Imperial College London

A Practical Operator Model of Biogas Yield from Full-scale Sewage Sludge Anaerobic Digestion

Jin Liu and Stephen R Smith

Department of Civil and Environmental Engineering, Imperial College London
Email s.r.smith@imperial.ac.uk

Imperial College London

Background

- Overall 80% of sewage sludge in the UK is treated using anaerobic digestion (AD)
- Anaerobic digestion is a practical and cost-effective method for the stabilisation and treatment of residual sewage sludge
- It is also a significant producer of renewable energy in the form of biogas
- There is still a lack of practical modelling tools available to guide operators and maximise the energy output

Imperial College London

AD is a dynamic system affected by multiple factors:

- Sludge composition
- Sludge age
- Primary SAS ratio
- Volatile fatty acid (VFA)
- Iron dosing
- Ammonia
- Pretreatment
- Asset age
- Hydraulic retention time (HRT)
- Temperature
- Dry solids (DS)
- Volatile solids (VS)
- Mixing efficiency
- Organic loading rate

Imperial College London

Data Summary

Routinely collected parameters:

- Temperature
- DS
- HRT

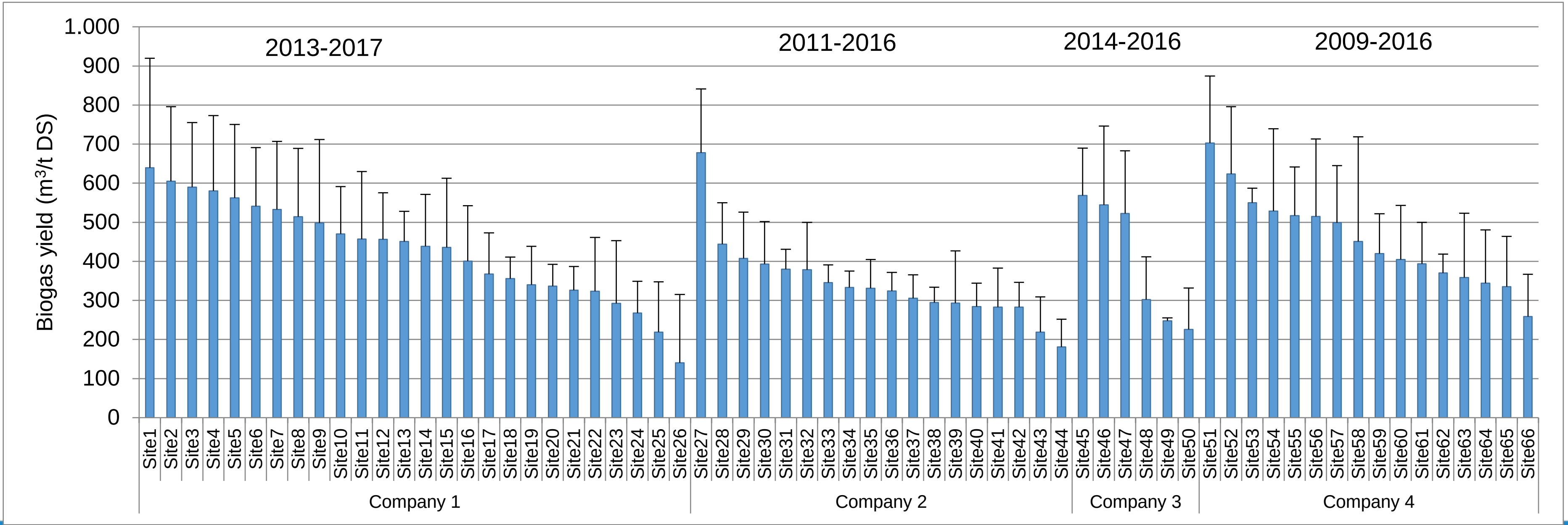
Additional parameters collected at specific sites:

- VS, sludge age, primary SAS ratio, VFA etc.

