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EXTENDED ADM1 MODEL FOR ANAEROBIC CO-DIGESTION OF AGRICULTURAL WASTES

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SPOKE, WP E TASK DI APPARTENENZA

Spoke 8 - Circular economy in agriculture through waste valorisation and recycling

WP 8.2 - Agroenergy production from wastes to reduce energy dependence

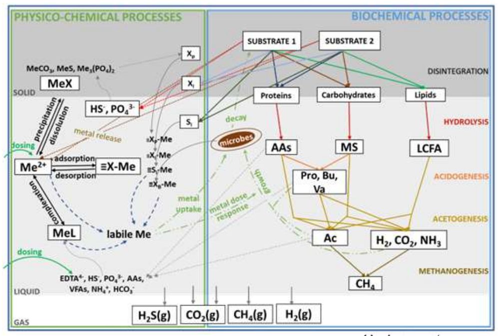
Task 8.2.1 - Biotechnologies to produce electricity/heat and advanced fuel from wastes

INTRODUCTION

- Large quantities of agricultural wastes are generated every year around the world. Anaerobic co-digestion is a widely accepted process for utilization of agricultural residues due to its advantages like low operational costs, applicability at any scale (scalability of the process), bioenergy production and circular economy .
- Anaerobic Digestion Model 1, ADM1 (Batstone et al., 2002) and its extensions are widely used for modeling co-digestion.
- Current models used for co-digestion lacks consideration of fundamental physico-chemical process like ionic strength effects and influence of substrate characteristics such as trace metal content and sulphur.
- This study presents a model-based approach to understand anaerobic co-digestion of agricultural wastes. The model is an extended Anaerobic Digestion Model 1 (ADM1) to define co-digestion where the biochemical and physiochemical framework are extended to include distinct disintegration factors based on substrate chracterisation, precipitation processes, trace metal speciation processes and effects of ionic strength.
- A local sensitivity analysis has been performed to filter most influential parameters amongst numerous parameters introduced in the new model framework.
- Model simulations have been performed for co-digestion of an agricultural waste (maize straw) with cow manure to study effects of substrate characteristics such as organic fractionation and trace metal content.

METHODOLOGY

- ADM1 model is extended to include co-digestion and physico-chemical processes (Fig. 1).
- Extensions made in biochemical module are according to George et al. (2024). Modified physico-chemical framework consists of:
  1. kinetic precipitation model,
  2. aqueous phase equilibrium model for inorganic complexation and organic complexation with metabolites - VFAs & AAs,
  3. kinetic model for EDTA complexation and
  4. kinetic adsorption model for cationic species, mainly trace metals.



Me^{2+}: Free metal ions; MeX: Metal precipitates; MeL: Metal ion associations; ≡X-Me: Absorbed metal; MeS: Metal sulphides; MeCO$_3$: Metal carbonates; Me$_3$(PO$_4$)$_2$: Metal phospates; ≡X$_p$-Me: Metal absorbed on precipitates; ≡X$_i$-Me: Metal absorbed on particulate inerts; ≡S$_i$-Me: Metal absorbed on soluble inerts; AAs: Amino acids; MS: Monosaccarides; LCFA: Long chain fatty acids; VFAs: Volatile fatty acids; EDTA: Ethyleneaminetetraacetic acid

Fig. 1. Schematic representation of ADM1 based co-digestion model

- For defining co-digestion, separate influent is defined for each of the feedstock. Presence of trace metal and fractions of carbohydrate, protein and lipid for each substrate are adopted from literature (Tolessa et al., 2023, Ezebuiro et., 2017).
- A local sensitivity analysis (LSA) based on one-factor-at-a-time method has been chosen to identify the most influential parameters on model outputs. The first-order partial derivative of the output variable (methane production, acetate and propionate concentration) with respect to the parameter under consideration is computed in order to analyse the impact of a changing parameter.
- Model simulations have been performed using substrates, cow manure and maize straw, at different mixing ratios to study the effects of substrate characterization, sulphur and trace metal content.

RESULTS

Sensitivity analysis

- Fig. 2a. shows that disintegration rate of co-substrate manure ($k_{dis\ manure}$) is more influential followed by that of maize ($k_{dis\ maize}$). Hydrolysis rates ($k_{hyd\ ch}$, $k_{hyd\ pr}$) also play a significant role in influencing model outputs. Metal uptake rate (k_{up}) during microbial processes is found to have influence on model output variable, propionate.
- Regarding influence of precipitation rates on methane production, FeS (kr_{FeS}) and FeCO$_3$ (kr_{FeCO3}) precipitation rates has the maximum effect followed by NiS (kr_{NiS}), MgNH$_4$PO$_4$ ($kr_{MgNH4PO}$), Ni$_3$PO$_4$ (kr_{Ni3PO4}), CoCO$_3$ (kr_{CoCO3}), Fe$_3$PO$_4$ (kr_{Fe3PO4}), NiCO$_3$ (kr_{NiCO3}), CO$_3$PO$_4$ (kr_{CO3PO4}), and other precipitates (kr_{CoS}, kr_{Ca3PO4}, kr_{CaCO3}, kr_{MgCO3}) (Fig. 2b).

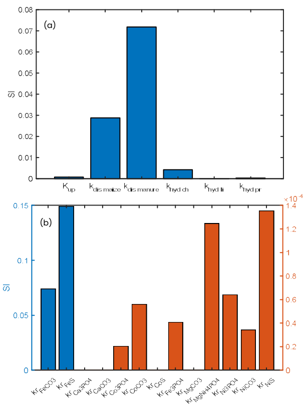


Fig. 2. Sensitivity index of (a) disintegration and hydrolysis rate constants w.r.t propionate (b) precipitation rate constants w.r.t methane

Numerical simulations

Co-digestion of maize straw with cow manure slightly increases biogas production compared to maize mono-digestion (Fig 3a). However, when trace metal effects were considered, mixing cow manure at 80% reduces biogas production due to trace metal deficiency in cow manure (Fig 3b).

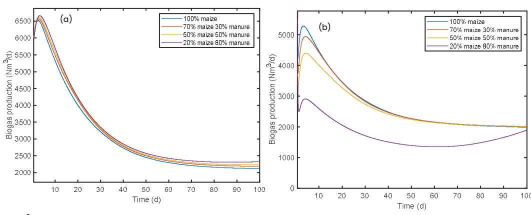


Fig. 3. Effect of co-digestion on biogas production (a) without and (b) with TM effects

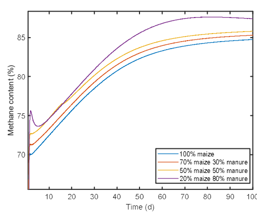


Fig.4. Effect of co-digestion on methane content

Co-digestion improved methane content in the biogas. Maximum methane content was observed when maize was co-digested with 80% manure (Fig. 4).

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