BIOWIN MODELLING TO REDUCE THE AVONMOUTH DIGESTER COMMISSIONING PROGRAMME FROM 6 MONTHS TO 6 WEEKS

Forgacs G. [1], Smyth M[1], Law I.[2] and Arnot T. C.[3]
[1]Aqua Enviro, UK, [2] Wessex Water Enterprises Limited (trading as GENeco), UK, [3] Water Innovation & Research Centre, UK

Abstract

In this study a novel accelerated restart strategy has been developed for a two stage anaerobic digestion system, involving acid phase digestion of sewage biosolids, followed by mesophilic digestion. The strategy involves start-up of the acid phase process, and then restart of the secondary mesophilic digesters, following a feed starvation period, and without re-inoculation. Process simulation with BioWin 4.1 software was coupled with continuous lab-scale trials to inform a full sized trial, which in turn defined the full plant restart schedule. Biosolids feed shut down period, and feed loading and feed acceleration rates were explored via lab-scale trials and simulation. The lab and simulation trials lead to the proposal of a 21 day restart profile for start-up and recovery of the two-stage anaerobic digestion process at Avonmouth. This profile involved an initial feed load of 39% of the normal steady-state flow, and a 5% daily feed flow ramp up rate, following a 3 week starvation period. This accelerated restart strategy was successfully deployed on a 24,500 m^3 anaerobic digester system in the UK. During restart the concentration of VFAs remained less than 1,500 mg L^{-1}, whilst pH and alkalinity were stable around 7.8 and 5,000 mg L^{-1}, resulting in a stable recovery.

Keywords

Acid phase digestion; Anaerobic digestion; BioWin; simulation; sludge; wastewater plant

Introduction

Start-up is considered as a most sensitive, challenging and critical stage in the operation of anaerobic digesters. During start-up the delicate balance between the different groups of microorganisms can be easily disrupted, because the microbial population varies in relation to pH optima, growth rates, inhibition levels etc. [1]. Moreover, a poorly executed start-up can lead to foaming, low treatment efficiency, or microbial death due to acid accumulation [2].

The main objective of this study was to develop a restart strategy for a two-stage anaerobic process, which required some maintenance of the first stage. For this purpose, process simulation, continuous lab-scale experiments, and full-scale trials were carried out. The result of these tests was used to determine an optimal restart profile for a full-sized AD plant at Avonmouth, UK.

Process description

The accelerated restart strategy was developed for the anaerobic digestion system of a large wastewater treatment plant. The anaerobic digestion process comprises a first stage of 6 acid phase digesters (APDs) working in series, a second stage of 8 large mesophilic digesters (MADs) working in parallel, and the total volume of the digesters is approximately 24,500 m^3 – see Figure 1. The need for a shut-down and restart was prompted by corrosion of the acid-phase digesters (APDs) resulting in the need for refurbishment. The remedial work also allowed bypasses to be fitted to the APD tanks. The original process had the APD train operating in series with the feed to the MAD systems, and by-passing of individual APD tanks to allow for remedial work was not possible due to the lack of piping. Therefore, the APD digesters had to be shut down during the repair work, leading to a subsequent disruption of the feed to the mesophilic digesters (MADs), and hence a significant disruption to biogas production, and a loss of revenue in terms of energy production. The biosolids stream needed to be limed prior to disposal, rather than digested, incurring significant additional costs. Hence an accelerated shut-down and restart strategy was required to minimise cost and energy losses.

