Anaerobic Digestion Fundamentals

Optimising the anaerobic digestion process through improved understanding of fundamental operational parameters

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INTRODUCTION

Sewage sludge management is a key aspect of wastewater treatment, both because of the potential environmental risk that sludge poses if not properly treated and because of the significant resource recovery potential that it offers. Anaerobic digestion (AD) is a well-established technology, accounting for about 70% of the sewage sludge treated in the UK, with around 150 operating sites of different size at UK wastewater treatment plant (WWTP). The process offers socio-environmental benefits reducing odour and associated vector attraction potential of the sludge, and reducing the greenhouse gas emission due to the degradation of the residual organics, as well as economic benefits arising from the recovery of energy under the form of biogas. The process is therefore one of the most successful and economically viable sludge treatment methods and it is likely to continue to have an expanding role as a principal technology for the treatment of sewage sludge. The AD of biodegradable matter is performed by a complex series of interdependent microbiological steps, and the process engineering is controlled by a combination of process conditions and critical physico-chemical parameters, such as reactor temperature, loading rate and mixing energy, sludge dry solid (DS) and volatile solids (VS) content, sludge biodegradable fraction, and many others depending on the type of wastewater collection network and up-stream processes. However, the biogas production performance is highly variable within and between sites and there is potentially significant scope to increase the treatment efficiency through a better understanding of the interactive effects of these parameters on the system.

MATERIALS AND METHODS

Aim and objectives

- The aim of the research is to provide quantitative information to optimise process configuration and control to maximise AD performance.

1. Quantify the interactive effects of temperature, OLR and PS:SAS.
2. Determine AD stability at different process conditions .
3. Determine impact of sludge physico-chemical properties on process efficiency.

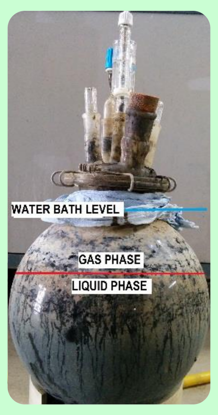
Autodigesters

Automatic semi-continuous 60L anaerobic digesters with online parameters monitoring

Thickening rig

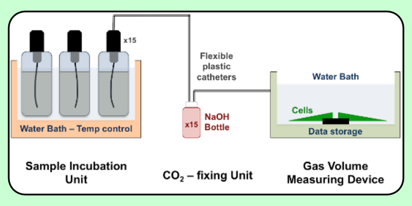
Raw sludge thickening unit, concentration up to 13% DS and avoid use of imported sludge.

Chemostats



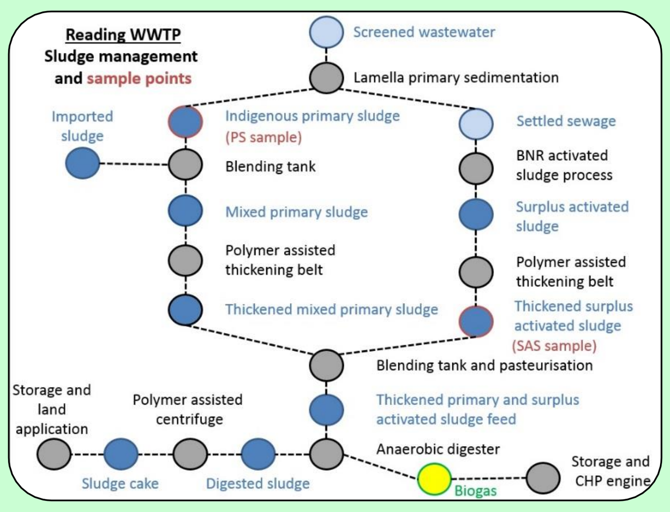
Manually-fed 8L anaerobic digesters for experimental control

