DEVELOPMENT AND ASSESSMENT OF A MODEL FOR CAMBI´S SOLIDSTREAM PROCESS USING "SUMO" WWTP SIMULATION SOFTWARE

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Abstract

The Cambi SolidStream process is a modification of the traditional Cambi Thermal Hydrolysis Process (THP) which is designed to enhance breakdown and stabilization of digested biomass, improve dewatering and boosting biogas production through recirculation of final dewatering centrate to the digester. The first full-scale installation is showing an outstanding performance with 75%Volatile Solids Reduction (VSR), 50% more biogas and a cake reduction of 62%. To develop the understanding of this system further the process became subject for a master thesis from TU Berlin. Within the scope of the master thesis a simulation model has been developed and assessed for the Cambi SolidStream process using Dynamita´s Sumo modelling software.

The model shows the same impact of the SolidStream installation as full scale results in terms of improved VSR with 25-26% points, and more work will be done to calibrate and optimize the model further. The centrate going back to the digester was shown to be easily degradable, giving an immediate increase in biogas production when introduced to the digester. Both full-scale data and the model showed stable operation of the digesters with very low Volatile Fatty Acid (VFA) to Total Alkalinity (TA) ratio.

Keywords

Anaerobic Digestion, Cambi SolidStream, Modelling, Sumo

Introduction

Depending on the country and the plant size, sludge management can have a share of 65-75% of the operating costs of a wastewater treatment plant (WWTP) (Vliegen 2016; Neyens et al. 2004) and 40% of total greenhouse gas emissions from wastewater treatment plants (Anjum et al. 2016). In this context, the scope of anaerobic digestion is expanding and new technologies are available, whose emerging drivers are energy and nutrient conservation and recovery as well as an intelligent sludge management concept (Batstone and Virdis 2014). The Cambi THP has been implemented in WWTPs around the globe in order to meet the growing demands on sludge management (Higgins et al. 2016) as well as nutrient and energy recovery (Rosenwinkel et al. 2015).

While THP sludge cake application as a soil improvement method is considered as a very attractive option for WWTP sludge management that meets both environmental and economic benefits (Cano et al. 2014) its potential for usage as a fertilizer is susceptible to regulations that may differ, depending on the country in question. In Germany, the amendment of the Sewage Sludge Ordinance (Klärschlammverordnung - AbfKlärV) strives a phase out policy for agricultural application of sludges from WWTP categories 5 and 6 (>60.000 Population Equivalent - PE) until the year 2025 (German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety 1992; BUMB 2015). However, these WWTP categories have a total share of 90% on the produced sludge in Germany (DWA 2015). Thus, the tightening of the AbfKlärV puts extra constrains on sludge management and, since sludge incineration becomes the main sludge disposal option (Dichtl 2016), WWTP operators are forced to maximize dewatering efficiency in order to reduce sludge cake volumes, since transportation and incineration costs for sludge are calculated per sludge weight (€/Mg sludge cake), while paying effort to not overshoot the plant budget.

In order to meet actual demands, Cambi has developed a modification of the traditional THP, named the Cambi SolidStream process. Cambi SolidStream was developed to improve the dewatering process after anaerobic digestion, while simultaneously increasing the gas production by recycling the high-strength centrate back to the digester.

The first SolidStream unit was built and installed at Geiselbullach WWTP in Olching, Germany in 2014. Geiselbullach WWTP had already since 2009 a continuous Cambi WAS-Only THP (THP-C) running on site. During 2014 and 2015 the THP-C was decommissioned and removed, and the SolidStream process optimized. Since 2015 the SolidStream has been running continuously producing excellent results in terms of both dewatering and biogas production. It treats around 4.745 MgDS/year with a Primary Sludge (PS): Waste Activated Sludge (WAS) ratio of 60:40, resulting from 250.000 PE. In 2016, SolidStream was able to reach 41% DS in the sludge cake.