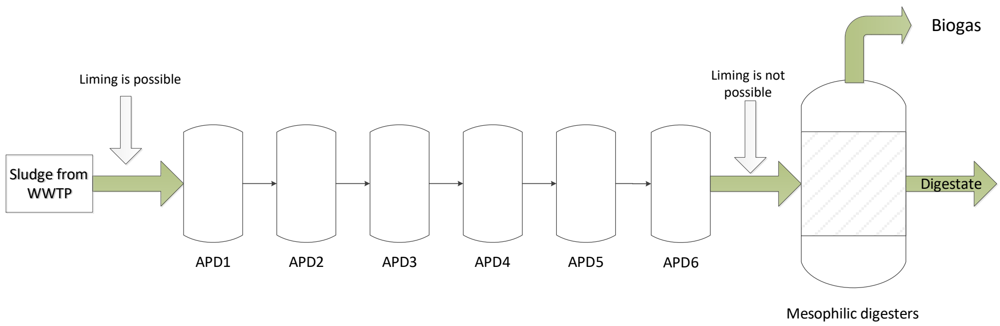

Figure 1: **Schematic of the AD, with the APD train ahead of the MADs**

Materials and Methods

Process simulation with BioWin

Simulation of the APD and MAD restart was carried using BioWin 4.1 (EnviroSim Associates Ltd., Canada). The BioWin software integrates the international ASM1, ASM2d and ASM3 models developed by the IWA with the anaerobic digestion model (ADM1). The integrated BioWin AS/AD model includes 50 state variables and 70 process expressions, which describe the processes occurring in activated sludge and anaerobic digestion systems, including biological, chemical, and physical processes, several chemical precipitation reactions, and gas–liquid mass transfer for six gases.

Lab-scale continuous experiment

The lab scale trials were conducted using equipment from Bioprocess Control AB, Sweden. This comprised 14 continuous 2 litre glass anaerobic digester reactors, each with a 500 mL CO_2 scrubbing unit, and a biogas volume measuring device. Simulation results, based on a model calibrated to the full scale process, were used to design the lab scale trials. The most rapid restart strategies were selected for lab trials if they also demonstrated a successful recovery profile via simulation.

Analysis – lab scale and full size trials

Total solids (TS), volatile solids (VS), and ash were analysed according to Standard Biomass Analytical Procedures. A HACH LCK365 Organic Acids cuvette test (50-2,500 mg L^{-1}) and a DR 2800UV–VIS Spectrophotometer (HACH, Germany), were used to determine volatile fatty acid (VFA) content. Alkalinity was measured with a Hanna Instruments pocket checker HI-755, after the samples were centrifuged and diluted (1:100). The pH was measured by an Orion 370 PerpHecT meter (Thermo Fisher Scientific, USA). Produced biogas volume was also recorded in real time.

Results and Discussion

Simulation outcomes

Table 1 shows the restart scenarios tested via simulation and their outcomes, using a dynamic model calibrated to the full sized AD plant. A simulation was deemed to be successful when all of the digesters recovered to full biogas production after the shut-down and restart period. In the case of failed simulations, the recovery profile was too “aggressive” and volatile fatty acids accumulated in the MADs causing process failure. In these cases, the concentration of VFAs exceeded 5,000 mg L^{-1} during the restart period, leading to pH falling below 6.2, and cessation of methane production. Simulations confirmed that an immediate, rather than tapered, shut-down of the MAD feed stream could be possible as the MADs could be restarted successfully under certain circumstances. The model indicated that the MADs are the bottleneck during the recovery process, as over-feeding can have a negative or catastrophic impact, and that the duration of the shut-down (no biosolids feed) period has a significant impact on the MAD recovery profile.

Table 1: Description and outcomes of simulated restart scenarios

Scenario	Shutdown period (days)	Initial Flow (% of the original)	Flow ramp up (% day^{-1})	Recovery period (days)	Simulation outcome
1	14	31	3	40	Successful
2	14	31	5	25	Successful
3	14	31	6	21	Successful
4	14	49	3	25	Successful
5	14	49	5	16	Successful
6	14	49	6	14	Successful
7	18	31	3	40	Successful
8	18	31	5	25	Successful
9	18	31	6	21	Successful
10	18	49	3	25	Successful
11	18	49	5	16	Failed
12	18	49	6	14	Failed
13	21	31	3	40	Successful
14	21	31	5	25	Successful
15	21	31	6	21	Failed
16	21	49	3	25	Failed
17	21	49	5	16	Failed
18	21	49	6	14	Failed

Experimental work (lab-scale and pilot-scale)

Simulations which resulted in a successful recovery outcome following shut-down and restart were tested experimentally in the lab, and all of these trials demonstrated successful recovery. Moreover, the experimental results showed a high degree of agreement with the model regarding biogas production, apart from at the end of the restart period where biogas production of the lab-scale trials did not recover to the original level. This can be explained by the absence of APD process in the experimental set-up, as the APD train increases the biogas productivity of the MADs by up to 18 %, since it acts as a pre-hydrolysis stage and renders the biosolids more amenable to methanogenesis.

