Efficient organic carbon utilization for combined nutrient removal and biogas production in hybrid biofilm activated sludge process


23-26 June 2021

8TH INTERNATIONAL CONFERENCE ON SUSTAINABLE SOLID WASTE MANAGEMENT
THESSALONIKI 2021
• Biological wastewater treatment processes developing technologies

• Organic carbon redirection for biogas production
  • energy recovery from waste ultimate goal for sustainable wastewater management

• Conventional single sludge activated sludge systems (CAS)
  - do not satisfy nutrient removal
  - no effective use of organic carbon
  - extremely energy demanding systems
  - large amount of waste: cost requirement for disposal
INTRODUCTION

- Hybrid systems integrated with biofilm processes
- Hybrid systems (i.e., moving bed bioreactor, MBBR, integrated fixed film activated sludge, IFAS)
  - alternative for cost-effective and reliable process upgrades
  - improved nutrient removal efficiency over conventional suspended activated sludge systems

- MBBR
  - successfully used to treat domestic and industrial wastewater with recalcitrant character
INTRODUCTION

- Hybrid systems are advantageous through entrapping and diverting organic matter before oxidizing it in subsequent aerobic phases.

- The process efficacy in the hybrid systems allow working at low sludge retention times holding the biomass on the carrier for longer times which could also let to efficient biogas recovery.

Conventional BNR

HAS-MBBR

ISTANBUL TECHNICAL UNIVERSITY
Pilot Studies

- Located at the headwork of a full-scale municipal wastewater treatment plant in Istanbul
- Inflow: 7 m³/day
- DO in MBBR 2-3 mg/L
- 2-Sludge System

hybrid biofilm pilot plant
Process Configurations and Simulation

SUMO® software influent flowrate of 100,000 m³/day (26.4 MGD)
MATERIAL & METHODS

Process Configurations and Simulation

SUMO® software influent flowrate of 100,000 m³/day (26.4 MGD)
## MATERIAL & METHODS

CODE fractions for referred municipal wastewater

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration, ( mg/L )</th>
<th>Fraction, % of ( C_T )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total COD, ( C_T )</td>
<td>610</td>
<td></td>
</tr>
<tr>
<td>Soluble COD, ( S_T )</td>
<td>180</td>
<td>30</td>
</tr>
<tr>
<td>Soluble inert COD, ( S_I )</td>
<td>35</td>
<td>5</td>
</tr>
<tr>
<td>Readily biodegradable COD*, ( S_B )</td>
<td>125</td>
<td>20</td>
</tr>
<tr>
<td>Slowly biodegradable COD, ( X_B )</td>
<td>370</td>
<td>60</td>
</tr>
<tr>
<td>Particulate inert COD, ( X_I )</td>
<td>60</td>
<td>15</td>
</tr>
</tbody>
</table>

Dimensions and required installations for treatment plant units (@15 °C)

<table>
<thead>
<tr>
<th>Process Unit</th>
<th>Unit</th>
<th>HAS-MBBR</th>
<th>CBNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-P volume</td>
<td>m3</td>
<td>7,000</td>
<td>7,000</td>
</tr>
<tr>
<td>Aerobic reactor volume</td>
<td>m3</td>
<td>11,000</td>
<td>70,000</td>
</tr>
<tr>
<td>Biofilm Reactor, MBBR</td>
<td>m3</td>
<td>30,000</td>
<td>-</td>
</tr>
<tr>
<td>Anoxic reactor volume</td>
<td>m3</td>
<td>14,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Total reactor volume</td>
<td>m3</td>
<td>62,000</td>
<td>102,000</td>
</tr>
<tr>
<td>Total biofilm area</td>
<td>m2</td>
<td>8,250,000</td>
<td>-</td>
</tr>
<tr>
<td>Internal Recirculation</td>
<td>m3/hour</td>
<td>-</td>
<td>12,500</td>
</tr>
<tr>
<td>Anaerobic Digester volume</td>
<td>m3</td>
<td>12,000</td>
<td>12,000</td>
</tr>
<tr>
<td>Total clarifier surface area</td>
<td>m2</td>
<td>20,000</td>
<td>17,000</td>
</tr>
</tbody>
</table>
MATERIAL & METHODS

Cost Analysis

• 15 years of operation covering a reasonable economical life of mechanical equipment

• Biogas from mesophilic anaerobic digestion (MAD) → a revenue

• Construction and installation unit prices
  Ministry of Environment and Urban Planning of Turkey
Pilot Plant Operation and Mass Balances

**Bio-P Tank**
- Influent WW
  - COD=534 mg/L
  - CODsol=226 mg/L
  - SS=342 mg/L
  - VSS=264 mg/L
  - TN=72 mg/L
  - NH₄-N=45 mg/L
  - TP=8.4 mg/L
  - PO₄-P=6.3 mg/L
- 3660 mgSS/L
- 2020 mgVSS/L

