Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA | agritech National Research Center for Technology in Agriculture

Modelling of a pilot-scale biogas plant fed on agricultural feedstocks

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SPOKE 8 – Circular economy in agriculture through waste valorisation and recycling
WP 8.2 – Agroenergy production from wastes to reduce energy dependence
TASK 8.2.1 – Biotechnologies to produce electricity/heat and advanced fuel from wastes

Motivation

Currently, model application has become imperative in the biogas field, to maximise the performances of AD facilities and to support the transition from biogas plants to biorefineries for the recovery of energy and material.

The Anaerobic Digestion Model No. 1 (ADM1) published in 2002 is the most popular model providing a comprehensive mathematical description of the anaerobic digestion (AD) process of waste sludge. Later, it was modified to include more detailed metabolic or physic-chemical processes, to adapt it to describe degradation of other feedstocks (e.g. agro-waste and food-waste), to include the effects of specific operational conditions, etc.

In addition, default values of ADM1 parameters commonly require further calibration when dealing with different feedstocks. Parameter estimation can prove challenging, due to the large and non-linear model structure resulting in low and/or highly correlated sensitivities of parameters as well as to the difficulty to collect informative experimental data set at full-scale facilities.

This work addresses the need for robust approaches to estimate kinetic parameters in continuous anaerobic co-digestion plants. Specifically, it outlines a procedure for including data from batch activity tests on digestate samples, in addition to the poorly informative dataset from conventional monitoring of biogas facilities (i.e. biogas flow rate and composition).

Materials and Methods

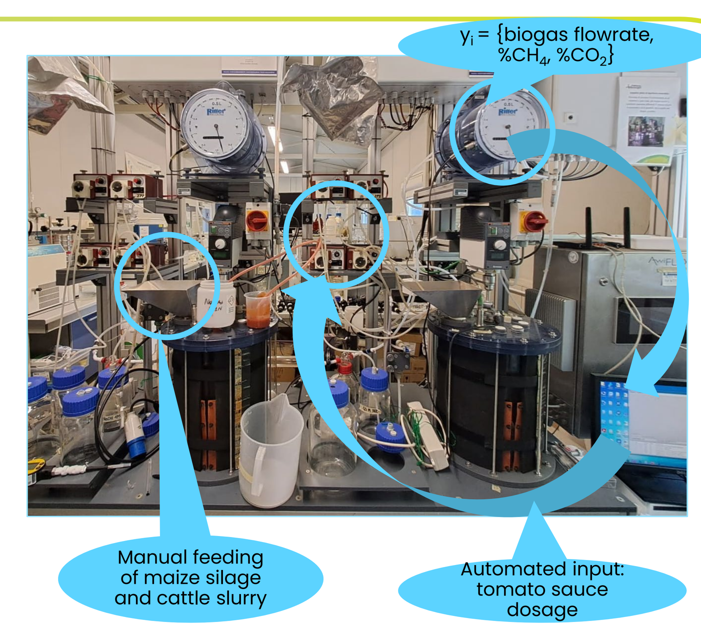
Experimental plan

Co-digestion of silage maize, cattle slurry and tomato sauce (pumpable)

Feedstock	Load [gFM/d]	COD/VS	OLR [gCOD/L/d]
Tomato sauce	96-198	1.21	0.68-1.31
Cow slurry	176-243	1.38	0.89-1.36
Maize silage	32-48.9	1.30	0.86-1.41
	Total HRT = 28-33 d		Total OLR = 2.7-3.6

Monitoring plan:

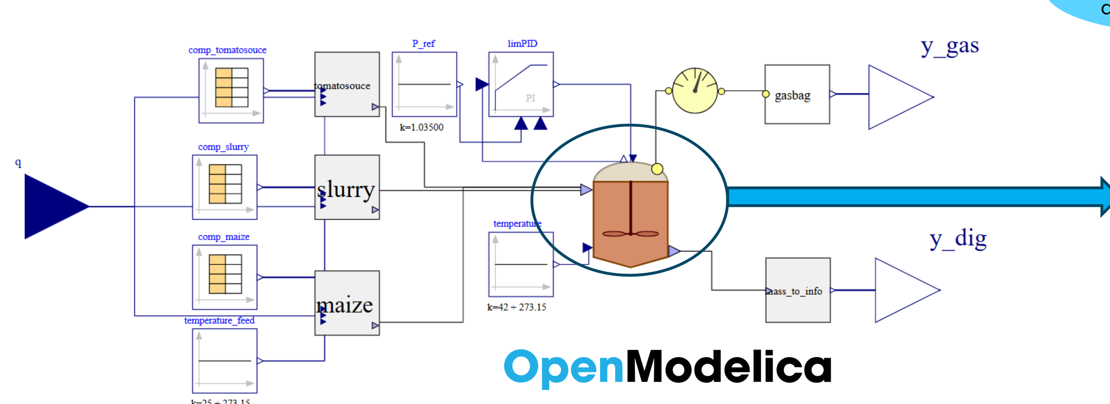
- Online measurements: gas flowrate, biogas composition (%CO_2, %CH_4, %O_2, ppm H_2S), pH.
- Offline measurements (3/week before every manual feeding): TS/VS, VFA, TAN, CODs, CODt, ortoP
- Offline activity tests (acetate, propionate), inhibition test (NH_3) and BMP.