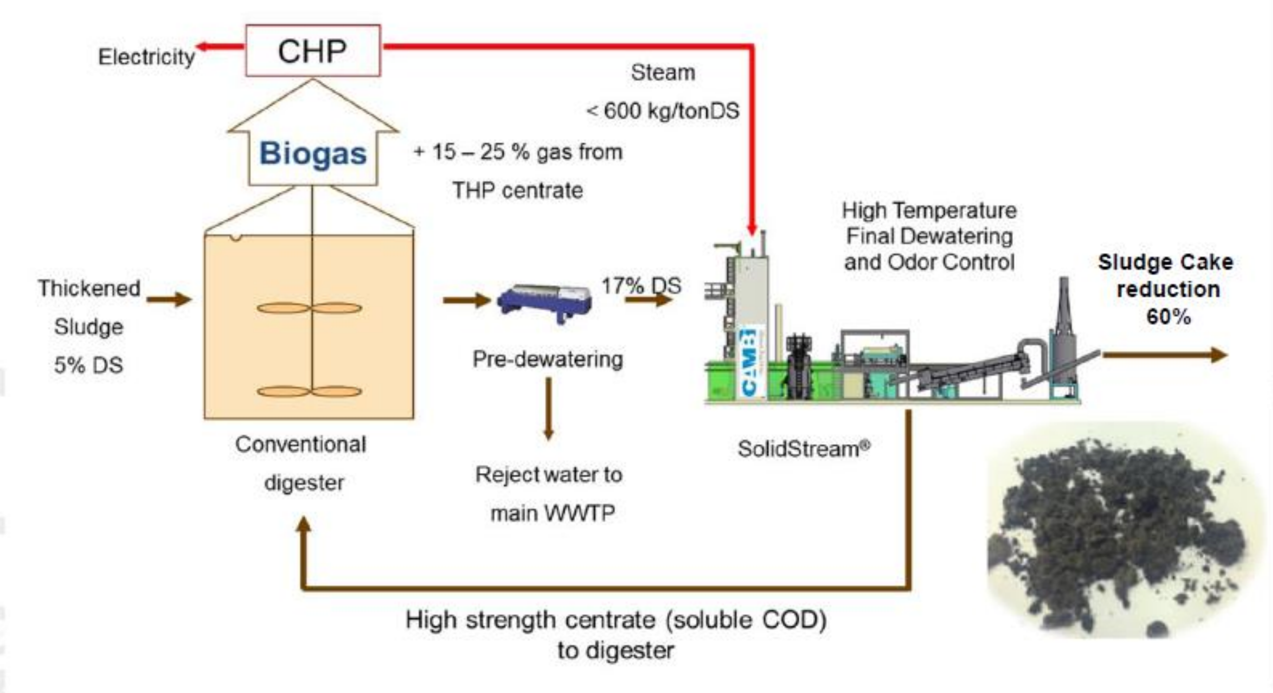

Figure 1: Cambi SolidStream process concept (Nilsen 2016)

The SolidStream process has a high positive impact on the digester and system VSR as well. The VSR of the system was 50% in 2006/2007 and is 75% in 2016. A biogas production of 6.400 m^3/d represents an increase of 50% compared to when the plant was run conventionally without any THP. The final dewatering potential has increased from 22% in 2006/2007 to 41% in 2016. The average cake reduction after SolidStream implementation is 62%.

Regarding digester performance, the recirculation of centrate from the final dewatering has not made a negative impact on the stability of the AD process which still has a very low VFA/TA ratio of around 0,06 and a stable pH at 7,2.

In January 2016, the SolidStream process became subject for a master thesis project at the TU Berlin. The aim of the master thesis is to develop a model for the SolidStream process using the environmental process modelling software "SUMO" in order to simulate its performance in a steady-state model as well as in actual operation, based on dynamic influent characterization from plant operation data. The SUMO software was developed by Dynamita SARL, Nyons, France, and was the software of choice for several reasons, including its user-friendly interface as well as its open-source process codes, which enable the user to have a better understanding of the calculations behind the model.