Imperial College London

Data Summary

Conventional mesophilic anaerobic digestion (MAD) dataset



Imperial College London

Multiple Regression Analysis

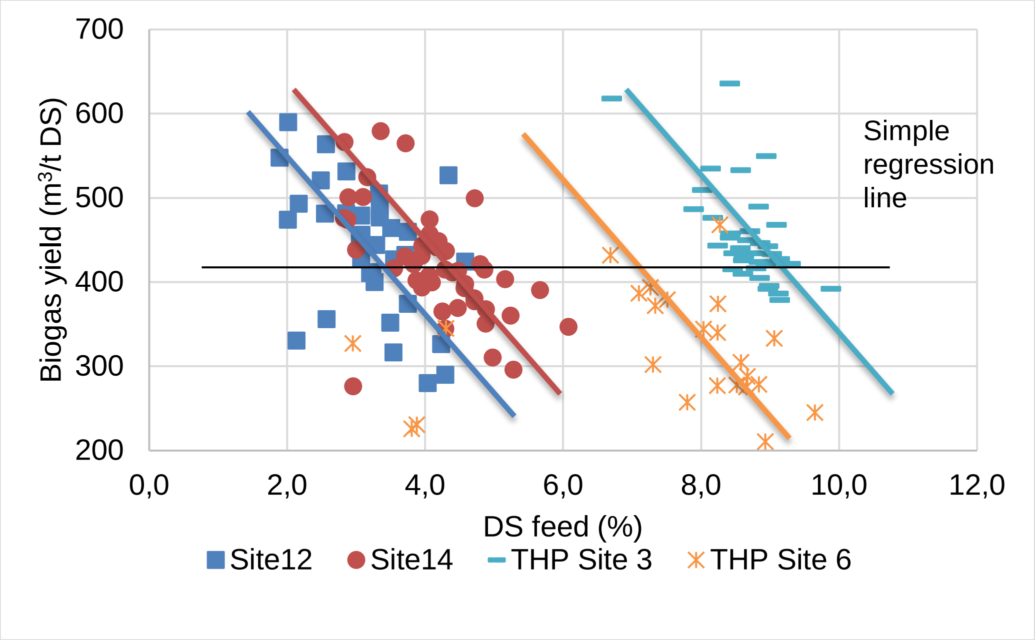
Simple linear multiple regression:

$$y = b_1x_1 + b_2x_2 + \ldots + b_nx_n + c$$

- Significant predictors are selected based on $P < 0.05$

However, the full-scale AD data are clustered

- Categorical factor: multi-level regression
- Centering approach: evaluating the relative changes



Imperial College London

Multiple Regression Analysis

Multi-level factor

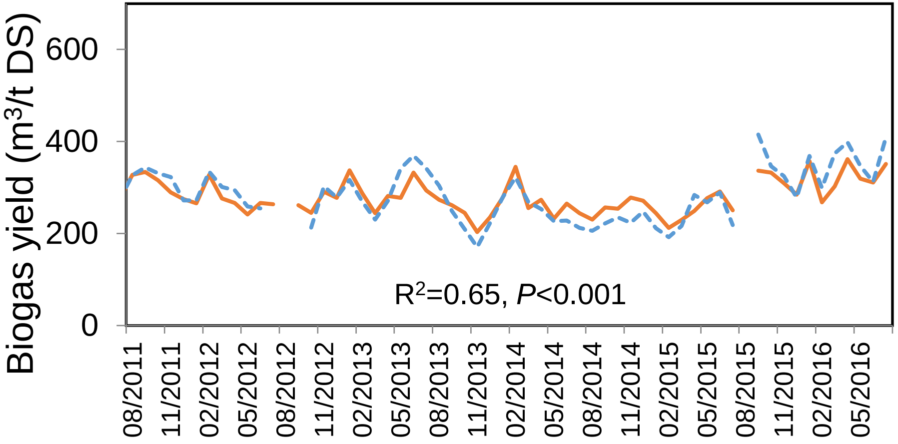
Conventional MAD model:

Biogas yield = 230.9 * (Ln(Temperature) - 3.6) + 136.2*(Ln(HRT) - 3.0) - 224.8 * (Ln(DS) - 1.5) + 75.5 * ((Ln(HRT) - 3.0) * (Ln(DS) - 1.5)) + site factor

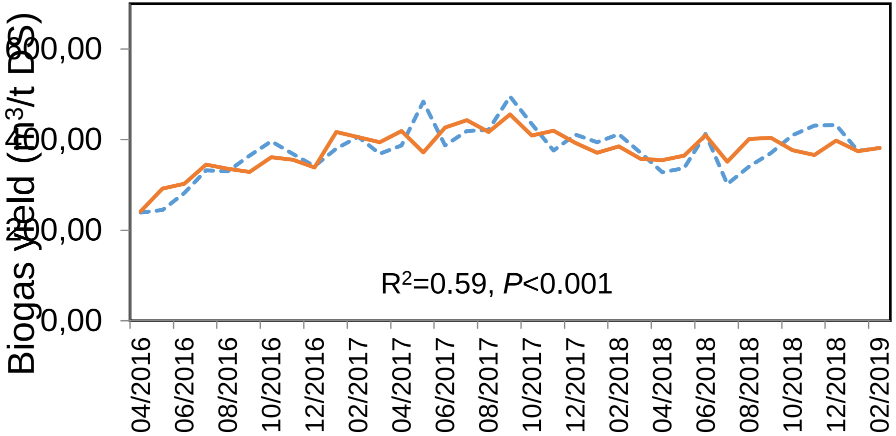
Variation explained:	0.46%	2.55%	5.31%	0.11%	42.42%

