Optimising Feedstock Flowrate to Improve the Performance of an Existing Anaerobic Digestion System

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Background

Renewable energy generation, World

Source: BP Statistical Review of Global Energy
Note: "Other renewables" refers to renewable sources including geothermal, biomass, waste, wave and tidal. Traditional biomass is not included.
Problem Statement

“What if we don’t change at all ... and something magical just happens?”

AD Model

ADM1
Predictive
Experimental

Literature

Anaerobic Digester

STANDARDIZED

100% QUALITY

9-count
12-count

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Aim & Methodology

Aim:
Investigate how first order models can be used with plant data to improve system control by balancing conflicting objectives.
Case Study
Component Models

**SHREDDER**
- Specify screen size (mm), motor speed (rpm) & flow rate (kg/min)
- Determine specific energy consumption (kWh/kg)
- Determine energy needed to heat feedstock to digestion temperature (kJ)
- Determine temperature of water required in coil (°C)
- Determine energy needed to heat water (kJ)

**DIGESTER**
- Heat Required
  - Determine energy needed to heat feedstock to digestion temperature (kJ)
- Heat Loss
  - Determine heat loss from the digester sides, top & bottom (kJ)
- Determine temperature of water required in coil (°C)
- Determine energy needed to heat water (kJ)

**Biogas Production**
- Use modified Gompertz model to determine daily biogas production (m3/kgVS)
- Determine daily biogas production (m3/day)

**H₂S SCRUBBER**
- Determine mass of H₂S to be removed (kg)
- Use literature to determine coefficients for modified Gompertz model
- Use modified Gompertz model to determine daily biogas production (m3/kgVS)
- Determine amount of adsorbent required (kg)
- Determine adsorbent cost ($) (°C)

**H₂O CONDENSER**
- Determine mass of water to be removed (kg)
- Use saturation vapour pressure vs. temperature table to determine dew point temperature (°C)
- Determine energy needed to cool biogas to dew point temperature (kJ)

**Heat Loss**
- Determine energy needed to heat feedstock to digestion temperature (kJ)

**Heat Required**
- Determine energy needed to heat feedstock to digestion temperature (kJ)
- Determine heat loss from the digester sides, top & bottom (kJ)

**Heat Loss**
- Determine heat loss from the digester sides, top & bottom (kJ)

**Determine specific energy consumption (kWh/kg)**
- Determine specific energy consumption (kWh/kg)

**Determine energy needed to heat water (kJ)**
- Determine energy needed to heat water (kJ)

**Determine temperature of water required in coil (°C)**
- Determine temperature of water required in coil (°C)

**Determine heat loss from the digester sides, top & bottom (kJ)**
- Determine heat loss from the digester sides, top & bottom (kJ)

**Determine biogas production (m3/day)**
- Determine biogas production (m3/day)

**Determine adsorbent cost ($)**
- Determine adsorbent cost ($) (°C)

**Determine amount of adsorbent required (kg)**
- Determine amount of adsorbent required (kg)

**Determine mass of H₂S to be removed (kg)**
- Determine mass of H₂S to be removed (kg)

**Determine energy needed to cool biogas to dew point temperature (kJ)**
- Determine energy needed to cool biogas to dew point temperature (kJ)
Optimisation Problem

• Scenario 1
  • Min. unmet demand (m³)
  • Min. biogas flared (m³)

• Scenario 2
  • Min. unmet demand (m³)
  • Min. biogas flared (m³)
  • Min. energy cost ($/kgVS)

• Optimisation Solver
  • NSGA II (Python)

\[
C_{EC} = \left( \left( E_{\text{shred}} + \frac{(E_{\text{heatwater}} + E_{\text{loss}} + E_{\text{condenser}})}{1000 \times 3.6} \right) \times C_{\text{elec}} + C_{\text{H2S}} \right) / (m_r \times VS)
\]
Optimisation Scenarios

- Feedstock Flowrate $m_f$ (kg/day)
- Balloon Level $V_9 - BL$ (m³)
- LPG Required $V_{LP}$ (m³)
- Energy Cost $C_{EC}$ (USD/kgVS)
- Biogas Produced $V_{BP}$ (m³)
- Biogas Flared $V_{BF}$ (m³)
- Gas Consumption $V_C$ (m³)

Min. unmet demand (m³)
Min. biogas flared (m³)

Min. energy cost ($/kgVS$)

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Current vs. Optimised System

Current System

- Feedstock Flowrate $m_f$ (kg/day)
- Balloon Level $V_{BBL}$ (m$^3$)
- LPG Required $V_{LPG}$ (m$^3$)
- Energy Cost $C_{EC}$ (USD/kgVS)
- Biogas Produced $V_{B-P}$ (m$^3$)
- Biogas Flared $V_{B-F}$ (m$^3$)
- Gas Consumption $V_C$ (m$^3$)

Optimised System

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Conclusions & Future Work

• Optimisation
  • Add weightings to objective functions;
  • Assign an environmental penalty to flaring biogas;
  • Components altered &/or sized differently & different system configurations e.g.
    • Alternate pre and post treatment technologies;
    • Passing biogas through CHP unit to generate electricity & heat;
    • Additional objective functions & decision variables.

• AD Model
  • Modified Gompertz model not suitable for digesters operating in continuous mode
  • Plant data for entire year & values of digester operational variables (pH, temperature etc.)
Thank You!

Questions?