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13th IWA Specialized Conference on Small Water and Wastewater Systems

5th IWA Specialized Conference on Resources-Oriented Sanitation

Athens, Greece, 16.09.2016

Impacts of blackwater co-digestion upon biogas production in pilot-scale UASB and CSTR reactors

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Outline

- Motivation
- Objectives
- Materials and Methods
- Results and Discussion
- Conclusion and Outlook

Motivation

Motivation

Why shall we use source-separated sanitation?

- **External pressures**, e.g. climate change, demographic change, scarcity of water, nutrients and energy
- Source-separated sanitation
  - ➢ is **flexible** and highly **adaptable** to face external pressures
  - ➢ allows easy **(re-)use of nutrients and energy**
  - ➢ allows **water savings**, especially by the use of vacuum toilets

Motivation

How will source-separated sanitation effect our existing wastewater treatment plants?

Basics assumptions:

- **Implementation** into existing water infrastructure will be **incremental**
- Conventional **anaerobic digestors** (for sludge stabilisation) usually have **large reserves** (up to 25%)

Assumptions for future wastewater composition:

- **Highly concentrated blackwater** from vacuum toilets or
- Blackwater from source-separated sanitation will be dilluted in the existing sewer system, resulting in a **higher concentration of nutrients and carbon compounds in municipal wastewater**

Objectives

Objectives

1. To find methods to **treat blackwater as a co-substrate for sludge digestion** and to **treat wastewater with increasing concentrations** of nutrients and carbon compounds
2. To determine **effects upon operation stability**, methane yield and COD elimination

Materials and Methods

Materials and Methods

Substrates - Blackwater

Blackwater was collected from vacuum toilets installed in the **LFKW at the University of Stuttgart** plus blackwater from the **local railway company**

Table 1. Chemical characterisation of blackwater from vacuum toilets (6 toilets, approx. 20 toilet users per day) of the LFKW at the University of Stuttgart.

Parameter	Unit	Mean value	Standard deviation	Median value	Min-max	Number of values (n)
pH	-	7.3	± 0.4	7.2	6.7 – 8.6	33
COD	mg/l	11,556	± 4,717	10,700	3,350 – 25,800	86
$COD_{soluble}$	mg/l	2,995	± 998	3,050	1,090 – 5,380	51
BOD_5	mg/l	5,772	± 1,601	5,989	3,750 – 7,424	5
TS	g/kg	8.6	± 3.2	8.1	4.1 - 20	77
VS	% TS	72.1	± 7.4	74.0	46.9 – 84.3	77

- 1/3 of COD is soluble → easy accessable for bacteria
- Solids content of 8.6 g/kg and organic content of 72.1% VSS

Materials and Methods

Substrates – sludge and municipal wastewater

Table 2: Chemical characterisation of sludge, municipal wastewater and blackwater from the local railway company

Wastewater stream	TS	VS	COD	$COD_{soluble}$	TSS	pH
	g/kg	%TS	g/l	g/l	mg/l	-
Mixed sludge	25.3±7 (n=28)	83.4±3.5 (n=28)	35.7±7 (n=28)	-	-	-
Municipal wastewater admixed with blackwater	-	-	3.5±3.2 (n=121)	0.22±0.16 (n=52)	2348±2632	-
Blackwater from the local railway company	4.0-10.0 (n=8)	37.7-68.2 (n=8)	2.9–12.6 (n=9)	-	-	7.2–8. (n=7)

- Mixed sludge was grinded before application
- Municipal wastewater was obtained from the LFKW
- Blackwater from the local railway company was used for load completion

