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A Short-Cut Model for Predicting Biomethane Availability after Biogas Upgrading

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Academic Work

Outilne

- Introduction
- Objectives
- Methodology
- Results – model development
- Results – model validation
- Conclusions

Introduction

- Production of biofuels from biomass and waste instead of using these sources "as is" = cleaner production[1,2]
  - reduction of overall greenhouse gases (GHG) emissions;
  - waste recovery;
  - reduction of environmental impacts;
- Therefore, biogas and biomethane = cleaner production
- "Raw" biogas use for CHP systems (H_2S removal necessary)
- Biomethane use (cleaning and upgrading necessary) for:
  - Vehicular use;
  - Injection on the grid;
- Substitution to NG (CO_2 emissions reduction)

[1] KURNIA et al, 2016
[2] LEME and Seabra, 2017

Introduction – biogas cleaning (H_2S removal)[1]

H_2S removal technology	Level of decontamination	Air intake into biogas required
Internal biological desulfurization	Very rough	Yes
Percolating filter plant	Rough	Yes
Bioscrubber plant	Rough	No
Sulfide precipitation	Rough	No
Ferric chelate	Rough	Yes
$Fe(OH)_3$ – bog iron ore	Fine	Both options
Fe_2O_3	Fine	Both options
Activated carbon – KI, K_2CO_3, $KMnO_4$	Fine	No
Zinc oxide	Fine	No
Surfactant	Fine	No
Absorption at glycol and ethanolamine	Fine	No
Algae	Fine	Yes
Direct oxidation	Fine	Yes

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[1] Deublein and Steinheuser, 2008

Introduction – biogas upgrading (CO_2 removal)[1]

Upgrading technology	CH_4 losses (typical)	CH_4 (vol%) in biomethane	Observations
Water scrubbing	Low (1-3%)	> 98%	High water demand; removes NH_3
Physical absorption	Low-Medium (2-4%)	> 96%	Different organic solvents available; removes H_2S, but may difficult regeneration of the solvent
Chemical absorption (amine scrubbing)	Very low (<0.1%)	> 99%	High heat demand; Low electricity consumption; removes H_2S; may produce high quality CO_2
Pressure swing adsorption (PSA)	Medium-High (4-9%)	> 97%	N_2/O_2 removal possible; requires fine H_2S pre-removal to protect adsorbent material
Membrane separation	Low-High (1-12%)	> 96%	Compact; low-medium energy requirements; membrane can be expensive

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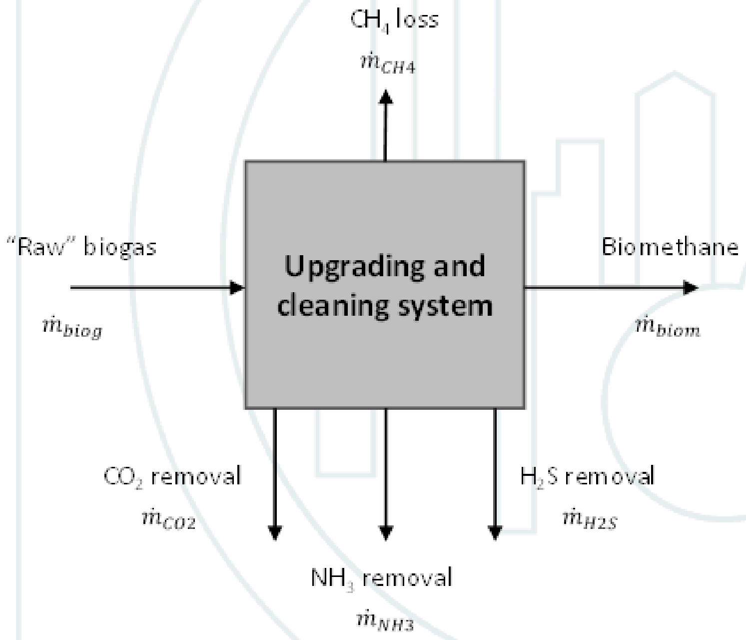
[1] Probiogas (2010);
Yang et al. (2014);
Sun et al. (2015);
Leme and Seabra (2017)

Objectives

- Present a model that consists only of dimensionless parameters to predict the biomethane availability after **any** given biogas cleaning and upgrading process;
- Combine other important parameters, like the biomethane lower heating value (LHV), Wobbe Index with the model;
- Validate the model using data from case studies, experimental or simulation of biogas upgrading, regardless of technology or organic matter feedstock.

