Anaerobic Loop Reactors: development of novel concepts and design criteria for airlift and agitated suspended sludge systems for industrial wastewater treatment

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Abstract
UASB and EGSB reactors are established reactor concepts whose operating ranges and limitations are know. To open new fields of application for anaerobic digestion and to account for foreseeable more extreme wastewater conditions due to water recycling, novel approaches based on the anaerobic contact process are investigated. Airlift loop as well as agitated loop reactors were developed to increase conventional organic loading rates and sludge retention efficiency. Developed process schemes and hydrodynamic characteristics of single and cascaded reactors are investigated in order to optimize transport limitations, shear stress and floc size distribution for adapted sludge systems in continuous plant operation.

Keywords
Industrial wastewater, anaerobic loop reactor, airlift and screw propulsion, shear stress, mixing, modelling of hydrodynamics, ADM1

MOTIVATION & SCOPE

Anaerobic wastewater treatment is a developed technology for the elimination of biodegradable carbon loads from industrial effluents. Well-known and established reactor concepts installed worldwide are UASB and EGSB reactor systems (van Lier 2008) whose functional principle is based on the high sedimentation velocity of pellets. The low growth yield of anaerobic bacteria requires an efficient retention to prevent sludge overflow for safe plant operation. Industrial wastewaters emitted by e.g. paper, food and beverage industry meet the conditions for stable biomass aggregation. However, problems for stable pellet growth are reported for several applications (Jeison, van Lier 2008) and wastewater composition will change due to increased closure of the industrial water cycles in the next decades (Geißen et al. 2012).

New concepts are required to overcome the above mentioned limitations of anaerobic digestion and to open new fields of applications in industrial wastewater treatment (e.g. treatment of membrane concentrates). The approach to be presented is to optimize the suspended sludge systems. For anaerobic airlift and agitated loop suspended sludge systems, as advancements of the conventional contact process, hydrodynamics can be controlled by circulation velocity caused by biogas recirculation or agitator speed. Counterproductive effects like mixing characteristics, transport limitations, shear stress and floc size distribution are optimized to achieve maximal overall degradation rates.

ANAEROBIC AIRLIFT LOOP REACTOR

An bench-scale anaerobic airlift reactor was designed, constructed and set into operation (V = 60 l); the process scheme is shown in Figure 1.

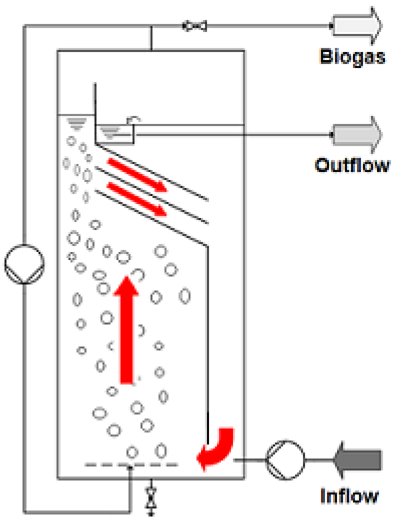

Figure 1. Scheme of anaerobic airlift reactor with integrated clarifier and external biogas recirculation to achieve defined pressure differences between downer and riser.

The hydrodynamics of the reactor system have been determined by measurement of flow velocities, mixing times and residence time distributions in dependence of the biogas recirculation rate. Exemplary results are shown in Figure 2. The pressure drop for the loop flow has been calculated and velocities can be predicted for different gas holdups in plant operation.