Materials and Methods

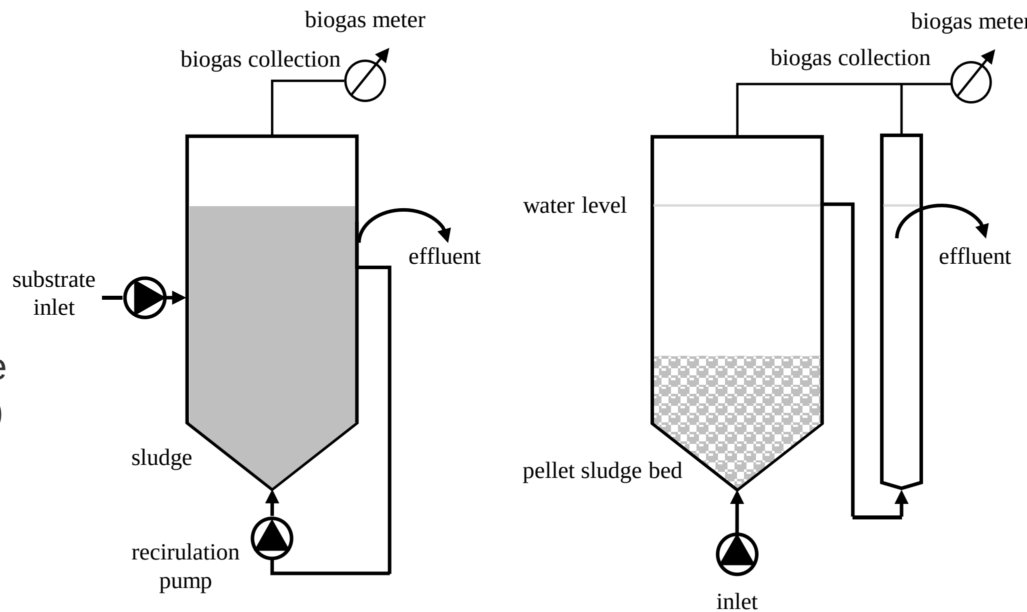
Anaerobic treatment method

- Continuosliy stirred reactor **(CSTR)** type was used for sludge treatment
- Upflow anaerobic sludge blanket **(UASB)** reactor was used for municipal wastewater treatment
- Both reactors had a **start-up time** (75 and 73 days)
- Increasing volumes of **blackwater** were **admixed to the substrates** and kept in storage tanks at 15°C
- Subtrates were **fed semi-continuosly in the case of the CSTR** every hour and **continuosly in the case of the UASB**

Materials and Methods

Setup of CSTR and UASB

HRT_{CSTR} = 21d
T = 34°C
V = 630L
primary and secondary sludge at a ratio 3:1 (v/v)



HRT_{UASB} = 10h
T = 34°C
V = 720L

Figure 1. Schematic set-up for CSTR (left) and UASB (right) reactors; substrate storage tanks are not depicted.

Results and Discussion

Results and Discussion

COD loading rates

Table 3: COD loading rates to the CSTR reactor (average ± standard deviation (number of values))

Transition state	$[COD_{BW}/COD_{tot} * 100\ \%]$ at the reactor inlet	0	1,8 ± 0,6 (12)	2,8 ± 0,6 (3)	18,3 ± 3,8 (7)	24,6 ± 6,7 (10)	33,8 ± 4,0 (9)
CSTR	[kg COD/(m³d)]	0,93 ± 0,5 (21)	1,6 ± 0,4 (17)	1,7 ± 0,3 (6)	1,2 ± 0,3 (13)	1,1 ± 0,2 (10)	0,9 ± 0,2 (11)