In general, modelling can be applied for various reasons. First of all, it can be implemented at existing WWTP in order to evaluate current status and identify optimization potentials. Moreover, it can be assistance for plant development and the whole pre-engineering process or to evaluate a potential project through focused simulations, thus representing a marketing tool as well. In both cases it can be considered as a useful assessment tool for consulting, engineering, marketing, WWTP operation that brings numerous benefits. Modelling has also proved to be a valuable tool for operator training, since simulation exercises using a model can help the operator to acquire instant experience in the behavior to be expected with changes in the inputs, system configurations and operational strategies e.g. assessing the effects of changes in waste loads and flows, operational modifications, like changes in recycles, and proposed modifications to plant configuration (WERF 2003).

Materials and methods

Within the period of three months, samples were collected and analyzed in the plant laboratory, which served as input and control values for model development as well as COD balances based on hydrolytic kinetic factors. Within the scope of the thesis, the model was assessed for its validity though comparisons with plant data. Furthermore, the model can be implemented for further investigations, e.g. the assessment of a two-stage Anaerobic Digestion (AD) process, co-digestion or Anaerobic AMMonium OXidation (Anammox) process integration. This can be done either through a focused SolidStream model, based on the assumption of a balance boundary or through a whole plant model including SolidStream. The latter may also be used to investigate interactions between AD and other plant components, such as the impact of primary settling tank performance on Inorganic Suspended Solids (ISS) integration in Primary Sludge (PS), the role of the aerobic Sludge Retention Time (SRT) on Volatile Suspended Solids (VSS) accumulation in WAS (Ekama et al. 2011; Sötemann et al. 2005) or the influence of Me^{3+}-dosage for Phosphorus(P)-precipitation on AD.

Definition of model balance boundary

Given the time limitation of a master thesis of six months, it was decided to implement a boundary balance that comprises the SolidStream relevant process components from sludge treatment. These include the following main components: Raw Sludge (RS) influent, Digesters, Pre-dewatering centrifuge, pre-dewatering centrate, SolidStream, Final dewatering centrifuge, Final dewatering centrate and Final dewatering sludge cake.

Data Collection and Sampling

For a period of three months, samples for each of the above balance boundary components as well as hydrolyzed sludge were analyzed on a weekly basis in the plant laboratory for the following parameters: DS, VS, Total Chemical Oxygen Demand (TCOD), Soluble Chemical Oxygen Demand (SCOD), Total Nitrogen (TN), Ammonia (NH_4^+-N), Total Phosphorus (TP), Orthophosphate (PO_4-P), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Potassium (K^+) concentration.

Data collection was supplemented with plant operational data that was collected on a daily basis. This set of data included: Plant influent volumetric (Q) and COD mass flows, PS and WAS influent characteristics (Q, TS, VS, TCOD, NH_4-N and TP mass flows and concentrations), Digester data (T, pH, DS and VS content of recirculation pump sludge, TA and VFA concentration, Digester DS and VS content, Digester SRT, Biogas volumetric flow, Biogas-CH_4 and H_2S concentration).

In addition, independent routine laboratory measurements were conducted from plant laboratory personnel on the parameters of both centrates. The sludge cake DS and VS content were measured weekly.

SUMO software

Modelling work and investigation of SolidStream and AD performance were conducted using a focus, as well as a full-plant model in the environmental process simulator SUMO (Dynamita SARL, Nyons, France). SUMO provides the user with capacity to encode any process model, and define parameters and parameter values (Boltz et al. 2016). To identify the characteristics of the raw sludge feed for the focus SolidStream model, a model of the primary and biological pre-treatment steps was run. For the whole plant model influent characterization was limited to the Geiselbullach WWTP average influent wastewater composition.

Sumo THP Process Unit

The Sumo THP Process Unit interprets influent composition as fractions of several components whose share on the total effluent sludge composition changes rapidly after thermal hydrolysis treatment. According to the Sumo THP Process Unit the sludge disintegration occurs in three sequential steps; Pasteurization, Solubilization and Viabilisation which are programmed as mathematical equations into the THP process code and illustrated in Figure 2.

