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Abstract. Anaerobic ammonium oxidation (Anammox) is a process of the nitrogen cycle that convert ammonium at the expense of nitrate (NO_3^-) to nitrogen involving bacteria. In recent decades, Anammox is utilized to process ammonium in wastewater plant. But, it has several weaknesses which long processing time and high sensitivity to disturbances are. In this study, control factor and operation technology are studied to overcome the aforementioned challenges. A sequencing batch reactor (SBR) is modeled using the activated sludge model (ASM). The general form of ASM is developed by International Water Association (IWA) and mainly use to study biological processes in hypothetical systems. In real operation, the concentration of NO_3^-, which is crucial to control, is hard to measure. Therefore, a soft-sensor is used such as conductivity and pH must be incorporated in the developmental model to reconstruct such a relationship and thus also to estimate the NO_3^-. Because ASM can be applied for optimization when carefully calibrated with reference data for sludge production and nutrients in the effluent, a lab-scale plant is used to verify and validate the developed model parameter. Besides, the lab-scale plant is used to test the developed control structure.

Keywords: ASM, ammonium concentration, nitrate, nitrite, wastewater treatment.

1. Introduction

In 1995, a biological process named 'Anammox' (anaerobic ammonium oxidation) in which ammonium is oxidized producing dinitrogen gas was found by researchers in Delft, the Netherlands. They discovered the process in a denitrifying fluidized bed reactor while observing ammonium disappearance [1]. In these days, the use of the Anammox process is extended to treat nitrogen-rich wastewater. It is considered by many as a promising process for nitrogen removal in wastewater [2]. Anammox has been applied at different scales from laboratory scale to full scale to treat ammonium-rich wastewater, such as sludge-digestion liquid [3-5], landfill leachate [6,7], coke-oven wastewater [8], monosodium glutamate wastewater [9], swine wastewater [10], pharmaceutical wastewater [11] and other kinds of wastewater [12-14].

The stoichiometric equation of the Anammox process is described in Eq. 1 [15]. From Eq. 1, it can be inferred that the Anammox process requires nearly equimolar concentrations of nitrite and ammonium. Furthermore, nitrate will be formed at a stoichiometric ratio of 0.2-0.3 mg NO_3^--N per mg NH_4^+-N removed [16].

$$NH_4^+ + 1.32\,NO_2^- + 0.066\,HCO_3^- + 0.13\,H^+ \rightarrow 1.02\,N_2 + 0.26\,NO_3^- + 0.066\,CH_2O_{0.15}N_{0.15} + 2.03\,H_2O \qquad (1)$$

In current operational experience, Anammox process has high sensitivity to disturbances. Therefore, it is vital to develop control systems able to keep the desirable operation. In this typical wastewater treatment process, activated sludge model (ASM) can be used to model Anammox process. ASM is widely used for process design and control in wastewater treatment process and highly dependent on parameter calibration to have a robust and reliable model. As for control, ion or chemicals content in wastewater are hard and take a long time to measure. Thus, the model should incorporate soft sensor for practical deployment in wastewater treatment plant.

Table 1. Research regarding soft sensor application for nitrogen removal and wastewater

Method(s)	Application	Predicted variable(s)	Reference
PCR, PLS, MPLS, FFNN	pilot-scale	PO_4-P	[17]
FFNN	laboratory-scale	PO_4-P	[18]
Elman NN	laboratory-scale	NH_4-N, NO_3-N, PO_4-P	[19]
MPCA, FFNN, ANFIS	laboratory-scale	NH_4-N, NO_3-N, PO_4-P	[20]
FFNN + fuzzy logic	municipal, industrial	COD, TN	[21]
MPCA + FFNN	laboratory-scale	NH_4-N, NO_3-N, PO_4-P	[22]

