Anaerobic Digestion in BioWin

Background

The user specified the digester operating pH in the previous version of BioWin. This is no longer necessary as pH is calculated. However, the user may override the calculated pH value, and fix pH at a desired value. We consider three anaerobic digestion examples:

- Anaerobic digestion of glucose.
- Digestion of mixed primary and waste activated sludge.
- Primary sludge fermentation to improve biological phosphorus removal.

Anaerobic Digestion of Glucose

Default stoichiometry in BioWin is tailored for municipal wastewater treatment systems. In the case of a synthetic waste such as glucose, we need to change one default value: the heterotroph CO₂ yield (fermentation at low H₂ partial pressure) is changed from 0.7 to 1.0.

In this example we simulate a flow-through anaerobic digester operated at an HRT of 10 days with a glucose solution as influent. The influent glucose stream, with COD of 10,000 mg/L, is specified as a State Variable (SV) input. [S_{BSC} = 10,000 mg/L].
We need to add nitrogen and phosphorus to the influent for biomass synthesis requirements.

**Note:** BioWin accounts for the following systems as state variables in the model:

- Carbonate (CO$_2$, HCO$_3^-$, CO$_3^{2-}$)
- Ammonia (NH$_3$, NH$_4^+$)
- Phosphate (H$_3$PO$_4$, H$_2$PO$_4^-$, HPO$_4^{2-}$, PO$_4^{3-}$ and PO$_4$ in metal complexes)
- Aluminum or iron species
- Calcium and magnesium

pH calculation and calculation of species distribution incorporates charge balances, so the concentrations of other cations and anions also must be specified. This is accomplished by defining two other state variables for the lumped concentrations of the remaining ionic species:

- Other cations (e.g. K, Na, etc.)
- Other anions (e.g. Cl, etc.)

For this example, we assume that nitrogen for synthesis is added as NH$_4$Cl, at a concentration of 500 mgN/L.

\[
\text{NH}_4^-\text{-N} = 500/14 = 35.7 \text{ meq/L}
\]
\[
\text{Cl anions} = 35.7 \text{ meq/L}
\]

Phosphorus for synthesis is added as K$_2$HPO$_4$, at a concentration of 100 mgP/L.

\[
\text{PO}_4^{3-}\text{-P} = 100/31 = 3.2 \text{ meq/L}
\]
\[
\text{K cations} = 6.4 \text{ meq/L}
\]

We need to add buffer capacity:

Add 45 meq/L of NaHCO$_3$
Na cations = 45 meq/L
CO₂ = 45 meq/L
Total ‘Other’ Anions = 35.7 meq/L
Total ‘Other’ Cations = 6.4 + 45 = 51.4 meq/L

A rule of thumb for gas production is that approximately 0.35 m³ methane is produced per kg COD removed. In this example the gas production rate is 0.23 m³/hr (5.52 m³/d) at 56.02% methane = 3.09 m³/d methane. The ‘delta’ COD is 10.0 – 1.45 = 8.55 kgCOD/day. That corresponds to 0.36 m³ methane per kg COD removed.

**Digestion of Primary and Waste Sludge**

This example considers anaerobic digestion of combined primary and waste activated sludge from a BNR system with bioP removal.

Pertinent system characteristics are as follows:

- Constant influent flow of 10 ML/d [COD = 600 mg/L; TKN = 40 mgN/L; TP = 8 mgP/L].
- PST with 60% solids removal and underflow set at 1% of the influent flow = 100 m³/d.
- Three-stage Bardenpho process operated at an SRT of 10 days. Wastage from the RAS is directed to a gravity thickener; WAS flow = 150 m³/d.
- Gravity thickener underflow (45 m³/d) is combined with primary sludge, as input to the anaerobic digester.
- Anaerobic digester operated at 36°C and an HRT of 20 days.

![Figure 9.2. Anaerobic Digestion of Primary and Waste Activated Sludge](image)

Go through the following sequence of steps:
1. Open the file **WAS and Primary Digestion.bwc**.

2. Review the operating conditions for the activated sludge system and the anaerobic digester.

3. Run the steady state. Review the performance. Open the **Album** to review specific details for the anaerobic digester.

4. Use the **Explorer** to evaluate concentrations of state variables in the digester. In particular, consider the Mg, ammonia and phosphate concentrations. What might happen?

5. In calibrating anaerobic digester performance to observed plant data it is likely that we may wish to adjust the volatile solids destruction. This is largely controlled by the rate of hydrolysis of biodegradable particulate COD. Use the **Explorer** to examine the concentration of slowly biodegradable particulate COD. Select the **Project/Parameters/Kinetic** menu option, and on the **OHO** tab, reduce the **Anaerobic Hydrolysis Factor (AD)**. Note the impact on the particulate SBCOD concentration and the VSS destruction.

**Primary Sludge Fermentation**

This example system demonstrates primary sludge fermentation.

Primary sludge is directed to a fermenter/clarifier system, with waste excess primary sludge withdrawn from the clarifier underflow to maintain an SRT of approximately 6.4 days in the fermenter.

A splitter is included in the configuration to allow fermentate to be directed to the activated sludge system, or to be discarded.

**FIGURE 9.3. PRIMARY SLUDGE FERMENTATION TO IMPROVE BIOPERFORMANCE.**
Go through the following sequence of steps:

1. Open the file **Primary fermentation for bioP.bwc**.
2. Review the operating conditions for the activated sludge system and the fermenter.
3. Note the two SRT calculations on the **Calculators** tab; one for the activated sludge system, and one for the fermenter system.
4. For the base case, discard all the fermentate, and run the steady state. Review the performance in terms of VFA generation, fermenter pH, P and N removal. Enter the results in **Table 9.1**. [See Album for details].
5. Run three steady state cases, adding one-third, two-thirds, and all the fermentate to the activated sludge system. Enter the results in **Table 9.1**.

**Table 9.1. PRIMARY SLUDGE FERMENTATION TO IMPROVE BIOP PERFORMANCE**

<table>
<thead>
<tr>
<th>Fermentate Flow to AS (L/d)</th>
<th>Fermentate VFA (mgCOD/L)</th>
<th>BNR in VFA (mgCOD/L)</th>
<th>BNR input TKN (mgN/L)</th>
<th>BNR input TP (mgP/L)</th>
<th>Effluent NO$_3$-N (mgN/L)</th>
<th>Effluent PO$_4$-P (mgP/L)</th>
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<tbody>
<tr>
<td>0</td>
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</tbody>
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- Table 9.1.