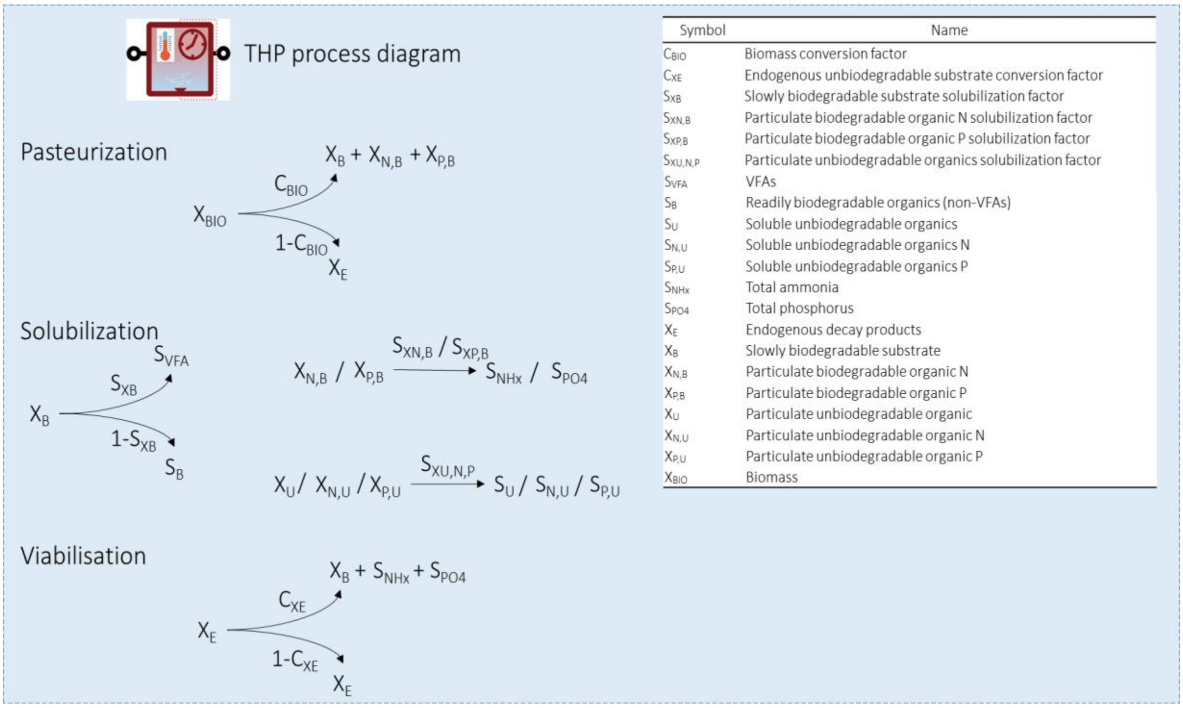

Figure 2: Sumo THP Process Code (Dynamita 2014)

Results and discussions

Sumo models

The following presents the layout of the SolidStream plant built at Geiselbullach WWTP in the Sumo models. In general, raw sludge enters the sludge treatment process chain at a PS: WAS ratio of

60:40. After AD the sludge is pre-dewatered and enters the SolidStream system. The centrate from the pre-dewatering is sent back to the WWTP. The hot hydrolyzed sludge enters the final dewatering centrifuge and the hot centrate from final dewatering is recirculated into the digesters and reduces the need for heating in the digester. Final dewatered sludge cake exits the system and is stored in a silo for final disposal.

SolidStream focus model

This model includes all the process components as they are found in the model balance boundary. In addition, it also contains two extra process units: A cyclone unit which can be regarded as a process unit that recirculates process gas from the SolidStream to the digester. Moreover, a dilution water dosage is integrated to simulate hydrolysate steam dilution during the thermal hydrolysis treatment, as well as the water content of the polymer additives used for final dewatering. Model “commissioning” from “cold start” was done through a step increase of digester Organic Loading Rate (OLR).