Model Validation – Conventional MAD

Data involved in model generation
(2011 - 2016)
Site 42



Independent datasets
(2016 - 2019)
Site 38



Predicted biogas yield   Observed biogas yield

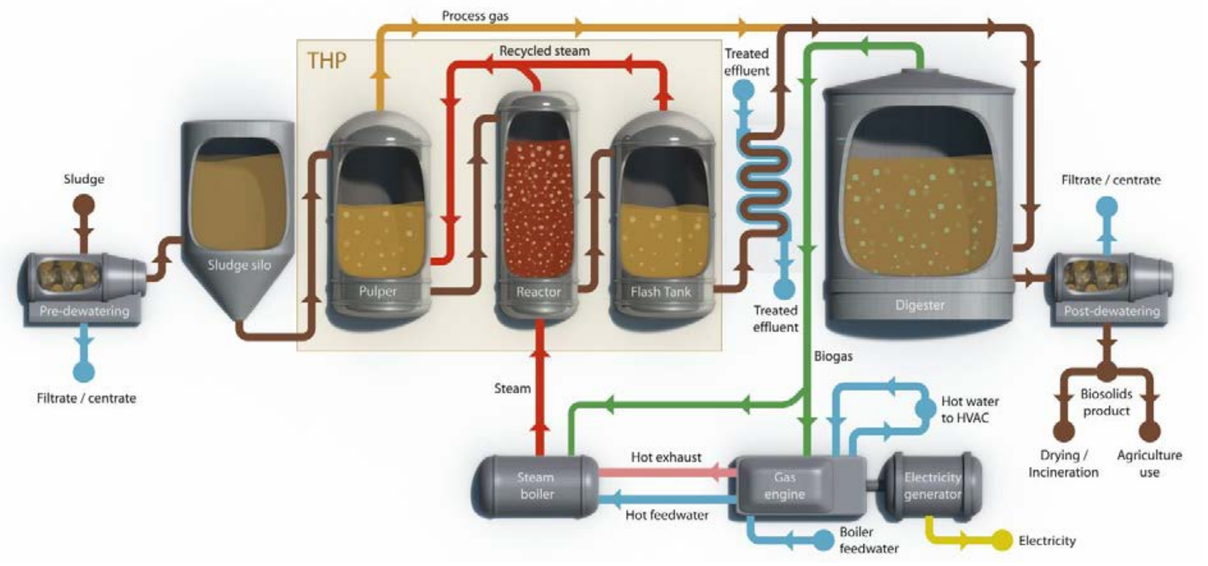
Imperial College London

Expansion of Advanced AD

Thermal hydrolysis process (THP)

Increases:

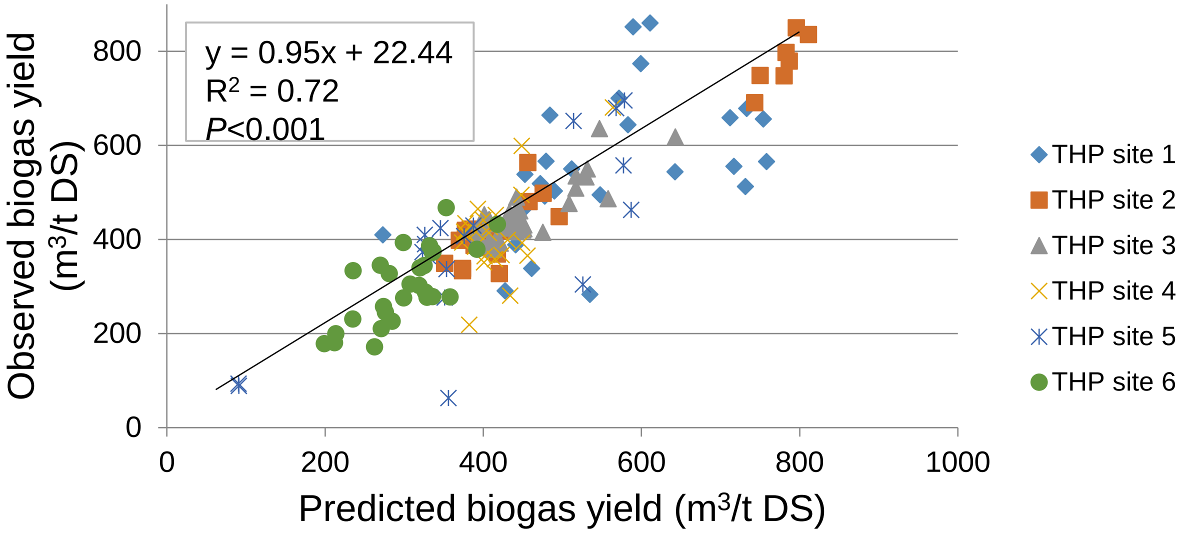
- Loading rate
- Biogas yield
- VS reduction
- Pathogen kill
- Dewaterability