Modelling

Dynamic system

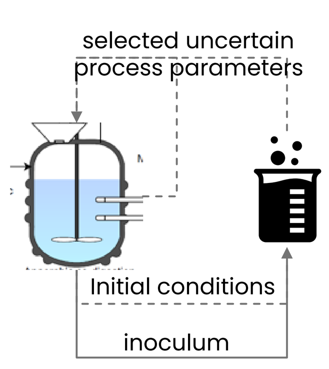
- mass balances, physico-chemical processes (solid-liquid, liquid-gas, acid-base)
- 40 state variables (chemical species and bacterial pop.) > 200 equations,
- uncertain influent composition
- ~ 100 process parameters (stoichiometries and kinetics) (~ 50 uncertain)…identifiability analysis and subsequent calibration!



OpenModelica

ADM1
Mono-digestion of sludge

agri-AcoDM
Co-digestion of agro-zootechnical feedstocks



Parameter selection scheme (PSS) exploiting the available measurements to reduce overfitting risks, based on:

- sensitivity analysis (local once-at-time and global multiple-at-time);
- correlation analysis (collinearity index).

Steady-state operation is poorly informative → exploitation of the informative content of the **batch tests** (activity and BMP tests. & **innovative initial conditions update** by semi-continuous reactor (UIT) simulations!

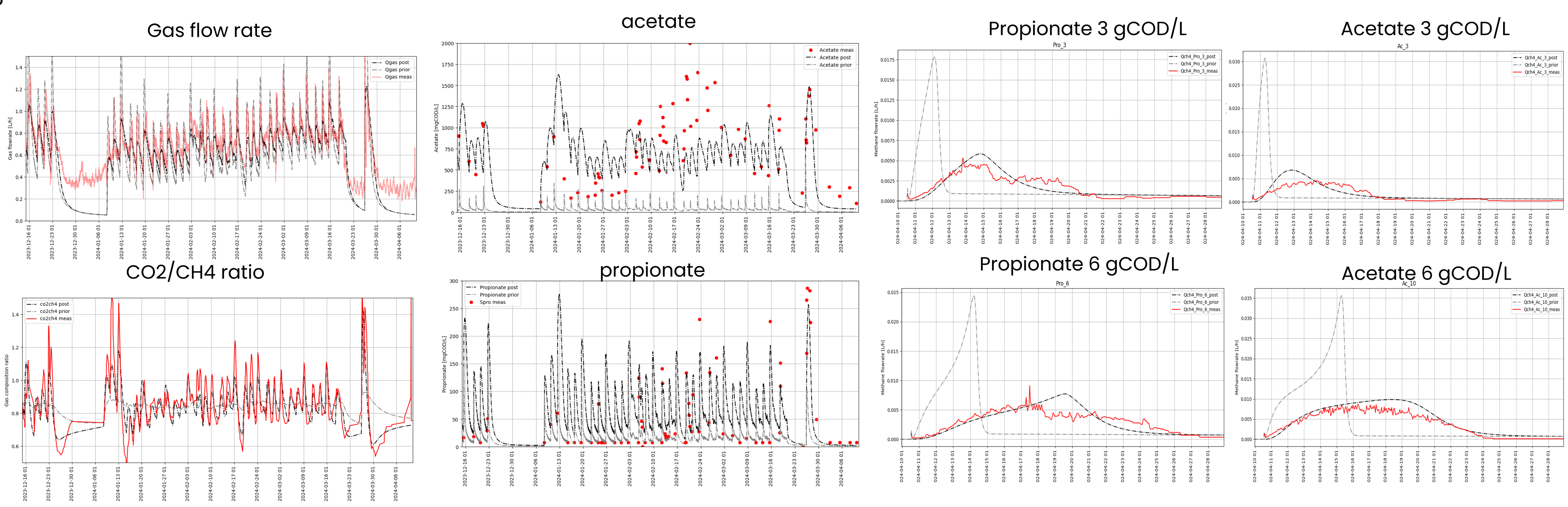
Calibration with differential evolution algorithm (SciPy) and loss function = 'normalized' least squares.

RESULTS

Parameter selection scheme → From 78 tested uncertain parameters (25 kinetic parameters), only 14 were selected.

Parameter name [UM]	Position in local SA ranking	Reference value	Calibrated value
k_hyd,xchr [1/d]	19	1.00	0.65
km_pro [kg_{CODs}/kg_{CODx}/d]	2	13.00	5.28
km_ac [kg_{CODs}/kg_{CODx}/d]	1	8.00	4.90
Ks_ac [kg_{COD}/m^3]	9	0.15	0.44
Ks_pro [kg_{COD}/m^3]	18	0.10	0.08
Ki_hac,ac [kg_{COD}/m^3]	5	2.20	7.94
Ki_hpro,pro [kg_{COD}/m^3]	4	2.20	3.26
km_su [kg_{CODs}/kg_{CODx}/d]	12	30.00	29.52
km_h2 [kg_{CODs}/kg_{CODx}/d]	13	35.00	21.38
Ks_h2 [kg_{CODs}/kg_{CODx}/d]	17	7.00 e-6	1.35 e-5
Ki_nh3 [mol_N/L]	3	1.80 e-3	2.70 e-3
Ki_h2,pro [kg_{COD}/m^3]	14	3.50 e-6	2.22 e-6
pH_UL,ac [-]	7	7.00	7.96
kLa (batch tests) [1/d]	10	10.00	1.05

Model performance: prior/post calibration vs data



Next steps

- Validation of the model's performance on different data sets
- Validation of a 'conventional' control scheme, where the agri-AcoDM model has the role to:
  - define 'offline' the optimal values of diet, methane flow rate and gas composition obtainable depending on techno-economic boundary constraints (i.e. setpoints);
  - represent the real plant in simulation to calibrate the controller parameters (PI).

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This study was carried out within the Agritech National Research Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1032 17/06/2022, CN00000022). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.