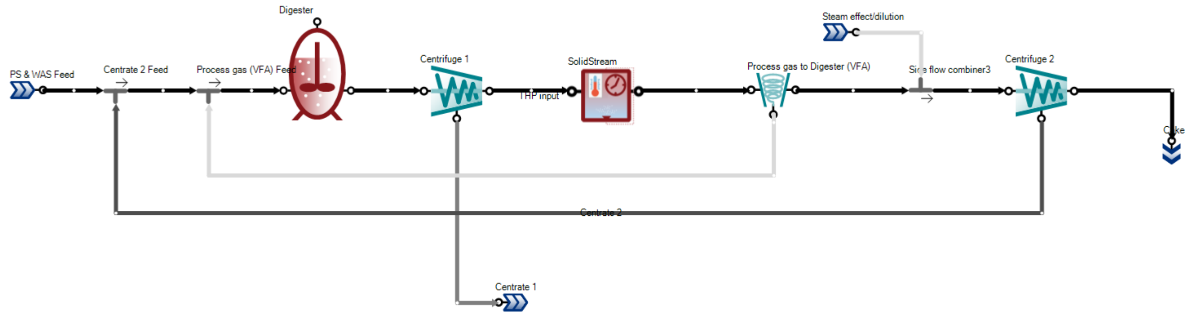

Figure 3: SolidStream focus model

Whole plant model including SolidStream

This model is developed to evaluate SolidStream performance in a whole plant simulation. This enables a higher degree of flexibility and a better understanding of the interactions of the SolidStream with other plant components. It could also be applied to assess further treatment scenarios. Influent characterization is carried out through plant inlet characterization (Q, TCOD, TKN, TP, Alkalinity, pH). Further fractionation is possible, if desired.

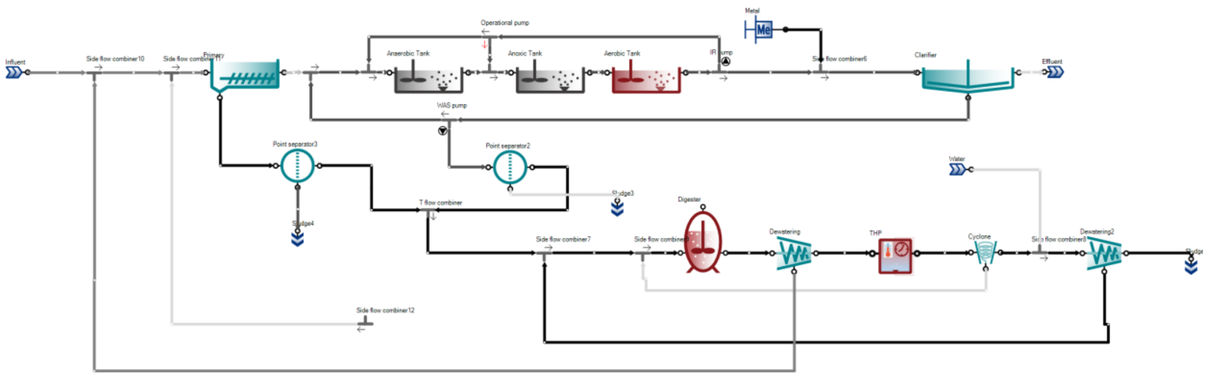

Figure 4: Whole plant model of the Geiselbullach WWTP including SolidStream

Comparing Sumo and operational data

VS content of Raw Sludge, Final dewatered cake and VSR of the system

Figure 5 shows the performance of the SolidStream process at Geiselbullach WWTP and the model prediction in terms of VS in the raw sludge, final dewatered cake and VSR. The VSR is calculated using the Van Kleek method.