Imperial College London

Combined Conventional-THP MAD Model Development

Apply conventional MAD model into THP datasets



Combined Conventional-THP MAD Model Development

<u>Conventional MAD model :</u>

$$\text{Biogas yield} = 230.9 * (\ln(\text{Temperature}) - 3.6) + 136.2*(\ln(\text{HRT}) - 3.0) - 224.8 * (\ln(\text{DS}) - 1.5) + 75.5 * ((\ln(\text{HRT}) - 3.0) * (\ln(\text{DS}) - 1.5)) + \text{site factor}$$

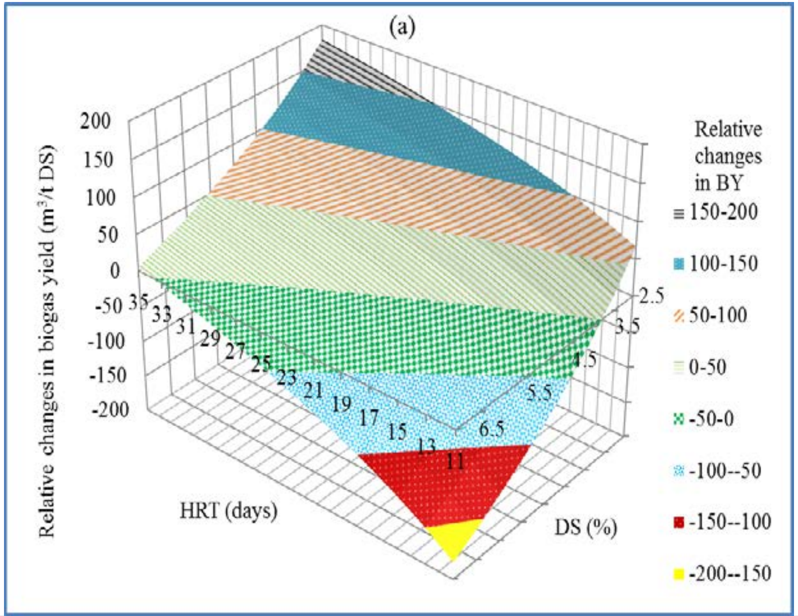
<u>Combined conventional-THP MAD model :</u>

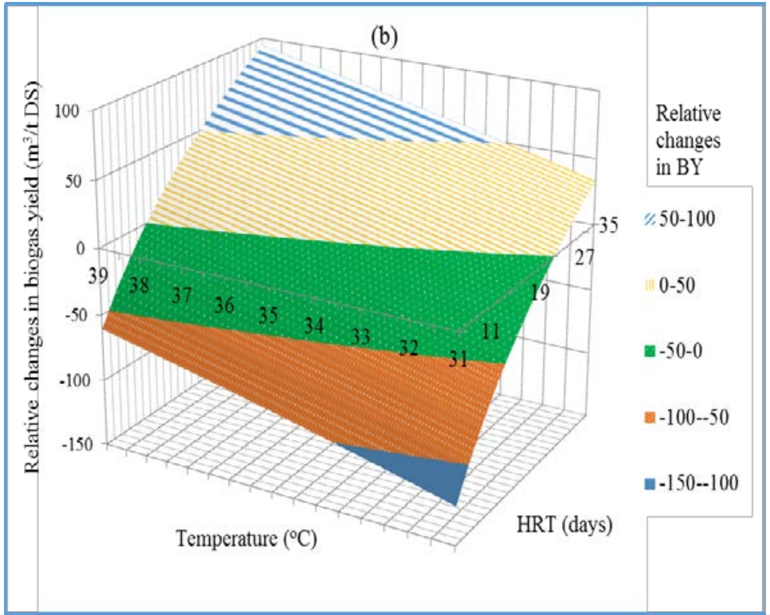
$$\text{Biogas yield} = 265.3 * (\ln(\text{Temperature}) - 3.6) + 133.7 * (\ln(\text{HRT}) - 3.0) - 216.4 * (\ln(\text{DS}) - 1.5) + 61.7*((\ln(\text{HRT}) - 3.0) * (\ln(\text{DS}) - 1.5)) + \text{site factor}$$