It is important to emphasise that the dynamic model was originally calibrated against historical full sized plant data, so the accuracy in modelling the lab scale trials is remarkable. The concentration of volatile fatty acids was relatively low throughout all of the laboratory trials. In all cases a small VFA peak (up to 1,000 mg L^{-1}) was observed during the first week of the restart period, due to reinstatement of the biosolids feed after the shut-down (starvation) period. The VFA peak reduced and stabilised in all cases as the microbial populations recovered, indicating a stable recovery following the restart.

Full scale trial

The feeding profile for the full-scale MAD restart trial was a little bit more “aggressive” than those investigated experimentally. The shutdown (no biosolids feed) period was 21 days and the feed ramp up period was 24 days – so about 5.5% flow increase day^{-1}. Biogas production was slightly higher over the first 17 days of restart compared to the model prediction. It is worth mentioning that during the full-scale trial the APD train was in operation, which probably increased biogas production of the MADs early in the restart period due to the pre-treatment / hydrolysis effect on biosolids. The simulation included a full restart of the APDs, meaning that at the MAD restart the biosolids had not received pre-treatment. The volatile fatty acid profile of the MADs was in agreement with simulation during the recovery period – the VFAs peaked with value of 1,081 mg L^{-1}, which was lower than simulation value of 1,729 mg L^{-1}. In either case the VFA concentration did not increase to the point where the microbial population was compromised.

Full-plant re-commissioning

The simulation outcomes, the results of the continuous lab-scale experiments, and the full sized trial were used to propose the full-plant restart strategy. This strategy comprised an initial load of 39% of the original maximum feed biosolids flow, and a 5% feed flow ramp up rate, after a 20 day long starvation period. The biogas and VFA profiles recorded at the full sized plant were consistent with the prediction from the simulation (Figure 2,3.) In the acid phase digesters the formation of the volatile fatty acid started directly after the restart, and it stabilized at level of 6-700 mg L^{-1}, which is considered an optimal value. The VFAs peaked around 1,100 mg L^{-1} after 10 days of the restart. By the time the MAD plant reached full feed flow, the biogas production exceeded 90% of the original yield, while all measured parameters including VFA, alkalinity, and pH indicated stable operation.

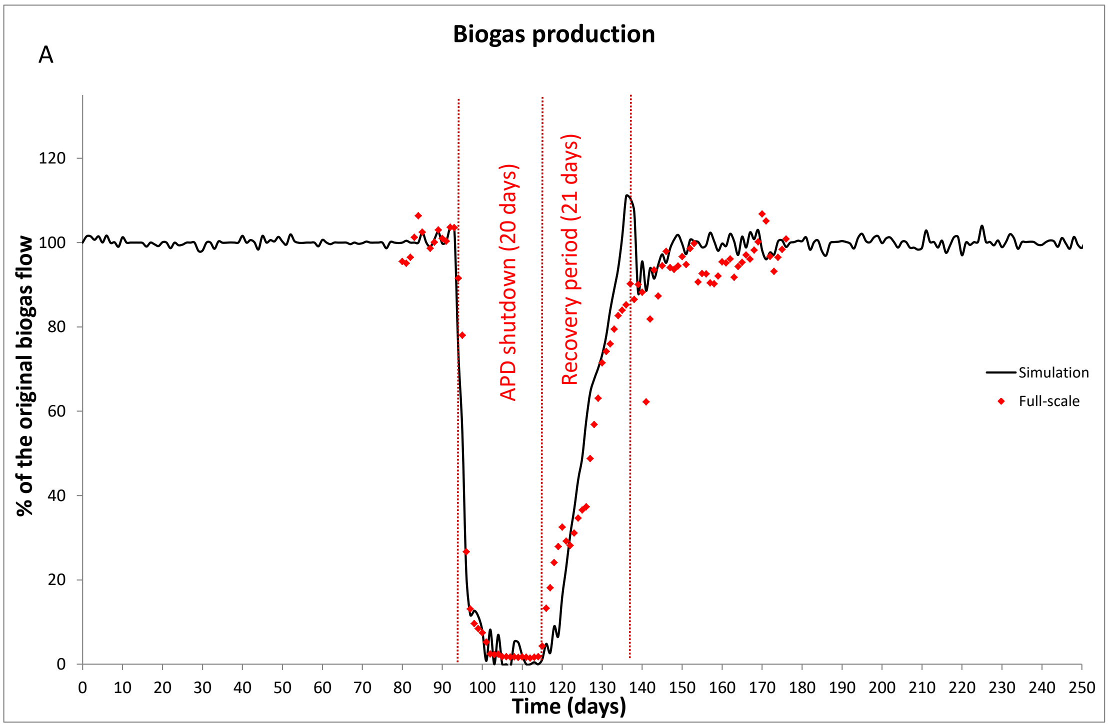

Figure 2: Simulation versus full-scale data from the MAD restart for biogas production