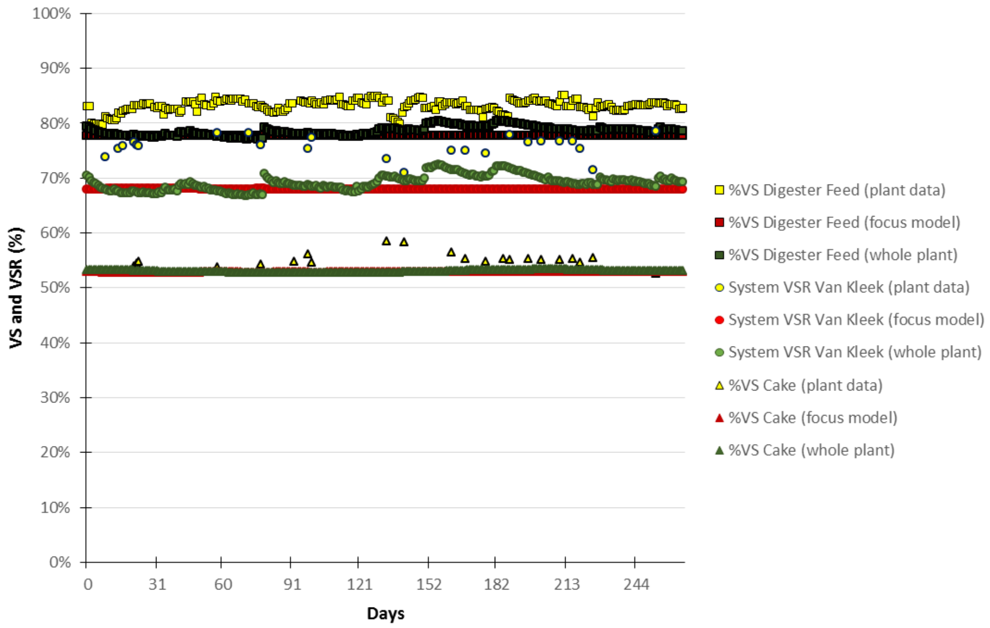

Figure 5: Volatile Solids in Digester Feed, Final dewatered Cake and VSR as predicted by model and actual plant data

In Figure 5 the operational data shows that the VSR remained stable at very high levels, around 75%, since the beginning of continuous SolidStream operation and throughout the whole evaluation period. This correlates with the low VS content in the final sludge cake at 54% VS, which is regarded as conditioned and stabilized. The results of the focus plant Sumo simulation for 265 days of operation are under predicting the Digester VS and VSR of the plant slightly. The model predicts an average VSR of around 68% which remains evident over the whole simulation time interval. The VS content in the final dewatered cake is predicted to be around 53%VS, agreeing well with full-scale data.

The same trend can be observed for the whole plant simulation results. Here, the average VSR was around 69% with an average cake VS content of 53%. Hence, altering WWTP inlet flows did not seem to have any impact on AD performance at the plant.

A model not including the SolidStream process was also run and the results in VSR are shown in Figure 6 and compared against plant data. The effect of the implementation of SolidStream is the same for both full-scale results and the model results. The model prediction with and without SolidStream matches the percent point increase in VSR of the full scale plant. The model predicts an increase from 40% to 68% VSR, giving an increase of 26% points. The plant data show an increase in VSR from 50% to 75% VSR, giving an increase of 25% points. Further work to calibrate the model is ongoing to improve the prediction of Digester feed VS to match operational data.