BMP test kit

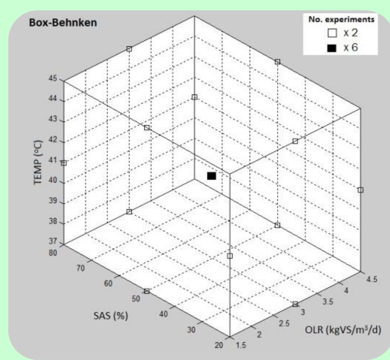


Batch digestion to determine BMP and biodegradability of sludge

Sludge feed source



Experimental design



13 Experiments have been planned following the Box-Behnken method, which allows sound and efficient statistical design of experiment

RESULTS

Performance

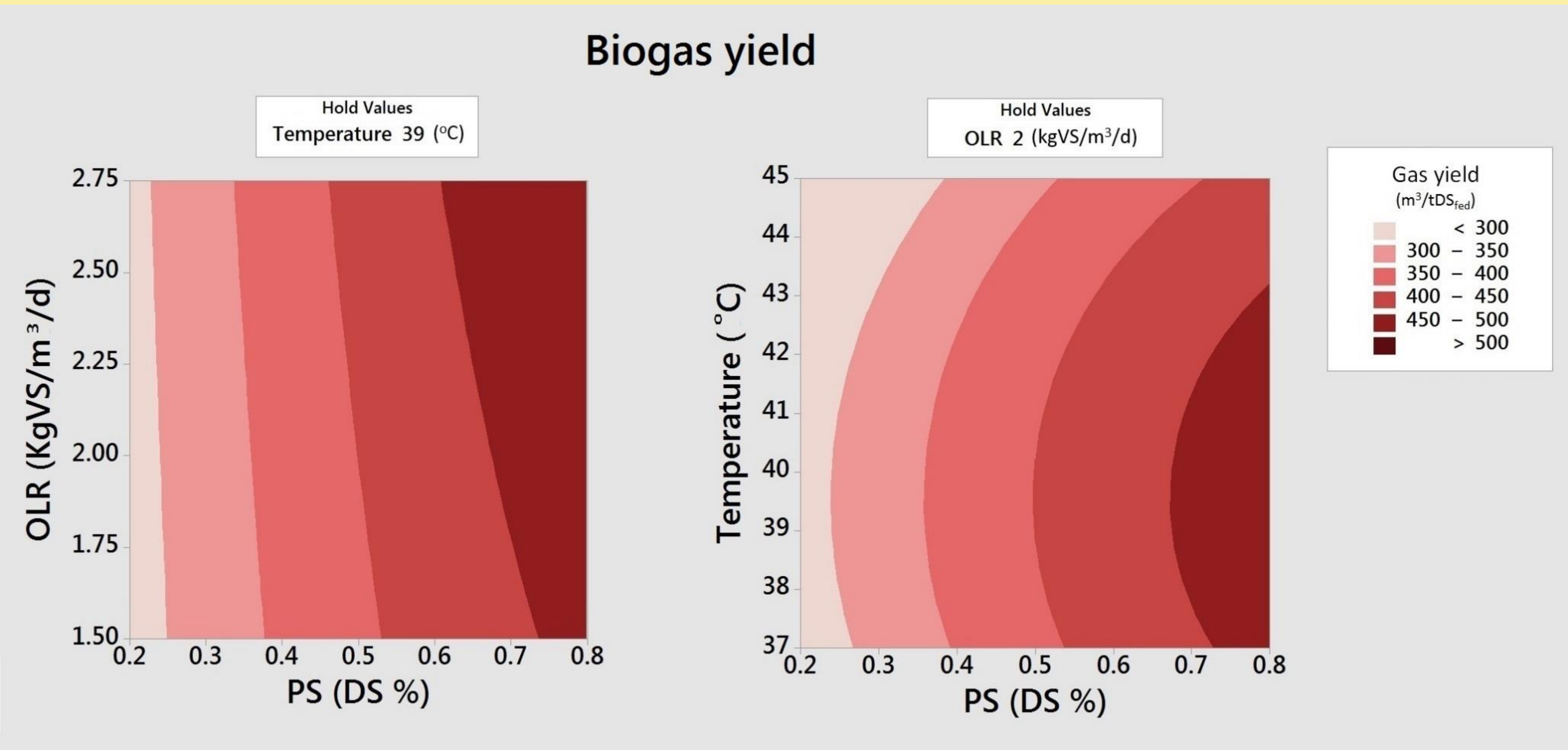


Figure 1 – Biogas yield as function of PS:SAS, OLR and Temperature, at constant HRT=16 days. Regression equation:
Gas yield = -2955 + 475.4 PS % - 2.0 OLR + 158.8 Temperature - 233.2 PS %*PS % - 2.009 Temperature*Temperature + 41.3 PS %*OLR
$R^2 = 80.2\%$

Maximising gas yield

The outcome of the regression model suggests that PS:SAS is the dominant effect on gas yield. This is expected and widely reported in literature, and it is due to the different nature and origin of PS and SAS. Figure 1 also indicate non-linearities in the interactions between PS:SAS*OLR and PS:SAS*Temperature, which suggest that there is scope