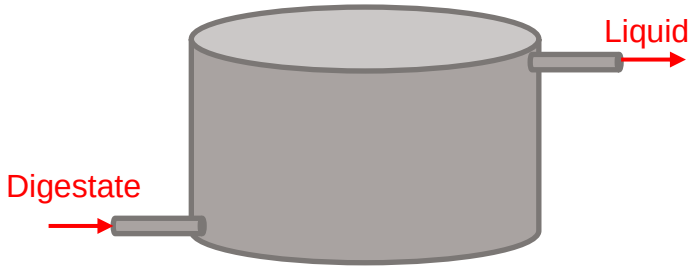
Timo Heikkilä's farm (Rusko, Southwest Finland)

- 2500 m^3 settling tank
- Semi-continous pumping of top liquid to another tank
- Solids with high P content removed with an excavator and transported 80 km to a crop farm



Continuous settling of pig slurry digestate

- Biopir Oy (Vehmaa, Southwest Finland)
- Starting soon: Nurmon Bioenergia Oy (Nurmo, South Ostrobothnia), also settling of pig slurry on farms?



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Methane potential of settled solids in Southwest Finland & suitable biogas plant locations

Biomass Atlas https://biomassa-atlas.luke.fi/?lang=en

- Southwest Finland: 550 000 t/year of pig slurry annually → 275 000 t of bottom 50% fraction → 72 GWh/year methane potential
- Optimal locations for two biogas plants (Loimaa and Vehmaa) digesting settled solids (bottom 50%) → 20 GWh/year methane potential

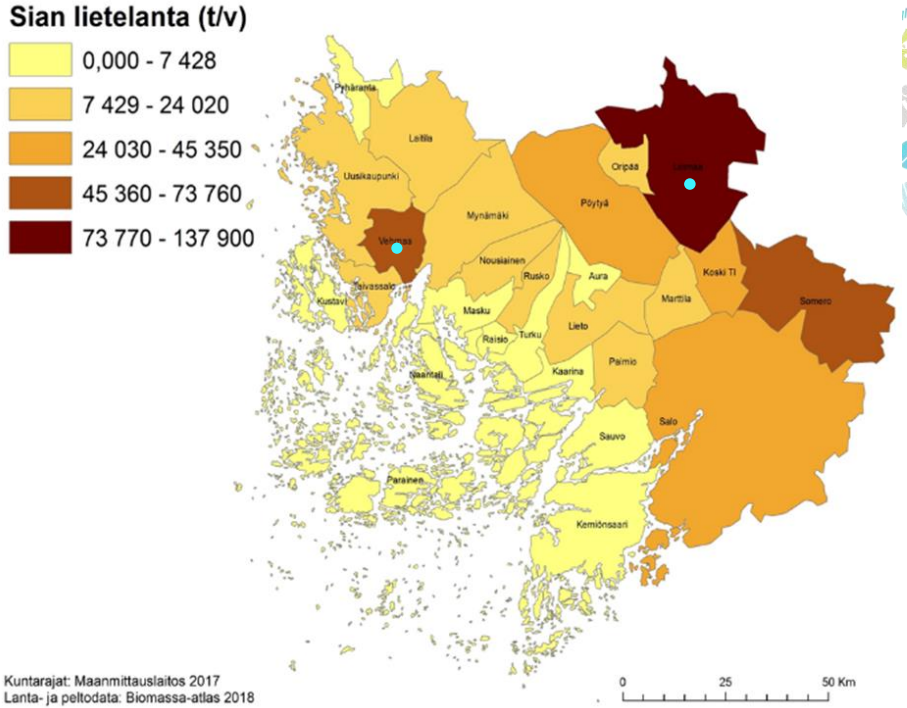

Table 10. Nutrient and methane potential concentrations for top fraction (50-100%) and bottom fraction (0-50%) of slurry settling, calculated with the separation efficiency model.

	DM (%)	OM (%)	BMP (kWh/t)	N (kg/t)	Sol. N (kg/t)	P (kg/t)	Sol.N/ P ratio
Slurry ex storage (0-100 %)	6.7	5.3	171	4.0	2.6	0.9	2.8
Top fraction 50-100 %	2.8	1.8	79	3.5	2.5	0.3	7.3
Bottom fraction 0-50 %	10.6	8.9	263	4.5	2.6	1.5	1.8

Table 11. Amounts of bottom fraction (lower half of slurry "column") feedstocks for centralized biogas plants in Southwest Finland and their methane potential and amount of nutrients.

	Bottom fraction (t/a)	BMP (MWh/a)	N (t/a)	Sol. N (t/a)	P (t/a)	K (t/a)	Sol.N/P ratio
Loimaa region	46 750	12 310	210	124	70	83	1,8
Vehmaa region	28 750	7 570	129	76	43	51	1,8

Thank you!

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