Use of AI for online control of nitrous oxide production in water resource recovery facilities

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Nitrous oxide ($\text{N}_2\text{O}$)

- 298 $\text{CO}_2$-equivalents (IPCC, 2013)

- Strong Ozone depleter (Ravishankara et al., 2009)

- Can make up 78% of WWTP carbon footprint (Daelman et al., 2013)

- WWTP operators / utilities need to perform environmentally responsibly and minimize all N emissions, including $\text{N}_2\text{O}$
  - It’s time we finally do something about it
The WRRF of 2015

Keywords: Efficiency, Operating, Water Quality, Control, Process, Phosphorus, N2O, Nitrogen, Costs, Resource Recovery, Energy, GHG, CH4
Total Nutrient DSS
for Online WWTP Supervision and Control

Risk Assessment Modelling for Diagnosing Process Risks (RR, N₂O, Bulking)

Knowledge base (KB) formulation and risk classification from literature and experience

Codification of KB in fuzzy logic, IF/THEN rule-based system (Matlab or Excel)

Defuzzification for assigning numerical risk value between 0 and 1 to qualitative result

Mathematical Modelling and Simulation Output

Total Nutrient Decision Support
- WQ / compliance
- Costs
- Energy efficiency
- GHG reporting
- Resource Recovery

Web-based reports / monitoring

Online Process Risk
Mimic human perception, learning and reasoning to solve complex problems (Chen et al., 2008)
Fuzzy Logic 101

Artificial Intelligence (AI) Techniques for DSS Implementation

Boolean Logic

Fuzzy Logic

Added DECISION SUPPORT
Risk Assessment Model for Assessing Risk of WWTP N₂O Production

- Complex microbial phenomena
- No widely validated and accepted mathematical models
- Significant amount of knowledge from literature
- Clear operational parameters already associated with "risk" (Kampschruer et al., 2009; Foley et al., 2010; Ahn et al., 2010; Chandran et al.; GWRC, 2011)
- Therefore, a qualitative N₂O production risk assessment modelling approach has been proposed (Porro et al., 2014).
N$_2$O Production Pathways from engineered BNR systems

**Nitrification**

- NH$_3$ $\rightarrow$ NH$_2$OH $\rightarrow$ NO$_2^-$ $\rightarrow$ NO$_3^-$
  - HAO

- NO $\rightarrow$ NOH
  - HAO

- N$_2$O (1, High DO)
- N$_2$O (2, High DO)
- N$_2$O (3, Low DO, High NO$_2$)

**Denitrification**

- NO$_3^-$ $\rightarrow$ NO$_2^-$ $\rightarrow$ NO
  - Nar

- NO $\rightarrow$ N$_2$O
  - Low COD, High NO$_2$

- N$_2$O (6, Low COD, High DO, High NO$_2$)

- N$_2$O (4, Low COD, High DO, High NO$_2$)

- N$_2$O (5, Low COD, High DO, High NO$_2$)

- N$_2$ (6, Low COD, High DO, High NO$_2$)
N₂O Risk Assessment Modelling Framework

Knowledge base (KB) formulation and risk classification from literature and experience

Codification of KB in fuzzy logic, IF/THEN rule-based system (Matlab or Excel)

- Effluent Quality Index (EQI)
- Operational Cost Index (OCI)
- Risk due NO₂
- Risk due to low DO
- Risk due to AOR
- Risk due to others
- Overall N₂O Risk

Influent Data  Mechanistic AS Model  Simulation Output

Online/SCADA Data -OR- Mathematical Modelling
Case Study: Eindhoven WWTP (Eindhoven, The Netherlands)
Eindhoven WWTP Aeration Tank No. 1

Nitrification

Denitrification

Location sensor:
- Dry sloids
- Ammonium
- Phosphate
- Oxygen (summer)

Location sensor:
- Nitrate (nitrification)
- Nitrate (denitrification)

Location sensor:
- Oxygen (winter)

Air compressor

influent
denitrification
Summer compartment
Winter compartment

O2
NH4
O2
Virtual $\text{N}_2\text{O}$ Risk Dashboard (EIN)

Aeration Tank 1 nitrification zone
Virtual N$_2$O Risk Dashboard (EIN)

Aeration Tank 1 nitrification zone
Virtual N\textsubscript{2}O Risk Dashboard (EIN)
Virtual $\text{N}_2\text{O}$ Risk Dashboard (EIN)

Aeration Tank 1 denitrification zone
Virtual N$_2$O Risk Dashboard (EIN)

**Nitrification**

**Denitrification**

**Overall Risk**
Online N\textsubscript{2}O Risk Ctrl Testing versus measured N\textsubscript{2}O

Eindhoven WWTP individual N\textsubscript{2}O risk (A), and overall N2O risk (B) with measured N\textsubscript{2}O in nitrification zone
Online $N_2O$ Risk Ctrl Testing via Simulation

DO-base case

DO-1.6 mg/L Based on Risk KB
Other Applications

- Assessing baseline process efficiency versus N₂O risk
- Sustainable benchmarking of UWS control strategies
  - Water Quality
  - Cost
  - Energy
  - GHG
  - Resource recovery
- Gaining mechanistic insight on all relevant N₂O production pathways
- Estimating N₂O emissions and monitoring total GHG reductions?
- N₂O Ctrl in *Total Nutrient DSS*
Total Nutrient DSS

Effluent Quality  Process  Bulking  Energy/€
Res. Recovery  GHG

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