Comparison of performance in an anaerobic digestion process: Sequential vs Non Sequential Models

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CONTENIDO

1. Anaerobic Digestion

2. Simple Model
   - Scenarios

3. Sequential Model
   - Scenarios

4. Comparisons

5. References
Anaerobic Digestion

- Anaerobic digestion has become a widely used model in development of water treatment plants, because it’s possible to obtain energy in the process by biogas production.
- Following the model presented in (Bernard O., Hadj-Zadok Z., Dochain D. 2001)[2], the phases of acidogenesis and methanogenesis are considered the key steps in the process.
- In simplified form, the model has the following structure

\[ S_A \rightarrow X_A + S_M \]
\[ S_M \rightarrow X_M + k_4 CH_4 \]

- This is, the input acidogenic sustrate \( S_A \) is consumed by the corresponding microorganism \( X_A \), which produces methanogenic sustrate \( S_M \), in the second phase, which is consumed by the methanogenic microorganism \( X_M \), producing methane.
The objective of this work is to analyze two different configuration for the bioreactors, and to compare their performances in steady state, in terms of:

- Conditions of Coexistence and Stability.
- Decontamination performance.
- Methane production.

The configurations considered are:

1. Acidogenesis and Methanogenesis in a single reactor. (Simple Model)
2. Separation of the processes of Acidogenesis and Methanogenesis in two reactors connected sequentially. (Sequential Model)
Figura: Operation Scheme for the Simple Model
### Simple Model

\[ \dot{X}_A = \mu_A(S_A)X_A - DX_A \]
\[ \dot{S}_A = -k_1\mu_A(S_A)X_A + D(S_{AIn} - S_A) \]
\[ \dot{X}_M = \mu_M(S_M)X_M - DX_M \]
\[ \dot{S}_M = k_2\mu_A(S_A)X_A - k_3\mu_M(S_M)X_M - DS_M \]
The growth function $\mu_A(\cdot)$ is Monod, and the growth function $\mu_M(\cdot)$ is Haldane.

This imply there’ll exist four possible steady states:

- Global Washout.
- Methanogenic Microorganism Washout.
- Coexistence steady state locally stable.
- Coexistence steady state saddle point.
Following the results presented in (Sbarciog, M., Loccufer, M., Noldus, E. 2010)[4], the following scenarios are identified in the model:

**Scenario I:** Only the washout steady state is feasible, and also is globally asymptotically stable from non negative initial conditions.

**Scenario II:** The steady states of global washout and methanogenic microorganism washout are feasible. The methanogenic microorganism washout is globally asymptotically stable from initial conditions greater than zero for microorganism populations.
Coexistence Scenarios

- **Scenario III**: Both steady states mentioned before are feasible, and also an additional steady state of coexistence is feasible. This last steady state is globally asymptotically stable from initial conditions greater than zero for microorganism populations.

- **Escenario IV**: All steady states mentioned before are feasible, and an additional steady state of coexistence is feasible, and it’s a saddle point. The methanogenic washout steady state and the locally stable coexistence steady state are reachable from initial conditions greater than zero for microorganism populations.
**Figura**: Example of the difference between scenarios III and IV.
**Figura:** Summary with all the scenarios. The white area is Scenario I. The grey area is Scenario II. The Yellow area is Scenario III, the green area is Scenario IV.
The alternative configuration considered is the separation of the treatments of acidogenesis and methanogenesis in two bioreactors connected sequentially, in which both microorganisms are in different reactors, isolated one from the other.
Sequential Model

**Figura**: Operation Scheme for the Sequential Model
Sequential Model

\[
\dot{X}_{A1} = \mu_A(S_{A1})X_{A1} - \frac{D}{r}X_{A1}
\]
\[
\dot{S}_{A1} = -k_1\mu_A(S_{A1})X_{A1} + \frac{D}{r}(S_{A1n} - S_{A1})
\]
\[
\dot{S}_{A2} = \frac{D}{1-r}(S_{A1} - S_{A2})
\]
\[
\dot{X}_{M2} = \mu_M(S_{M})X_{M} - \frac{D}{1-r}X_{M}
\]
\[
\dot{S}_{M1} = k_2\mu_A(S_{A1})X_{A1} - \frac{D}{r}S_{M1}
\]
\[
\dot{S}_{M2} = -k_3\mu_M(S_{M2})X_{M2} + \frac{D}{1-r}(S_{M1} - S_{M2})
\]
Sequential Model

It should be noted that for the dilution rates in the reactors, two variables are used. The variable $D$ is the quotient between the water flow and the liquid volume in both reactors, and the variable $r \in [0, 1]$ represents the fraction of liquid volume in each reactor, $r$ for the first reactor, $(1 - r)$ for the second reactor.
The Sequential Model has the same scenarios as the Simple Model, this is, it has two scenarios of washout of some microorganisms (scenarios I and II), and two coexistence scenarios with different conditions of stability (III and IV).

Also, the conditions of global stability are the same as in the Simple Model.
**Figura** : Example of diagrams of scenarios for $S_{AIn} = 5(g/l)$ and $S_{AIn} = 10(g/l)$
Results

1. The Simple Model is capable of a larger range of dilution rates for coexistence and global stability zones than the Sequential Model.

2. Given a fixed $D$ value for both models, the Simple Model always is better in decontamination.

3. The Sequential Model is capable of better methane production than the Simple Model.

4. If in both systems a strategy of maximal methane production is set, the Sequential Model is capable of obtaining better results of production than the Simple Model, and also is capable of improving some results in decontamination, by an strategy of selecting values of selecting the correct $(D, r)$ values for this effect.

5. If the methane production is restricted in zones of global stability, the pattern repeats at a lesser scale.
References


