CFD modelling of the mixing in an industrial anaerobic membrane bioreactor (AnMBR)

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**Introduction**

**General Concepts. AnMBR**

- Multistage process that combine the efficiency of a bioreactor and water treatment capability of the membrane. [2]
- Designed for the treatment of certain types of wastewater and is more efficient than traditional aerobic processes (Figure 1).

*Figure 1.* Comparison between MBR (a) and AnMBR (b) process. Taken from Pentair[1].
Introduction

General Process

• Industrial scale reactor.
  • 22 m of high x 22 m diameter.

• It features a mechanical stirrer of high energy consumption (11 kW).

Figure 2. Memthane® process, base of study. Taken and modified from Pentair[1].
Objectives

• General Objective
  • To perform a CFD analysis of the mixing of an AnMBR only through injection points.

• Specific Objectives
  • To simulate on CFD the bioreactor under standard operating conditions.
  • To do a conceptual analysis and design of different injection points using CFD.
  • To determine the best configuration (points of injection and tank modification with baffles) to improve mixing.
Methodology

Discretization of the geometry:

• Pre Volumetric mesh.
• Polyhedral mesh.
• Prism layer mesh (boundary layer).

Figure 3. Combination of different mesh models, applied to a geometry section.
Results

Fluid Characterization

Correlations dependent on temperature for density, thermal conductivity and specific heat:

\[
\rho \left[ \frac{kg}{m^3} \right] = 776.17 + 180396 \, T - 0.0034589 \, T^2
\]

Viscosity function of the shear rate.

@20 gr/L

\[\eta = 0.2546 \gamma^{-0.724}\]

Figure 4. Viscosity results for the studied fluid
Results

Current Reactor

2 inlets, 2 outlets.

- Process input.
- Entrance of recycling used to heat the reactor.

Mechanical stirrer rotating at 200 RPM

Figure 5. Current reactor geometry
Results
Current Reactor (cont...)

Figure 6. Velocity profiles in the current reactor. (a) velocity contours and (b) Stream lines

Average Velocity: 38 m/s
Results

Reactor without Impeller

Figure 7. Velocity profiles in the reactor without impeller. (a) velocity contours and (b) Stream lines

Average Velocity: $5.33 \times 10^{-2} \text{ m/s}$
Results
Modification 1

• Inlet pipe inclined to 45° and the direction was changed from perpendicular to tangential.

Figure 8. Graphic description of the inlet modification.
Results
Modification 1 (cont...)

Average Velocity: $1.29 \times 10^{-1} \text{ m/s}$

Figure 9. Velocity profiles in the reactor with the inlet modification. (a) velocity contours and (b) Stream lines
Results
Modification 2

- Baffles were implemented in the tank. Idea obtained from ABB [5].

Figure 10. Graphic description of baffles.
Results
Modification 2 (cont...)

Figura 11. Velocity profile in the reactor with baffles. (a) velocity contours and (b) Stream lines

Average velocity: $1.41 \times 10^{-1} \text{ m/s}$
Results
Modification 3

The baffles support (axis) will be used as a recirculation inlet pipe (interior recycling). The size of baffles and shape must be adjusted to maintain a constant pipe size.

Figure 12. Velocity profile in the reactor with the interior recycling. (a) velocity contours and (b) Stream lines

Average velocity: $1.11 \times 10^{-1} \text{ m/s}$
Results
Modification 4

• A second set of baffles was added and the inlet recirculation was maintained.

Figure 13. Graphic description of implemented baffles.
Results
Modification 4 (cont...)

Figura 14. Results of speed in the reactor with two sets of baffles and the interior recycling. (a) magnitude and distribution. (b) Stream lines

Average velocity: $0.85 \times 10^{-1} \, m/s$
Results

Grid Independency test

<table>
<thead>
<tr>
<th>Cell Number [Thousands]</th>
<th>Simulation Time [hr]</th>
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<tbody>
<tr>
<td>59</td>
<td>9.25</td>
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<tr>
<td>71</td>
<td>9.5</td>
</tr>
<tr>
<td>136</td>
<td>10.75</td>
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<tr>
<td>642</td>
<td>27</td>
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<tr>
<td>1083</td>
<td>42</td>
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</tbody>
</table>

*Figure 15. Mesh analysis results*
## Results Summary

<table>
<thead>
<tr>
<th>Modification</th>
<th>Average Velocity $[\cdot 10^{-1} \text{ m/s}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor without impeller</td>
<td>0.53</td>
</tr>
<tr>
<td>Inlet modifications (Mod 1)</td>
<td>1.29</td>
</tr>
<tr>
<td>Inclusion of baffles (Mod 2)</td>
<td>1.41</td>
</tr>
<tr>
<td>Inlet in the interior (Mod 3)</td>
<td>1.11</td>
</tr>
<tr>
<td>Inlet in the interior and two baffles (Mod 4)</td>
<td>0.85</td>
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</tbody>
</table>
## Results

### Velocity Comparison

<table>
<thead>
<tr>
<th>Reactor Type</th>
<th>Average Velocity [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current AnMBR</td>
<td>35</td>
</tr>
<tr>
<td>Modified AnMBR</td>
<td>0.85 \cdot 10^{-1}</td>
</tr>
<tr>
<td>Expanded Granular Sludged Bed (EGSB)</td>
<td>0.1 – 0.5 \cdot 10^{-1}</td>
</tr>
<tr>
<td>Inlet Recirculated Reactor</td>
<td>0.7 – 1.5 \cdot 10^{-1}</td>
</tr>
</tbody>
</table>

- Similar order of magnitude with comparable anaerobic reactors.
- Evidence of unnecessary energy consumption in current reactor.
## Results

### Operating Cost analysis

- Energy saving up to 50%.
- The costs associated with the implementation of the modifications or the maintenance of these were not taken into account in this analysis.

<table>
<thead>
<tr>
<th></th>
<th>Current Reactor [€/month]</th>
<th>Modified Reactor [€/month]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process inlet pumping cost</td>
<td>1.565</td>
<td>1.948</td>
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<tr>
<td>Recycle inlet pumping cost</td>
<td>2.818</td>
<td>5.120</td>
</tr>
<tr>
<td>Mechanical stirrer</td>
<td>10.047</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>14.430</td>
<td>7.068</td>
</tr>
</tbody>
</table>
Conclusions & Future Work

• It is possible to obtain a homogeneous mixing in an AnMBR system without the need to include a mechanical stirrer.

• Modifications to the system are suggested.
  • These are simple to build/manufacture and to include in the current system.

• For a better understanding of the system behavior it is necessary to take into account phenomena such as the (bio)reactions carried out inside the reactor and the presence of a third phase (produced gas methane) that will add more mixing.


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