for process optimisation. An increase in OLR generally brings benefits to the yield, this can be explained with the increase in buffering brought by increasing solids concentration, which maintain more stable conditions within the reactor, as explained in the 'Reactor stability' section.

Temperature appears to bring beneficial benefits up to around 40ºC, above which yield decreases. Explanation to this lies in the complex interactions happening within the anaerobic reactor, with positive effects of increasing temperature such as increased hydrolysis rate and enhanced enzymatic activity, counteracted by negative effects such as decreased gas solubility, increased fraction of toxic undissociated compounds and possible denaturation of cells walls.

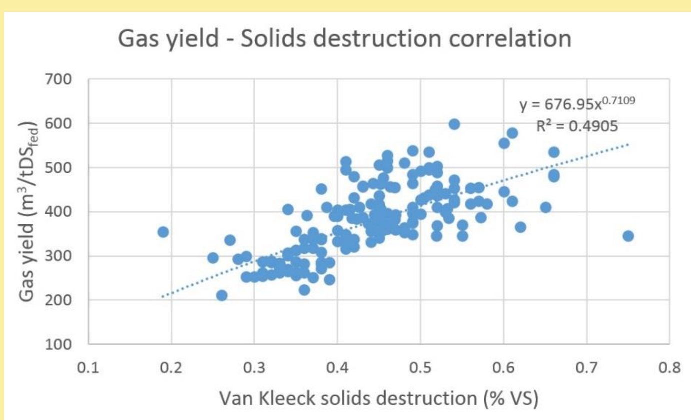


Figure 2 – Correlation found for daily averages for gas yield and solids destruction.
A power function was found to have a better goodness-of-fit coefficient compared to a linear function.

