Linear time invariant model of anaerobic digestion of waste activated sludge

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Linear time invariant model of anaerobic digestion of waste activated sludge

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Activated Sludge Plant

- Anaerobic digestion: Waste to energy
- Mathematical model for analysis
- LTI model:
  - Stability analysis
  - Parameter sensitivity
  - Kinetic estimation
  - Controller design

Anaerobic Digestion No. 1

- Particulate matters
  - Carbohydrates
    - Sugars
    - Propionate
    - Acetate
  - Proteins
    - Amino acids
    - Butyrate
    - Valerate
  - Lipids
    - Fatty acids
    - Hydrogen
  - Methane

- Particulate inert
- Soluble inert
Activated sludge

Particulate

Activated sludge

Acidogens

Methanogens

Substrate

VFAs

Methane

<table>
<thead>
<tr>
<th>ADM1</th>
<th>Simpler version</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 soluble + 6 ions + 3 gases</td>
<td>7 major components</td>
</tr>
<tr>
<td>35 ODEs</td>
<td>7 ODEs</td>
</tr>
<tr>
<td>25 kinetic constants</td>
<td>8 kinetic constants</td>
</tr>
</tbody>
</table>
Linear Time Invariant

- **Linear:** Input $\times n \rightarrow$ Output $\times n$
- **Time invariant:** Same model applies, now and then

Mass balance

$$\Delta x = \text{Input} - \text{Output} + \text{Generation} - \text{Consumption}$$

Differential equation

Nonlinearity: Biomass growth, input - output

Linearization via Taylor Series

$$x = \left\{ (sI - A)^{-1}B \right\} x_{in}$$

LTI model

Analysis
Linearization

- Biomass growth rate

\[
\frac{k^A S X^A}{K^A + S} \approx \frac{k^A \bar{S}}{K^A + \bar{S}} X^A + \frac{K^A k^A \bar{X}^A}{(K^A + \bar{S})^2} (S - \bar{S})
\]

\[
\frac{k^M V X^M}{K^M + V} \approx \frac{k^M \bar{V}}{K^M + \bar{V}} X^M + \frac{K^M k^M \bar{X}^M}{(K^M + \bar{V})^2} (V - \bar{V})
\]

- Input and output

\[
D(A^{in} - A) \approx D(A^{in} - \bar{A}) - \bar{D}(A - \bar{A})
\]
Model Validation

- A multivariable $6 \times 6$ model of anaerobic digestion of activated sludge
- Verification against original model
Kinetic Constant Estimation

Hydrolysis and biomass decay: 1\textsuperscript{st} order
Kinetic parameter is straightforward

Biomass growth: Monod
Need steady state concentration + least square

Open/closed loop step/impulse test for model identification
**System Behavior**

- **Recommended control structure**
  - Independent individual controller preferable
  - Substrate through biomass, biomass via substrate

- **Stability**
  - Original process is stable
  - Imbalance in acidogens growth and decay rate causes instability

- **Sensitivity**
  - Biomass is more sensitive to influent condition compared to substrate
  - Methanogens is the most sensitive parameter
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Antonius Yudi Sendjaja, Youming Tan, Santosh Pathak, Yan Zhou, Maszenan bin Abdul Majid, Wun Jern Ng

Thank You
Industrial Process Control

HOWEVER
Model based control requires good mathematical model
Controller design

- **Feedback**
  - Influent COD increase  □ Adjust OLR  □ Effluent ok!

- **Feedforward**
  - Temperature decrease  □ Adjust OLR  □ Effluent ok!

Mathematical model:

1. Black box
2. White box
3. Grey box