Methodology

- Black-box model



Upgrading and cleaning system

"Raw" biogas $\dot{m}_{biog}$

Biomethane $\dot{m}_{biom}$

CH_4 loss $\dot{m}_{CH4}$

CO_2 removal $\dot{m}_{CO2}$

NH_3 removal $\dot{m}_{NH3}$

H_2S removal $\dot{m}_{H2S}$

Methodology

- Mass balances: Global, CH_4, CO_2, H_2S, NH_3 and inerts (O_2 and N_2)
- Methane loss: $\dot{m}_{CH4} = x_m . \dot{m}_{biog} . f_{loss}$
- Dimensionless parameters:
  - $X_{BM/BG} = \frac{\dot{m}_{BM}}{\dot{m}_{BG}}$ - mass conversion factor of biogas into biomethane by the process;
  - $Y_{BM/BG} = \frac{Q_{BM}}{Q_{BG}}$ - volumetric conversion factor of biogas into biomethane by the process;
  - $r = \frac{1}{1-x_c-x_s-x_n}$ - biogas mass contamination factor;
  - $r' = \frac{1}{1-x'_c-x'_s-x'_n}$ - biomethane mass contamination factor;
  - $r_m = \frac{1}{x_m . f_{loss}}$ - methane mass retention factor of the upgrading and cleaning system
  - $R_{CO2} = \frac{\dot{m}_{CO2}}{x_c . \dot{m}_{BG}}$ - CO_2 mass removal factor of the upgrading and cleaning system
- x_m, x_c, x_h, x_n → mass fraction of components of biogas
- x'_m, x'_c, x'_h, x'_n → mass fraction of components of biomethane (standard)
- f_{loss} → CH_4 loss factor of the upgrading technology

Results – model development

- $X_{BM/BG} = r' \cdot \left(\frac{1}{r} - \frac{1}{r_m}\right) \longrightarrow \frac{1}{r_m} \ll \frac{1}{r} \longrightarrow X_{BM/BG} = \frac{r'}{r}$
- $x'_m = \frac{x_m - 1/r_m}{X_{BM/BG}} \longrightarrow \frac{1}{r_m} \ll x_m \longrightarrow x'_m = \frac{x_m}{X_{BM/BG}}$
- $x'_c = x_c \cdot \frac{1 - R_{CO2}}{X_{BM/BG}}$

Density correction factor

- $Y_{BM/BG} = X_{BM/BG} \cdot \frac{G_{BG/m}}{G_{BM/m}}$, where $G_{BM/m} = \frac{X_{BM/BG}}{F_{mc}}$ and $\boxed{F_{mc} = \left(x_m + \frac{\rho_m}{\rho_c} \cdot x_c.(1 - R_{CO2})\right)}$
- ρ_m, ρ_c → densities of CH_4 and CO_2 (H_2S contribution is considered negligible)
- $G_{BG/m}, G_{BM/m}$ → specific gravities of biogas and biomethane related to pure methane

Results – model development

- Lower Heating Value:

$$LHV_{BM} = \frac{x_m . LHV_m}{X_{BM/BG}} \longrightarrow$$

Pure methane LHV

- Wobbe Index (gas interchangebiality)

$$Wb_{BM} = \frac{x_m . LHV_m}{X_{BM/BG}^{\;1,5}} \cdot \left(\frac{F_{mc}}{G_{m/air}} \right)^{0,5} \longrightarrow$$