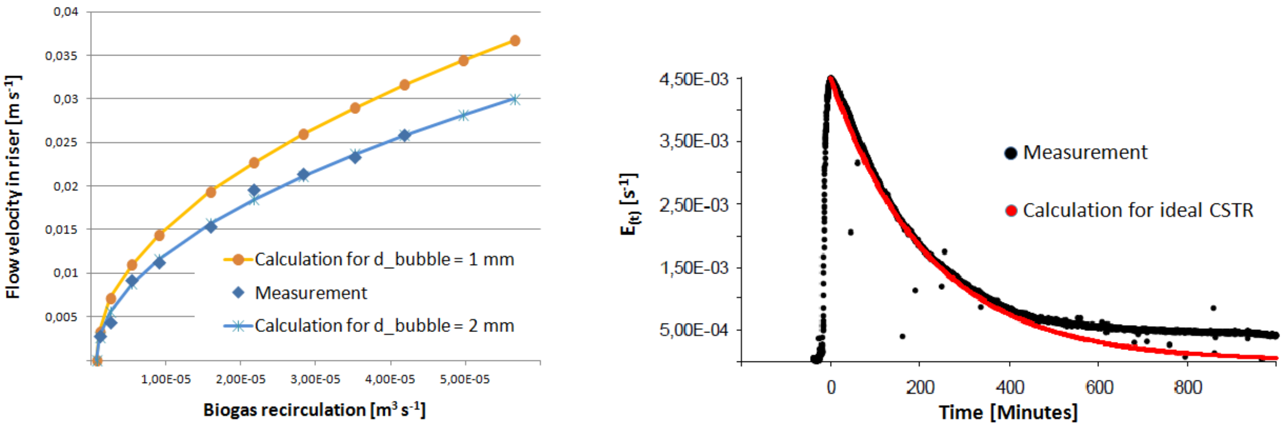

Figure 2. Measured and calculated (average gas bubble size 1 and 2 mm) velocities in the riser of the anaerobic airlift reactor for different biogas recirculation rates (left); measured and calculated (ideal stirred tank reactor) residence time distribution functions $E_{(t)}$ for gas flow rate of $0.50*10^{-5}$ m^3 s^{-1}

Further, Reynolds and Peclet numbers are calculated to characterize turbulences in 2- and 3-phase flow for different reactor compartments. Regarding the mixing behaviour of the anaerobic airlift reactor, a gas flow rate of $3.50*10^{-5}$ m^3 s^{-1} was identified for a residence time distribution comparable to an ideal stirred tank reactor. However, the resulting turbulent flow prevents biomass sedimentation. Large scale Eddies are induced by the external gas injection whose energy does not dissipate; rotation energy of water bodies is propagated into the lamella separator.

For the anaerobic airlift reactor stable operation was not achieved. Re-constructions of the three-phase separator were not able to prevent sludge-bulking and large scale turbulences, lower gas surface loading rates cause local clogging which lead to higher pressure drops in the systems until the internal loop-circulation broke down, see Figure 3.

Figure 3. Anaerobic sludge clogging within the lamella separator because of low flow velocities (left); accumulating sludge within the integrated clarifier because of turbulence eddies underneath which prevent sedimentation

However, efforts for the anaerobic loop reactor have been stopped for suspended sludge but the system will be put into operation again for pellets to investigate degradation behaviour at high loading rates for expanded sludge beds.

ANAEROBIC AGITATED LOPP REACTOR

Based on the experiences for the airlift loop reactor, a novel concept was developed considering a screw agitator similar to the Archimedes screw as drive propulsion system for the loop flow located within the draft tube; see flow diagram in Figure 4. Thereby, the gas surface load is not elevated for plant operation, turbulences are correspondingly reduced as well as sludge bulking and subsequently overflow can be prevented.