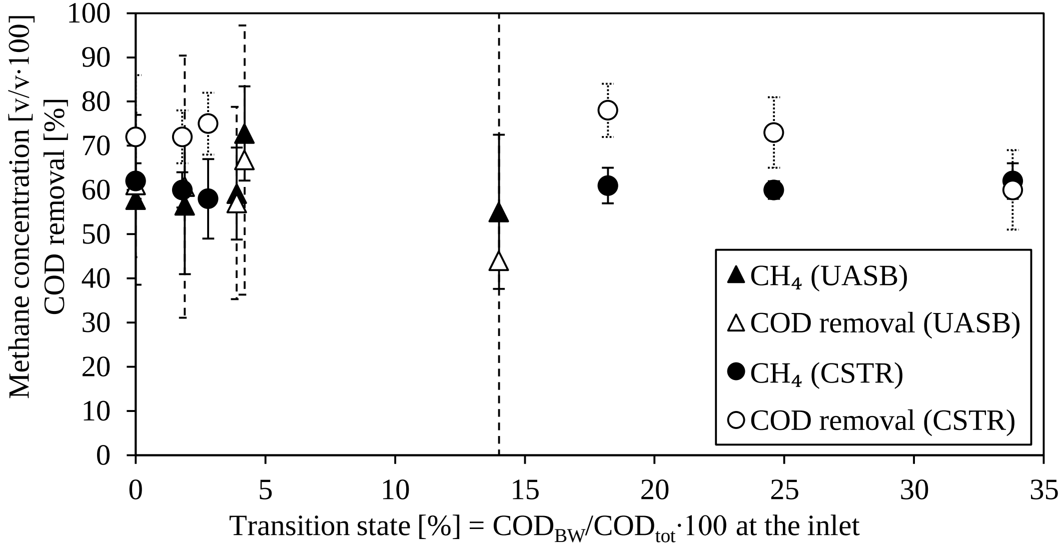
Table 4: COD loading rates to the UASB reactor (average ± standard deviation (number of values))

Transition state	$[COD_{BW}/COD_{tot} * 100\ \%]$ at the reactor inlet	0	1,9 ± 1,6 (20)	3,9 ± 3,5 (26)	4,2 ± 3,4 (28)	14,0 ± 17,2 (28)
UASB	[kg COD/(m³d)]	6,8 ± 2,5 (5)	6,1 ± 3,4 (17)	8,4 ± 6,2 (27)	7,8 ± 6,2 (28)	7,7 ± 7,4 (28)

- CSTR: COD loading rate decreases due to dillution by blackwater
- UASB: COD loading rate is not linked to increasing blackwater concentrations but with varying COD concentrations in municipal wastewater

Results and Discussion

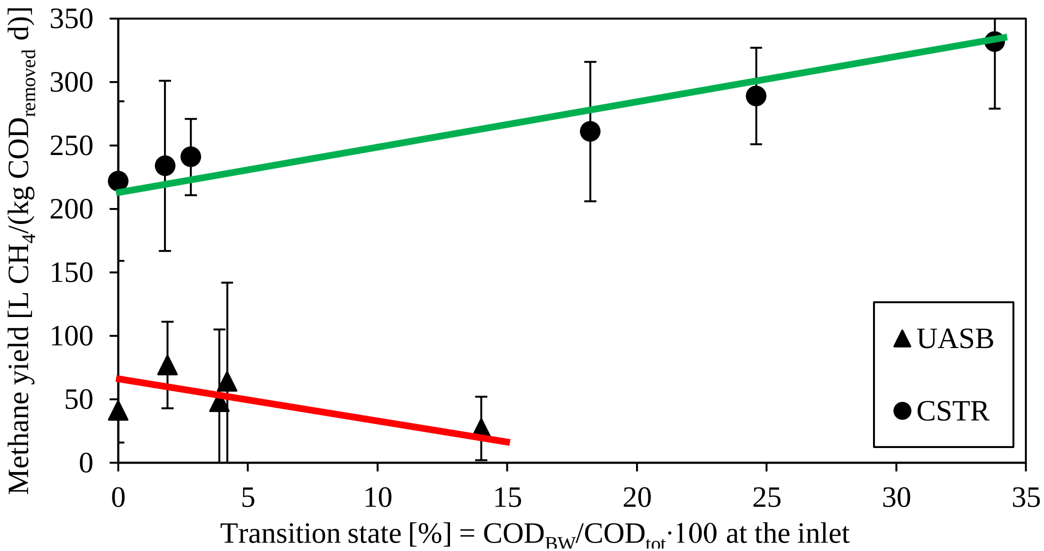
Methane concentration and COD elimination during different transition states