Reactor stability

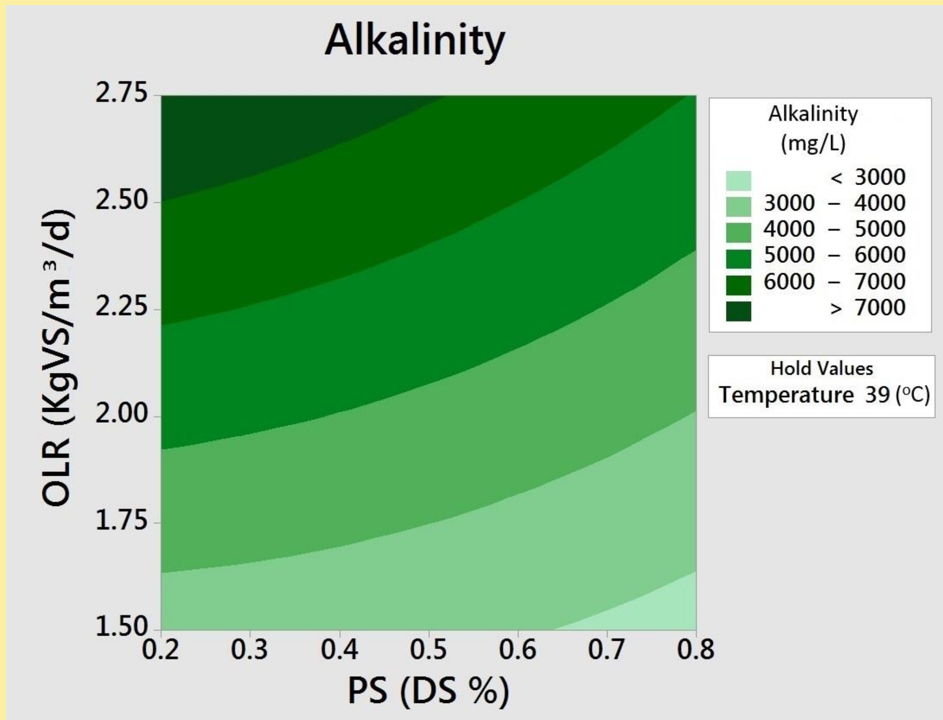


Figure 3 – Alkalinity concentration, function of OLR and PS:SAS, at constant temperature of 39 ºC and HRT=16 days. Regression equation:
Alkalinity = -7076 + 9388 PS % + 3716 OLR + 130.0 Temperature - 1721 PS %*PS % - 1322 PS %*OLR - 184 PS %*Temperature
$R^2 = 98.4\%$

Bio-chemical stability indicators

A number of chemical parameters are key stability indicators in AD, such as alkalinity, total volatile fatty acids (VFA), ammoniacal nitrogen, gas methane (CH_4) and carbon dioxide (CO_2) fraction.

The treatments tested highlighted the significant impact of the control variables over most of the stability indicators. For example alkalinity (Figure 3) plays a vital role in maintaining stable conditions inside an AD reactor, by buffering the impact of weak acids and minimizing pH changes. This in turn ensures that biological activity is not inhibited by acidic conditions, and that organic material degradation is maximised.

Other significant changes have been found in the presence of ammoniacal nitrogen, which concentration is primarily governed by the proportion of SAS fed into the anaerobic reactor. The highly proteinaceous composition of SAS provides the substrate for the production of ammoniacal nitrogen, which can be toxic for cells at certain temperature and pH conditions. None of the treatment tested has been found inhibited by ammonia.

Reactor acidification

One of the treatment tested (Figure 4) has been found unstable in the long term.

The large fraction of readily biodegradable material (PS=80%), at high temperature (41 ºC), meant that hydrolysis rate was faster than methanogenic rate. This factor combined with poor buffering offered by the low OLR (1.5 kgVS/m³/d), led to a slow but constant decrease in pH and accumulation of VFA. Up to the point that metabolism could no longer be sustained and gas production halted.

The significant indicators of acidification, from earliest to latest, were constant pH decrease, VFA accumulation, CH_4 fraction decrease , CO_2 fraction increase and gas volume reduction.