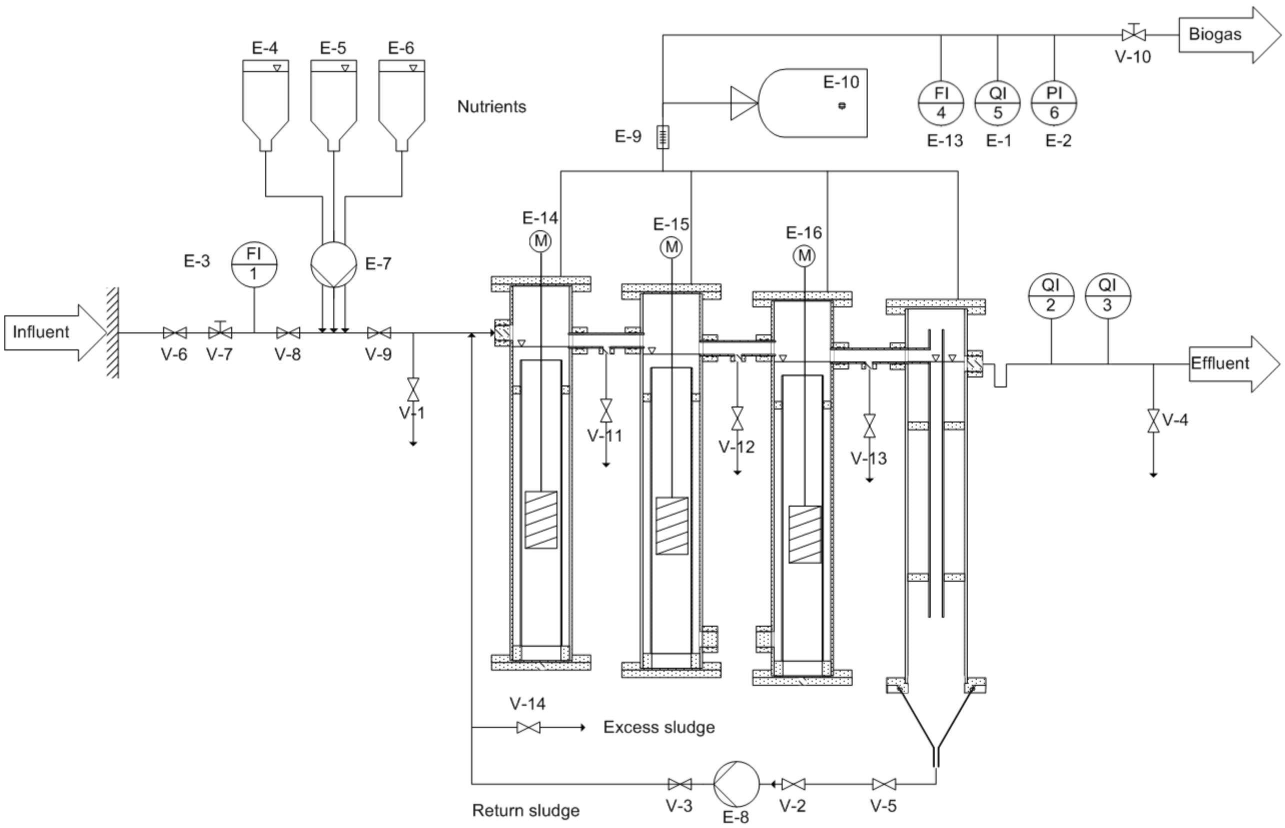

Figure 4. Anaerobic agitated loop reactor cascade for dosed synthetic wastewater

Point of origin is the conventional anaerobic contact process, today having its niche for the wastewater treatment of sugar industry effluents but having low space-time yields. It is extended for a cascade of agitated loop tanks to avoid back mixing, to maximize degradation rates at first order reaction rates and to maximize de-gassing in front of the clarifier.

An identical plant will be operated in parallel except having classic contact process tanks as reference.

At the moment, both plants are under construction and hydrodynamic experiments will start in December. In June 2013 first operation results for COD removal efficiency, space and sludge loading rates, biological activity, shear stress and floc size distributions as well as pressure drop functions for the three-phase system will be presented coherently.

MODELING AND SIMULATION OF ANAEROBIC LOOP REACTORS

A hydrodynamic model based on tanks-in-series has been developed for a reactor with loop drive mechanism which is suitable for airlift as well as agitator systems. It was coupled to the ADM1 in Matlab® Simulink™ Simba® to calculate experiments in parallel. Operational ranges in terms of space and sludge load will be investigated by theoretical approaches and compared to experimental results to identify process limitations and to confirm design criteria.

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REFERENCES

Geißen, S.-U., Bennemann, H., Horn, H., Krull, R., Neumann, S. 2012 Industrieabwasserbehandlung und -recycling – Potenziale und Perspektiven. *Chemie Ingenieur Technik* **84**(7), 1005-1017.

Jeison, D., van Lier, J. B. 2008 Anaerobic wastewater treatment and membrane filtration: a one night stand or a sustainable relationship? *Water Science & Technology* **57**(4), 527-532.

van Lier, J. B. 2008 High-rate anaerobic wastewater treatment: diversifying from end-of-the-pipe treatment to resource-oriented conversion techniques. *Water Science & Technology*, **57**(8) 1137-1148.