- **CSTR: not affected by blackwater**; slight increase of methane concentration at higher transition states
- **UASB: increase in biogas quality** and COD removal efficiency (except for malfunction at 14% transition state)

Results and Discussion

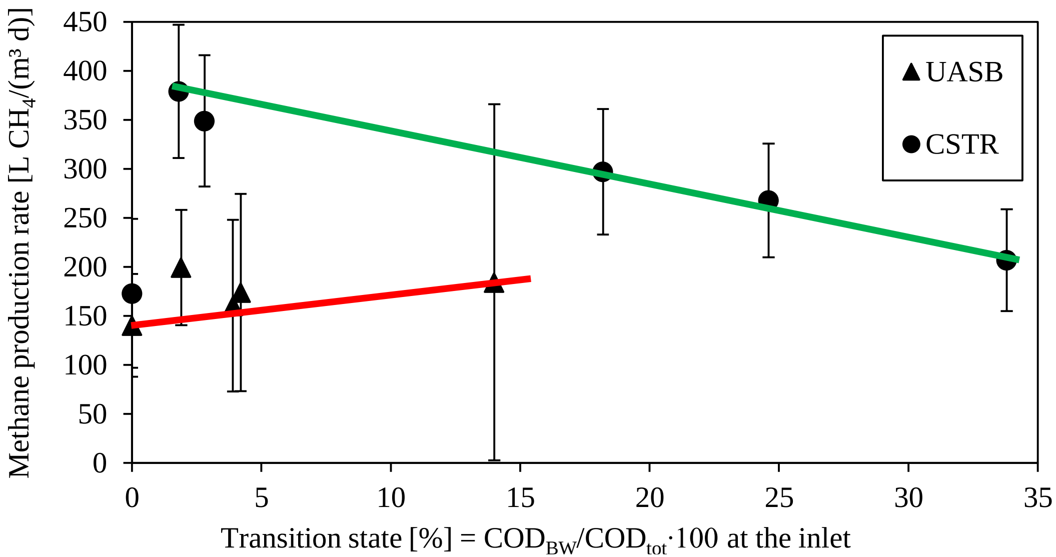
Methane yield during different transition states



- **CSTR: increase in methane yield** due to lower organic loading rates and better degradability of blackwater
- **UASB: COD was not digested** properly and accumulated (can be ascribed to the modified design)

Results and Discussion

Methane production rate during different transition states



- **CSTR: methane production rate decreased** due to lower organic loading rates
- **UASB: no statement can be made** due to high standard derivations

Conlusion and Outlook

Conclusion and Outlook

- For the investigated transition states for blackwater, co-digestion may be achieved in two alternative solutions:

  integration of anaerobic blackwater treatment into existing CSTR tanks for sewage sludge digestion or

  combined wastewater and blackwater treatment within a UASB reactor

- **Removal of organic matter was successfully** carried out in both cases.

  CSTR: COD removal ranged from approx. **70–78 %** up to 25 % transition, while at a high transition state of approx. 35 % blackwater (%COD) in the influent 60 % COD removal were reported.

  Within the **UASB** reactor, COD removals of **57–67 %** were achieved previous to the process failure.

Conclusion and Outlook

- **Co-digestion of blackwater** with raw sludge proved better in terms of biogas generation within the CSTR reactor; **increasing methane yields of 222 to 332 l CH_4/kgCOD$_{removed}$** were reported at blackwater load fractions in the influent (% COD) of 0 to 35 % respectively. For the UASB no statements with regards to methane yield could be made.
- Despite fluctuations in the substrate composition a **stable operation of the CSTR** was reported, which was supported by relatively constant methane concentrations in **biogas of approx. 60 %** as well as **COD removal efficiencies >60 %** over the entire CSTR operation.
- The incremental **blackwater displacement to the anaerobic stage favours biogas production.**
- Further research about effects of inert COD on nitrogen removal stages has to be conducted.

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Thank you!

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