Specific gravity of pure methane related to air

NB: Contributions of H_2S and NH_3 are disregarded

Results – Model validation

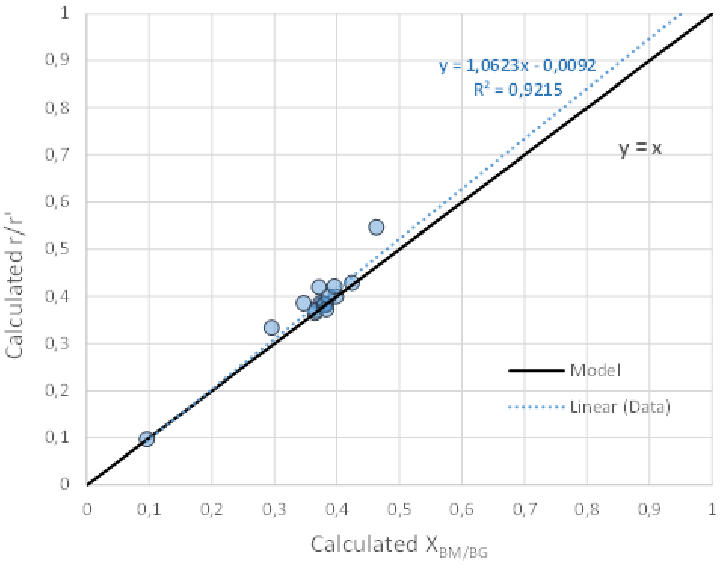


Figure 2: *Data and model correlation.*

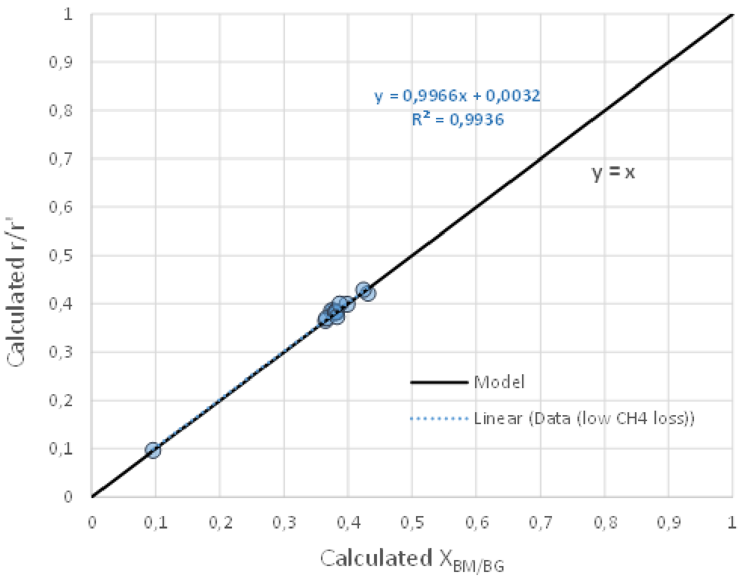


Figure 3: *Data and model plot considering only data with methane loss lower than 3%.*

Results – Model validation

Data from high methane loss on upgrading

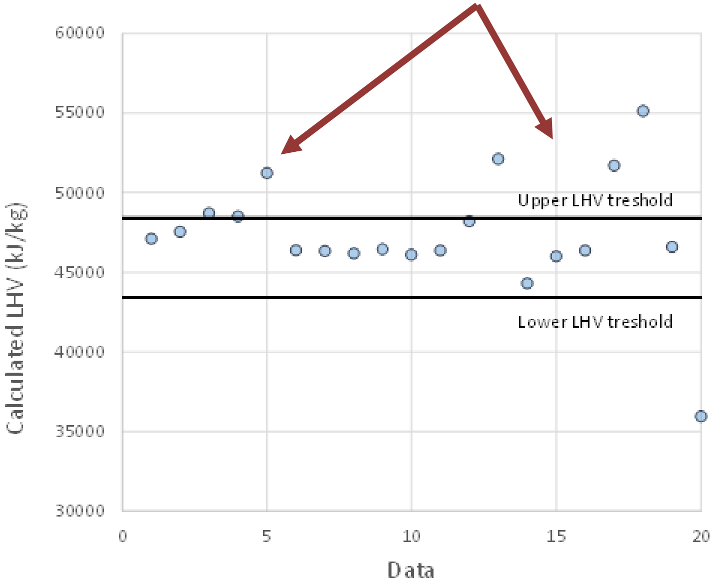


Figure 4: *Model fitting for LHV.*

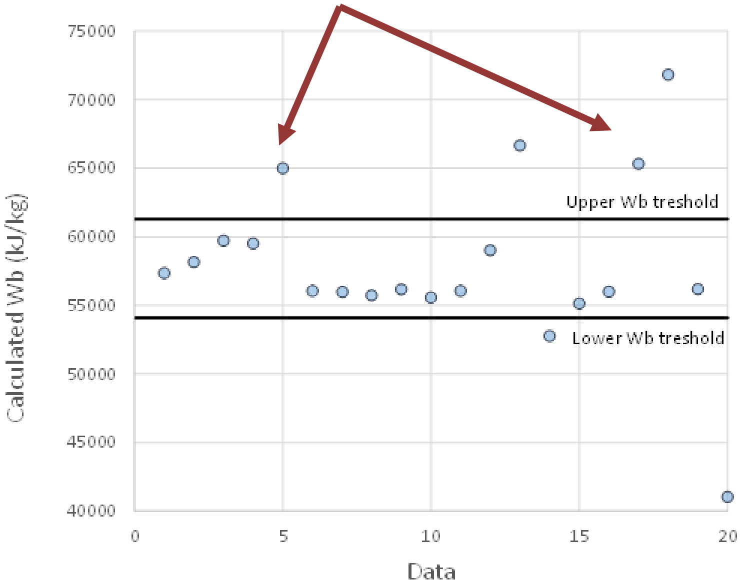


Figure 5: *Model fitting for Wobbe Index.*

Conclusions

- Data from literature fitted to the model with a R^2 parameter of 0,994. LHV and Wobbe Index were inside the defined range of acceptable values → very satisfactory correlation;
- Model based solely on a mass balance → no differentiation on data regarding the organic feedstock for biogas or the technology used to perform the upgrading;
- Simple model → very suitable for conceptual engineering projects and estimation of CO_2 emissions reduction by GN substitution;
- Limitation: predicting biomethane availability on upgrading process with CH_4 losses higher than 3% (not be a suitable choice for PSA or membranes).

Thank you!

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