Stimulation of aerobic and anaerobic biological processes by ultrasound

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Outline

Full scale applications of ultrasound
  • Anaerobic Sludge Digestion
  • Aerobic Activated Sludge Process

Ultrasound / acoustic cavitation - principles

Ultrasound on aerobic biomass - recent research
Volatile solids reduction by anaerobic degradation

VS reduction [%] vs. Digestion time [d]

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Anaerobic Digestion Improvement

• the rate determining step of anaerobic sludge degradation is sludge hydrolysis

• scientific/technical approach to overcome limitations: disintegration of sludge prior to fermentation
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Bamberg WWTP, Germany

Ultrasound installation in 2004:
Sonication of 30% (in 2004) - 80% (in 2007) of the TWAS
(~ 70 – 100 m³/d) @ 2 - 3 kWh/m³
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![Graph showing biogas production and VS degradation from 2003 to 2010.]

- Biogas production in 1000 m³/a
- VS degradation [%]


- Biogas production:
  - 2003: 1700 m³/a
  - 2004: 1500 m³/a
  - 2005: 1800 m³/a
  - 2006: 2000 m³/a
  - 2007: 2200 m³/a
  - 2008: 2400 m³/a
  - 2009: 2800 m³/a
  - 2010: 3000 m³/a

- VS degradation (%):
  - 2003: 30%
  - 2004: 35%
  - 2005: 30%
  - 2006: 35%
  - 2007: 40%
  - 2008: 45%
  - 2009: 50%
  - 2010: 55%
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Combating foaming digester

activated sludge tank → secondary clarifier → WAS thickener → WAS sonication

100 %
digester
Meldorf WWTP, Germany

Compact Generator for Five Sonotrodes

Instrumentation Panel *

Optional Sound Enclosure

Sonolyzer™ 5 kW Reactor Module

* Customized for this plant
Activated Sludge Process Improvement

Bünde WWTP

Status in 2006
- Designed for 40.000 pe Load
- 54.000 pe Nitrification/Denitrification
- Sludge age Θ=22 d
- Bulking sludge in winter
- Low dewaterability of sludge

Results
- Significant reduction of N in effluent (N < 5mg/l)
- No foam/bulking sludge on AS tanks
- Reduction of excess sludge by 25%
- Dewaterability of digested sludge +2%

Test
- March – June 2006
- US on partial stream of WAS (30%)
- Back in anoxic zone
- Installation of US system Sept 2006
Activated Sludge Process Improvement

Bünde WWTP – enhancing N removal

primary sedimentation → activated sludge tank → secondary clarifier

WAS thickener

WAS sonication

30% → 70%
Activated Sludge Process Improvement

**Seevetal WWTP - Bulking Sludge Control**

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Seevetal WWTP – no US control
Ultrasound / Acoustic Cavitation - Principles
Ultrasound / Acoustic Cavitation - Principles

Sound pressure
\[ P = P_A \cdot \sin2\pi f t \, (\text{kPa}) \]
\[ (P_A)^2 = 2I \cdot \rho \cdot c \]

\( I = \text{sound intensity} \, (\text{W/cm}^2) \)
\( c = \lambda f \, (\text{m/s}) \)
\( \lambda = \text{wave length} \, (\text{m}) \)
\( f = \text{frequency} \, (\text{s}^{-1}) \)

Sound waves

Radius of bubbles in μm

- Creation
- Growth
- Implosion
- Hot Spot

Time in μs

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Acoustic Cavitation

Ultrasonic horn

Ultrasonic pressure field
Ultrasonic Impact on Activated Sludge (Biomass)

- sludge floc
- liquid
- bacteria
- inert particle
- extra-cellular polymer

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Ultrasonic Impact on Activated Sludge (Biomass)

Impact on soluble phase (< 0.45µm) – COD

Waste activated sludge sample, thickened: TS = 6.5%, VS = 74.1%
Ultrasonic Impact on Activated Sludge (Biomass)

Impact on soluble phase – proteins

**Activated sludge WWTP Seevetal**

- $y = 0.5565x + 0.836$
  - $R^2 = 0.9013$

- $y = 0.8956x + 4.6708$
  - $R^2 = 0.8335$

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Ultrasonic Impact on Activated Sludge (Biomass)

Oxygen Uptake Rate

Activated sludge WWTP Seevetal

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Ultrasonic Impact on Activated Sludge (Biomass)

Enzymatic activity

Energieeintrag [Wh/l]

INT-DHA us / INT-DHA₀

Messwerte • Median

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Ultrasound on activated sludge and *M. parvicella*

- Scanning electron microscopy, SEM
- Transmission electron microscopy, TEM
Activated Sludge - Scanning electron microscopy

Activated sludge floc
Activated Sludge - Scanning electron microscopy

10 (Wh/L)

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Activated Sludge - Scanning electron microscopy

Activated sludge floc

no US

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Activated Sludge - Scanning electron microscopy

9 (Wh/L)
Activated Sludge - Scanning electron microscopy

20 (Wh/L)

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M. parvicella - SEM

2 (Wh/L)

5 (Wh/L)
M. parvicella - TEM

a) 0.5 µm

b) 200 nm

10 (Wh/L)
Ultrasound /Acoustic Cavitation - Principles

**Sound pressure**

\[ P = P_A \cdot \sin 2\pi f \cdot t \]

\[ (P_A)^2 = 2I \cdot \rho \cdot c; P_A = a \cdot \sqrt{I} \]

\[ I = \text{Sound intensity (W/cm}^2) \]

\[ c = \lambda \cdot f \text{ (m/s)} \]

**Example**

f=20 kHz \((20,000s^{-1})\), \(c=1,500 \text{ ms}^{-1}\) in water, \(\lambda=7.5 \text{ cm}\),

*Ultrasound sonotrode operates at* \(I = 25 \text{ (W/cm}^2)\)

\[ \rightarrow P_A = 8.5 \cdot 10^5 \text{ N} \cdot \text{m}^{-2} \text{ or sound pressure oscillations between} \]

+8.5 to –8.5 atm \((\text{at 20,000 times per second})\)
Ultrasound impact on biomass

Conclusion

The impact of high-power ultrasound at low/moderate energy input on microbial biomass is caused by cavitation and sound pressure oscillations:

• **floc deagglomeration**
  better diffusion and mass transfer of substrates and oxygen,
  release of extracellular EPS (proteins, carbohydrates,...)

• **cell wall opening and damage**
  cytoplasm is „attacked“ and released,
  release of well degradable soluble DOC,
  release of proteins

  ......

• intensifies aerobic as well as anaerobic processes
Thank you for your attention

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