Optimization of biomass mixing in biogas digesters

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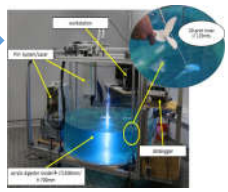
Research issue

- Mixing is a crucial process in anaerobic biodigesters → Homogeneous concentration of biomass leads to an efficient biogas production
- Mixing contributes most to the parasitic electrical energy consumption of a biogas plant (up to 50%) → 35,040 €/a (plant 500 kW rated yearly power, 8% parasitic energy consumption; 0.20 €/kWh)
- In order to optimize biogas plants efficiency, it is valuable to investigate the mixing process of the biomass in a digester tank → Comprehensive investigations in reality are difficult to manage and can be very costly. It is helpful to carry out experiments at laboratory down scale and to computer simulate the mixing characteristics using a fluid dynamics model (CFD). Finally, to upscale model after validations.

Methodology

1:12 scale-down

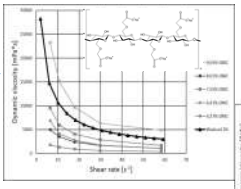
REAL DIGESTER



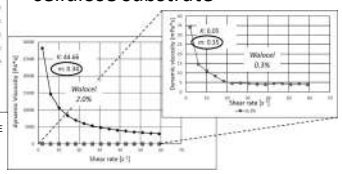
LABORATORY DIGESTER

- Digester and mixers scale-down by a 1:12 factor (Ø = 1.5 m, Vfluid = 800 l)
- Biomass substituted by an artificial substrate based on cellulose with proper rheology
- Mixing investigations in terms of flow velocity of the cellulose substrate

REAL SUBSTRATE

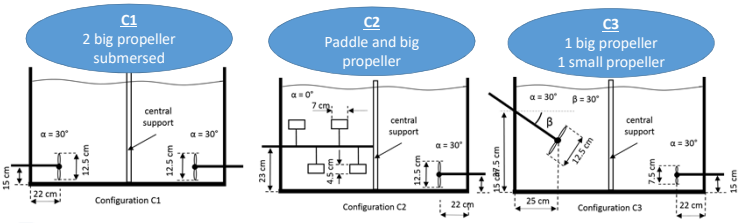


NON-NEWTONIAN WATER-CELLULOSE (WALOCEL) MIXTURE

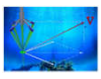


ARTIFICIAL SUBSTRATE

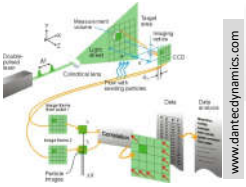
- Mixing using two types of mechanical stirrers: propeller and paddle
- Definition of 3 mixing configurations for analyzing flow dynamics
  - Symmetric flow (C1)
  - Different type of mixer and asymmetric flow (C2)
  - Asymmetric flow (C3)



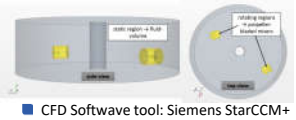
- Optical (PIV) and acoustic (ADV) setup to detect the flow pattern
- CFD simulations



- ADV based on Doppler effect



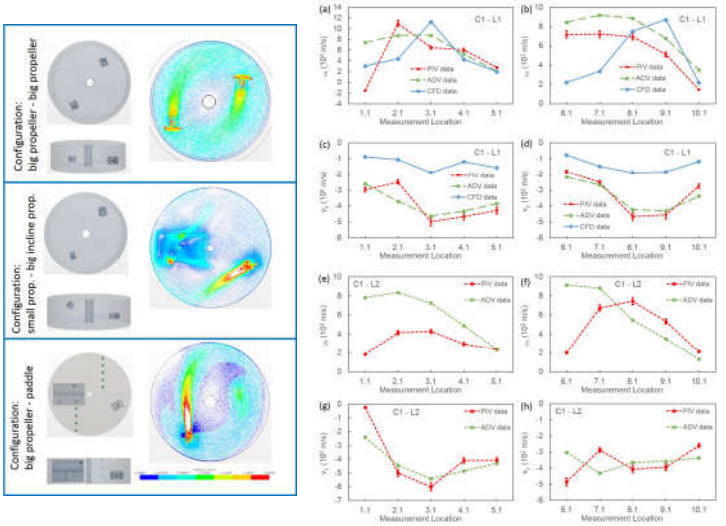
- PIV based on laser illuminated seeding particles