Imperial College London

Combined Conventional-THP MAD Model

Impact of HRT, DS and temperature on performance

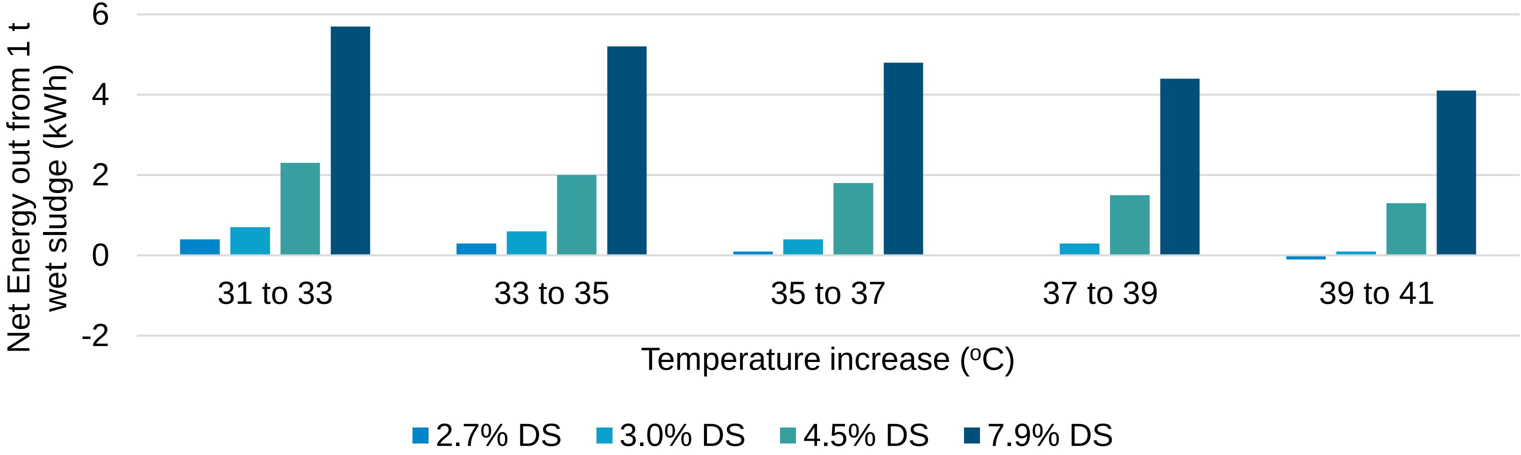




Imperial College London

Optimisation Strategies

Net energy balance - changing temperature and DS



Energy required to heat 1 t wet sludge is 2.3 kWh. 2.7% DS is the lower 5% percentile range value of monthly average operational data for conventional MAD sites; 3.0% is the break point sludge feed DS for a positive net energy balance for MAD; 4.5% and 7.9% DS are the mean values of monthly average operational data for conventional and THP MAD sites, respectively.

Imperial College London

Conclusions

- The first time that simple operational models of the AD process have been developed based on full-scale operational data

- Important to balance the three key operational parameters (temperature, HRT, and DS) to optimise the energy balance of the process

- Increasing sludge solids content improves overall AD energy balance

- **Liu, J. and Smith, S.R. (2020) A multi-level biogas model to optimise the energy balance of full-scale sewage sludge conventional and THP anaerobic digestion. *Renewable Energy* 159, 756-766**

Imperial College London

Acknowledgements

- This research was sponsored by Anglian Water Services Ltd, Severn Trent Plc, Thames Water Utilities Limited, United Utilities Group Plc and Yorkshire Water Services Ltd
- The views expressed in the presentation are those of the authors and do not necessarily represent the companies supporting the research