**Primary Clarifier**
- SS=7260 mg/L
- COD=71 mg/L
- CODsol=56 mg/L
- TN=25.8 mg/L
- NH₄-N=16 mg/L
- TP=10.4 mg/L
- pH=7.74

**Anoxic Tank**
- COD=37 mg/L
- SS=7520 mg/L
- VSS=3680 mg/L
- NO₃-N=3.4 mg/L

**Aeration Tank**
- NH₄-N=0.5 mg/L

**MBBR**
- SS=33 mg/L
- VSS=32 mg/L
- COD=71 mg/L
- CODsol=56 mg/L
- TN=25.8 mg/L
- NH₄-N=16 mg/L
- TP=10.4 mg/L
- pH=7.74

**Final Clarifier**
- NH₄-N=0.5 mg/L
- NO₃-N=5.5 mg/L
- NO₂-N=1.2 mg/L
- TP=0.9 mg/L
- PO₄-P=0.6 mg/L
- pH=7.72

**Influent WW**
- COD=534 mg/L
- CODsol=226 mg/L
- SS=342 mg/L
- VSS=264 mg/L
- TN=72 mg/L
- NH₄-N=45 mg/L
- TP=8.4 mg/L
- PO₄-P=6.3 mg/L

**Effluent WW**
- COD=28 mg/L
- SS=13 mg/L
- CODsol=226 mg/L
- VSS=12 mg/L
- TN=9.5 mg/L
- NH₄-N=1.3 mg/L
- NO₃-N=5.5 mg/L
- NO₂-N=1.2 mg/L
- TP=0.9 mg/L
- PO₄-P=0.6 mg/L
- pH=7.72

Pilot plant layout and the mass balance obtained in the HAS-MBBR configuration
## RESULTS

### Simulation Studies

Process comparison regarding steady state effluent quality

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Influent</th>
<th>HAS-MBBR</th>
<th>CBNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total COD</td>
<td>mgO$_2$/L</td>
<td>610</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>mgN/L</td>
<td>55</td>
<td>7.94</td>
<td>9.44</td>
</tr>
<tr>
<td>Total ammonia (NH$_4$)</td>
<td>mgN/L</td>
<td>41</td>
<td>5.64</td>
<td>1.84</td>
</tr>
<tr>
<td>Nitrate (NO$_3$)</td>
<td>mgN/L</td>
<td>-</td>
<td>1.08</td>
<td>6.44</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>mgP/L</td>
<td>8</td>
<td>0.72</td>
<td>0.58</td>
</tr>
<tr>
<td>Orthophosphate (PO$_4$)</td>
<td>mgP/L</td>
<td>5</td>
<td>0.52</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Targeted effluent quality

- TN 10 mgN/L
- TP 1 mgP/L
## RESULTS

### Simulation Studies

Operational Parameters for hybrid AS-MBBR and CBNR systems

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Configuration</th>
<th>HAS-MBBR</th>
<th>CBNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average air requirement, $Q_{Air}$</td>
<td>Nm$^3$/hour</td>
<td></td>
<td>33000</td>
<td>36000</td>
</tr>
<tr>
<td>Mixing energy requirement</td>
<td>kWh/day</td>
<td></td>
<td>2500</td>
<td>3850</td>
</tr>
<tr>
<td>Daily biogas production</td>
<td>m$^3$/day</td>
<td></td>
<td>8900</td>
<td>7000</td>
</tr>
<tr>
<td>Solids retention time</td>
<td>days</td>
<td></td>
<td>3.5</td>
<td>18</td>
</tr>
</tbody>
</table>

Volume requirement of anoxic reactor in HAS-MBBR $\sim$ 44% smaller than CBNR

$\sim$ 40% reduction in the Total Volume
RESULTS

Cost Analysis for System Configurations

CAPEX advantage of HAS-MBBR over CBNR ($2.1M) can be significant for the developing countries

CAPEX advantage of about 7%.
Cost Analysis for System Configurations

Energy consumption due to aeration, mixing, internal recirculation and other processing units

Energy production from biogas
- Nitrification process will not be the decisive factor for sizing the bioreactor compared to conventional BNR system.

- The adsorption capability of return activated sludge provides ultimate organic carbon capture without loosing carbon aerobically.

- The diversion at the head of the HAS-MBBR configuration allows management of organic carbon (i.e., using in denitrification or/and anaerobic digestion) during real time operation.

- Model simulations and techno-economic analysis proved that the proposed HAS-MBBR has great advantages over CBNR systems.
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References


References


Thank you for your attention