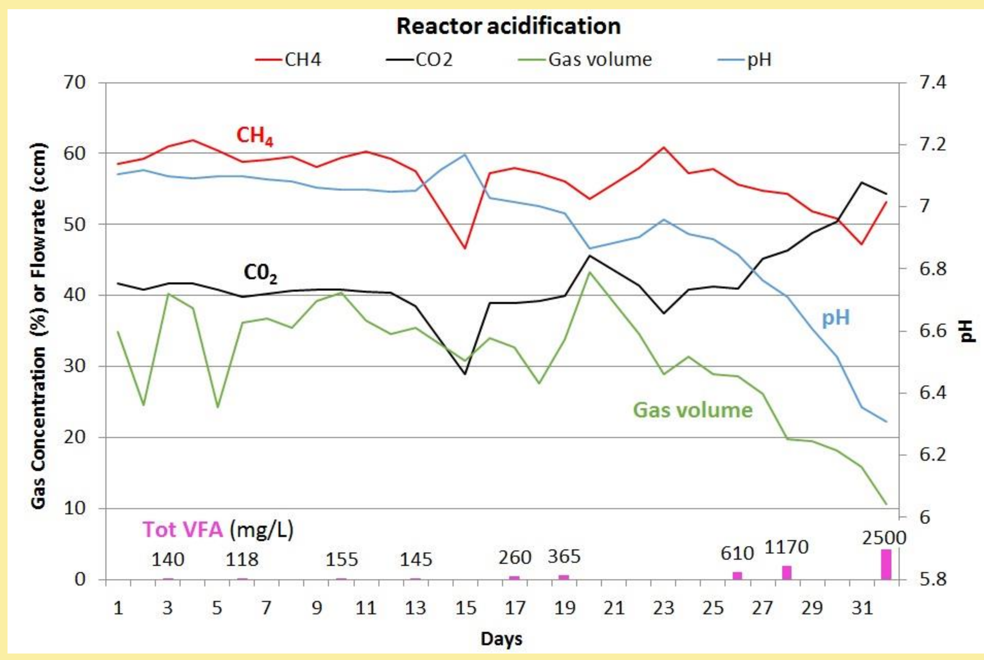


Figure 4 – Reactor acidification. Conditions:
PS:SAS=80:20, OLR=1.5 kgVS/m³/d, Temperature=41 ºC, HRT=16 days

CONCLUSIONS

Anaerobic digestion as core technology to improve overall WWTP sustainability

The results from the optimisation of AD performance can be used to understand the impact of upstream process performance on overall cost and energy consumption of WWTP.

In this example four scenarios are modelled (Table 1), to determine what is the cascade impact of having a poorly performing primary sedimentation tank (PST) and an efficient sludge thickening system. Between the effects modelled are: PS:SAS, OLR, activated sludge pant oxygen demand, poly consumption, energy generated and value of incentives.

The results (Figure 5) indicate that overall a WWTP with a good performing PST and thickening system can reduce energy and polymer cost by up to 32% and displace up to 31% more energy compared to the worst case scenario

Process	Parameter	Assumptions	
		Good	Poor
PST	TSS removal	45%	60%
	COD removal	25%	40%
	Unthickened PS DS%	2.0%	1.5%
Thickening	Backmixing in place	Yes	No
	Thickened PS DS%	7%	4%
	Thickened SAS DS%	6%	4%

Table 1 – Assumptions for different scenarios

Definition	Unit	Value
Influent flow	m³/d	100,000
Influent wastewater strength	gCOD/m³	500
Influent wastewater solids	gTSS/m³	200
COD oxidation yield	gVSS/gCOD	0.45
PS volatile solids	VS/DS	80%
SAS volatile solids	VS/DS	75%
PS poly demand	gActive/kgDS	1.5
SAS poly demand	gActive/kgDS	3
Digester temperature	ºC	39
Methane percentage of biogas	(% vol)	60%
Engine efficiency	(% CV)	38%
Cost of electricity	£/MWhe	95
ROC incentive	ROC/MWhe	0.5
ROC value	£/ROC	45
Cost of PS polymer	£/kgActive	2
Cost of SAS polymer	£/kgActive	2.8