- CFD Softwave tool: Siemens StarCCM+
- Simulation setting:
  - k-ε turbulence model
  - steady-state
  - moving reference frame to implement rotation
  - fluid region static

Results

- Flow velocity values measured with PIV and ADV setups are in very good accordance → indication that the experimental method is correct
- CFD results are in good agreement with the experimental PIV&ADV data → validation of the CFD model



- Further measurements and experimental results with the scaled-down laboratory digester:
  - Torque on stirrer shaft
  - Electrical power consumption
  - Fluid temperature
  - Mixing tiime

Power consumption (P) and torque (T) developed using small and big propeller. SD: standard deviations of the sets of measurement values. *i= Walocel substrate or air*

Type of shaft	Medium	(P_{liq}) [W] SD=±0.1	T_i [N·m] SD=±0.001	P_{wat} [W] SD=±0.01	T_{wat} [N·m] SD=±0.001
without propeller	Air	19.5	0.002		
with small propeller	Walocel 0.3wt%	25.4	0.029	0.66	0.004
with big propeller	Walocel 0.3wt%	23.1	0.027	0.36	0.006

- Further calculations and simulation results with the CFD model:
  - Criteria analysis
  - Portfolio of technical values vs. economic values
  - Benefit analysis
  - Upscale CFD simulations

Conclusions

- 0.3wt% cellulose-water mixture is a suitable model substrate of biomass in terms of non-Newtonian properties, shear thinning fluid, Ostwald-de Waele power-law model of rheology
- Artificial substrate is helpful for visualization of flow characteristic
- PIV results are in good accordance with ADV values
  - Since PIV is more complex and expensive, ADV can be used
- Electrical power consumption results indicate that small propellers need higher energy input to obtain an efficient mixing
- CFD developed model is validated by the PIV&ADV experimental results and is suitable for new mixing configurations
- Up-scale of CFD simulations (digester with Ø = 18 m, fluid level = 5.5 m, fluid volume = 9600 l) are in progress

References

[1] Conti F., Wiedemann L., Sonnleitner M., Saidi A., Goldbrunner M., Monitoring the mixing of an artificial model substrate in a scale-down laboratory digester, *Renewable Energy* **2019**, 132, 351-362.
[2] Conti F., Wiedemann L., Sonnleitner M., Goldbrunner M., Thermal behavior of viscosity of aqueous cellulose solutions to emulate biomass in anaerobic digesters, *New J. Chemistry* **2018**, 42, 1099-1104.
[3] Wiedemann L., Conti F., Saidi A., Sonnleitner M., Goldbrunner M., Modelling mixing in anaerobic digesters with computational fluid dynamics validated by experiments, *Chem. Eng. Technol.* **2018**, 41, 2101-2110.
[4] Conti F., Wiedemann L., Saide A., Sonnleitner M., Goldbrunner M., Mixing of a model substrate in a scale-down laboratory digester and processing with a CFD model, *Proc. 26th European Biomass Conference (EUBCE)*, Copenhagen **2018**, 811-814.
[5] Wiedemann L., Conti F., Janus T., Sonnleitner M., Zörner W., Goldbrunner M., Mixing in biogas digesters and development of an artificial substrate for laboratory-scale mixing optimization, *Chem. Eng. Technol.* **2017**, 40, 238-247.
[6] Wiedemann L., Conti F., Saidi A., Sonnleitner M., Goldbrunner M., Investigation and optimization of the mixing in a biogas digester with a laboratory experiment and an artificial model substrate, *Proc. 25th Eur. Biomass Conf. EUBCE*, Stockholm **2017**, 889-892.

Funded by:

Federal Ministry of Education and Research

FORSCHUNG AN FACHHOCHSCHULEN

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UTS

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