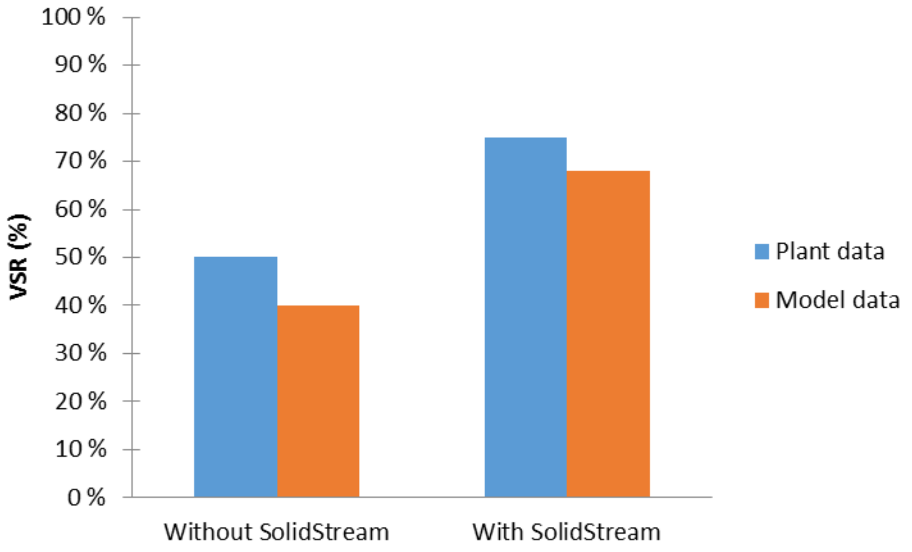

Figure 6: **Comparison of predicted VSR with model and plant data, with and without SolidStream**

Biogas Production

The specific biogas production has increased significantly after the installation of the SolidStream process. The effect was confirmed in a dynamic focused Sumo simulation with data starting from the beginning of SolidStream operation. The SolidStream was taken in service on day 249 and remained in operation till day 275, when it was stopped for maintenance work. Both model and full-scale results show that the centrate is highly biodegradable giving an instant increase in biogas production as illustrated in Figure 7. This is also supported by BMP tests previously done by Cambi (Oda Kjorlaug, personal communication, August 15, 2016) that shows a VSR of up to 90% of the SolidStream centrate.

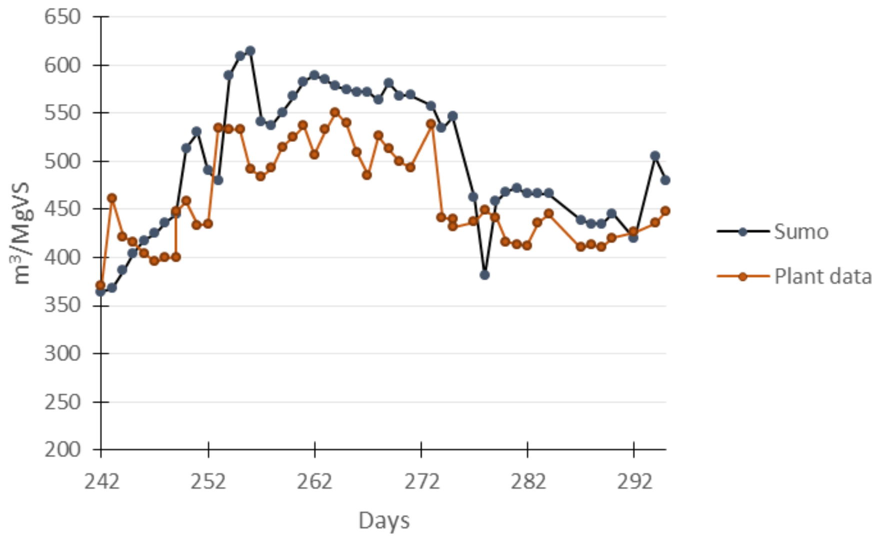

Figure 7: **Specific biogas production during a period at Geiselbullach WWTP illustrated by plant data and simulation**

Digester stability, VFA/TA ratio

The Geiselbullach WWTP has two digesters operating in parallel. Data from Digester 1 is presented in Figure 8. The digesters have had a stable performance after converting from THP-C to SolidStream. During the spring of 2016 when SolidStream has been in continuous operation the Total Alkalinity (TA) of Digester 1 has increased, so has also the Volatile Fatty Acids (VFA) levels. The pH has remained stable, and the process monitor parameter VFA/TA is stable and very low at around 0.06. A level of VFA/TA greater than 0.3 is usually defined as a digester upset (Jolly et al. 2014).