Table 2 – Other relevant assumptions used for the modelling

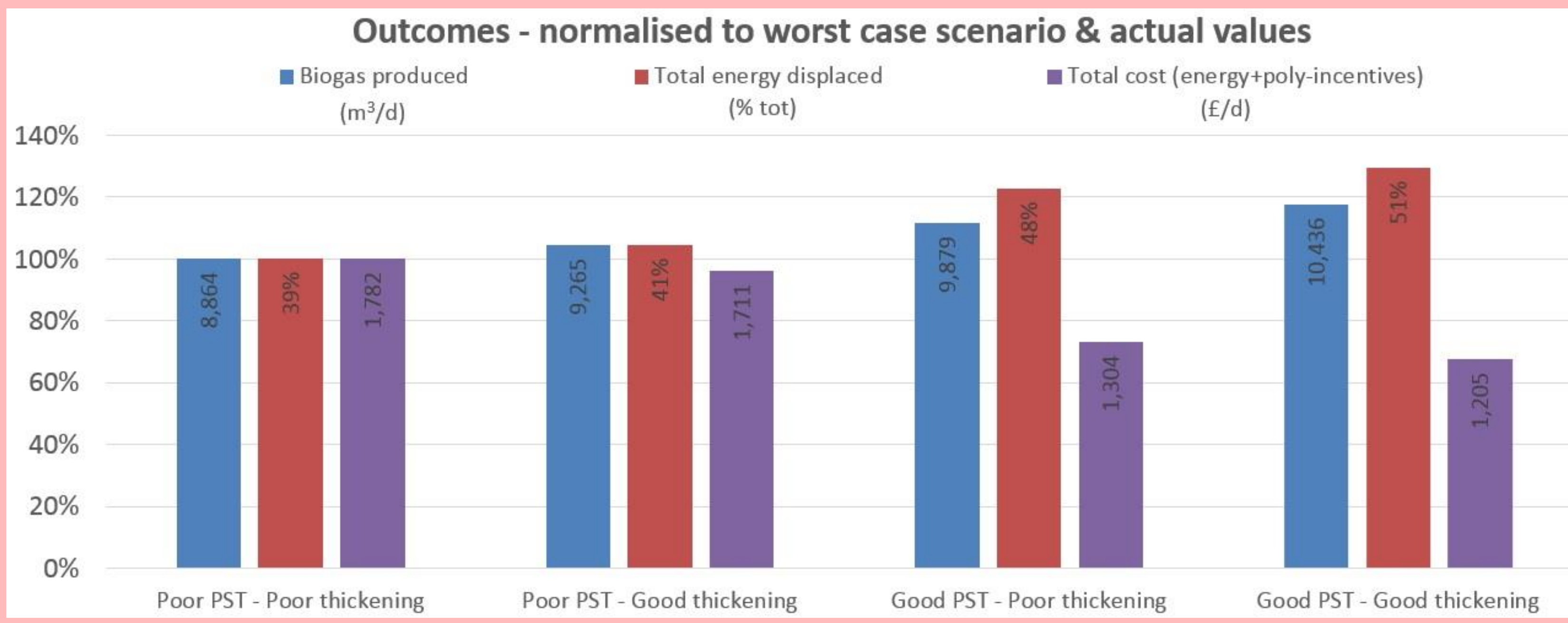


Figure 5 – Outcomes of the modelling using results from the experimental research

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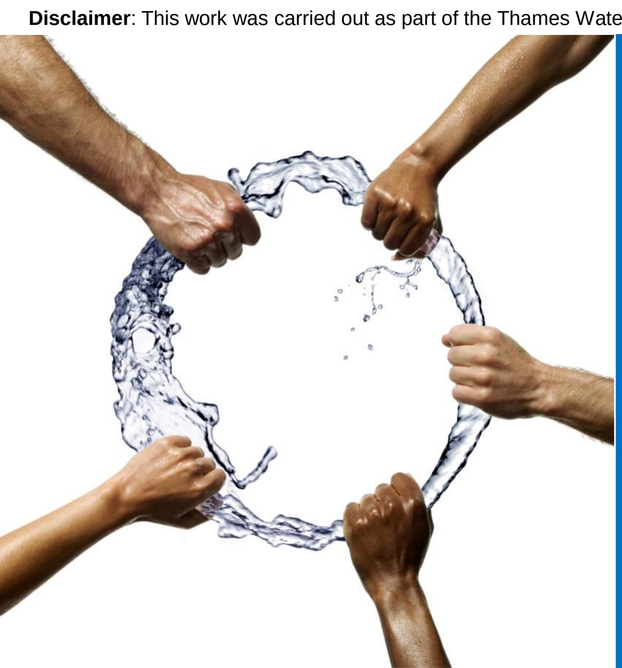

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