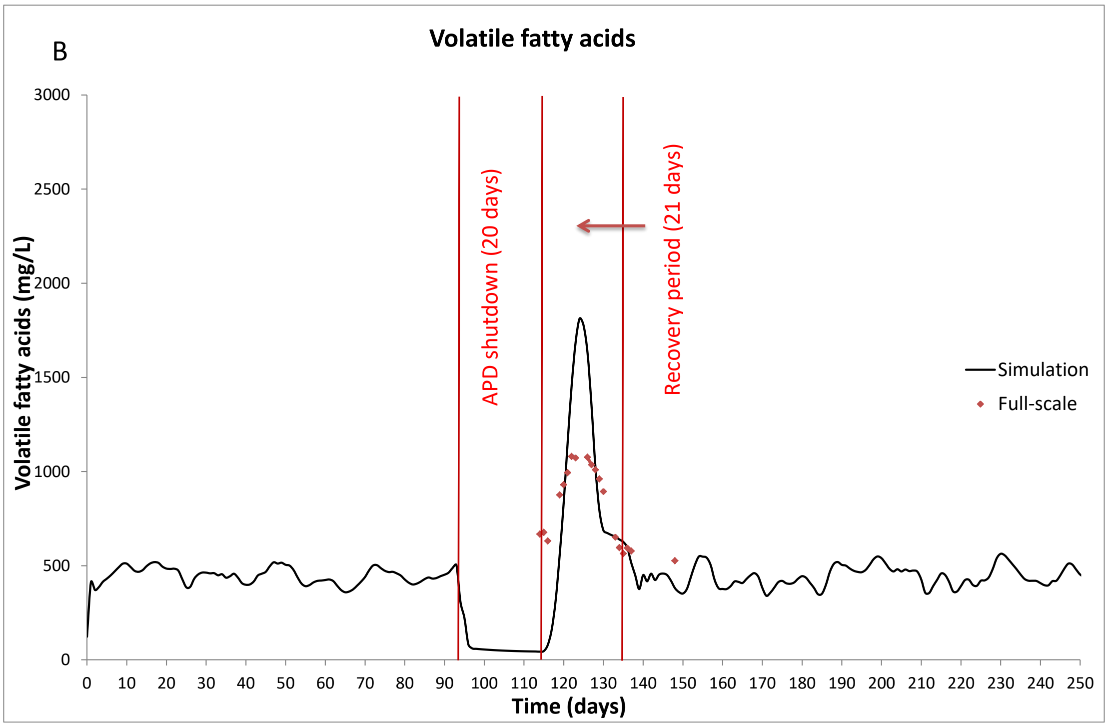

Figure 3: **Simulation versus full-scale data from the MAD restart for biogas production**

Conclusions

In this study, an accelerated restart strategy is presented for mesophilic anaerobic digesters, involving an immediate shut-down, followed by a period of zero feed during plant maintenance higher up the process train, and then a rapid restart. A process simulation model, lab-scale MAD tests, and a full sized MAD trial were used to propose a restart strategy for the plant MADs, which did not installation of a temporary biosolids feeding system. Moreover, the strategy had an accelerated time frame compared to typical conservative start / restart strategies which resulted in significant cost savings.

Acknowledgements

We would like to acknowledge funding from Wessex Water and EPSRC IAA Grant reference number EP/K503897/1.

References

Lins, P., C. Reitschuler, and P. Illmer, *Development and evaluation of inocula combating high acetate concentrations during the start-up of an anaerobic digestion.* Bioresource Technology, 2012. **110**(0): p. 167-173.

Zhao, B.-H., et al., *Dynamic modeling the anaerobic reactor startup process.* Industrial & Engineering Chemistry Research, 2010. **49**(16): p. 7193-7200.