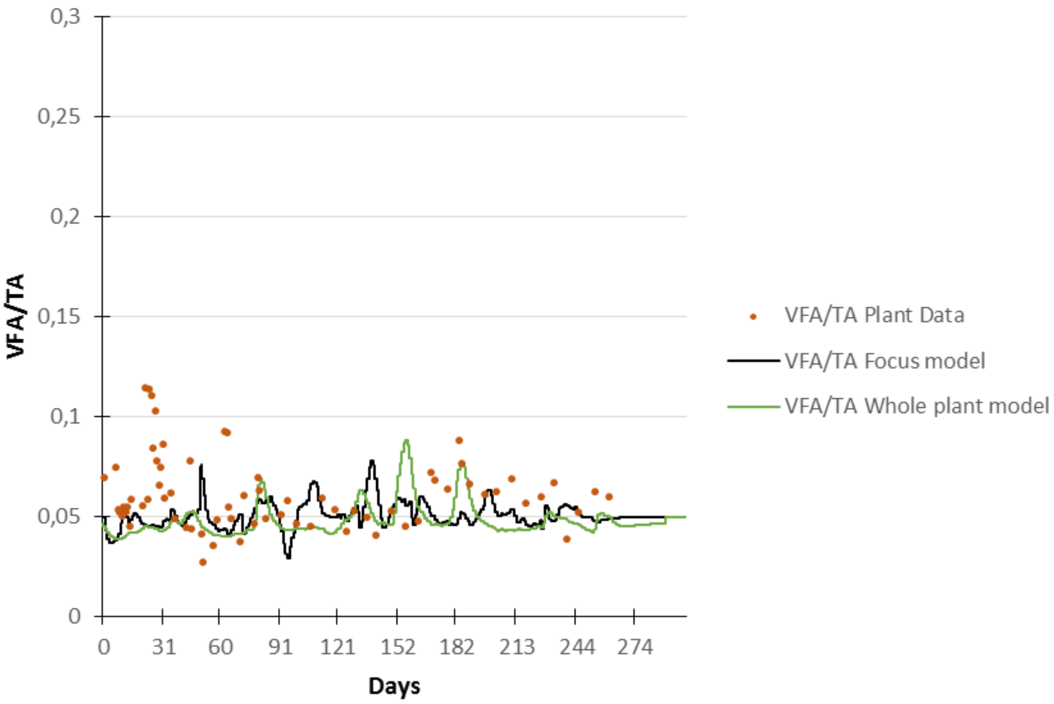

Figure 8: Average VFA/TA ratio in Geiselbullach Digesters (whole plant model)

A stable digester performance could be demonstrated well in both the focus and whole plant model. Figure 8 shows the results of a Sumo simulation for the average VFA/TA ratio in both digesters in the focus model. The average value is VFA/TA=0,050.

The same as discussed above applies for the results of the whole plant model Sumo simulation. The average VFA/TA ratio here is on average 0,048. Summarizing the plant and simulation data it can be stated that recirculation of SolidStream centrate results in a stable AD operation in terms of low VFA to TA ratio.

Conclusions

- Cambi SolidStream is a new configuration of the Cambi THP technology and full scale operating data shows a 50% increase in biogas production, 75%VSR and 62% cake reduction at Geiselbullach WWTP.
- A model was set up in attempt to predict the performance of the digestion plant. Both the focus and whole plant model could justify the positive impact of the installation of the Cambi SolidStream process on the system VSR, predicting an increase in 26% points from the model compared to 25% points in full-scale. Further work is ongoing to optimize and calibrate the model.
- Full scale data and the model showed that the introduction of high-strength centrate gave an instant improvement in biogas production indicating that this centrate is easily degradable in the digester.
- The model shows that VFA concentration peaks are quickly evened, a fact which is supported by the low average VFA/TA ratio of 0,034 (focus model), 0,047 (whole plant model) and 0,06 (plant data) indicating a stable digester performance.

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