ANFIS : Adaptive Network-based Fuzzy Inference System
FFNN : Feedforward Neural Network
MPCA : Multiway Principal Component Analysis
MPLS : Multiway Partial Least Squares
PCR : Principal Component Regression
PLS : Partial Least Squares

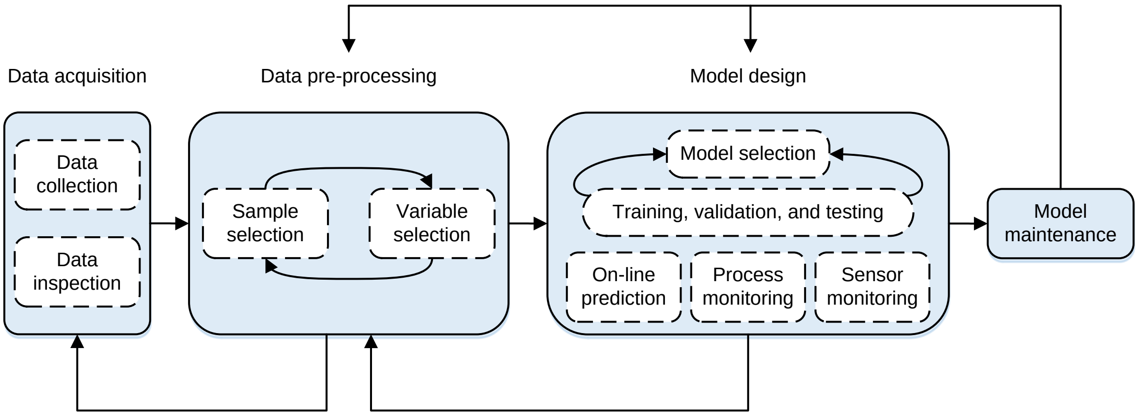


Fig. 1 Overview of the design steps for data-derived soft-sensors (redrawn from [23,24]).

Research regarding soft sensor implementation in wastewater treatment has been done for many years as shown in Table 1. Almost all predicted variables are in ion form. The steps in Fig. 1 are required to design data-driven soft sensor.

2. Control Development

Most of existing water treatment processes have been controlled by online sensor-based feedback control. However, the sensor has many problems. In addition to the sensors, we have listed several problems with existing technologies. (1) It has a risk of the online sensor fault and error. (2) The online monitoring value under the sequencing batch reactor (SBR) operating condition is unreliable as the measured value under various changing conditions. (3) Optimum operation and cost saving effect is insignificant due to the control of the predetermined cycle. (4) Sensor investment cost and operation and maintenance (O & M) cost increase for stable operation. (5) There is a lack of response to uncertain raw water and environmental conditions. (6) O & M optimization is not considered as an important direction for satisfaction of effluent condition. In order to overcome these technical problems, we have devised a novel control strategy.

2.1. Feed Condition

Feed condition check is a method that was used previously. A slightly different method is proposed while measuring influent condition in equilibrium (EQ) tank instead of SBR. Since the tanks measuring influent condition differ, but all conditions except temperature are identical, influent condition is measured in the EQ tank. Despite the same characteristics of the two tanks, the reason for getting data from the EQ tank is that EQ tank condition is relatively stable compared to the SBR because the EQ tank doesn't have mixing and aeration occur.

2.2. Generating Candidate Sequencing Set

In order to exclude unnecessary sequencing sets, process constraints are sets based on information obtained from the operator's experience or reference and literature surveys. This sequence constraint condition will be added continuously through experiments. In this case, the restriction condition is for example, a condition such that the mixing process must be performed after the filling process. By entering these conditions, some of the sequence count sets can be excluded. These conditions can be narrowed down further by checking, such as the literature survey and experimentation, as mentioned above.

2.3. Knowledge Base Boundary Condition

Based on the control strategy of the commercial process, the following knowledge-based boundary conditions are collected and can be continuously added using the intuition or experiment data through the experiment.

(1) Filling / Mixing / Aeration / None
(2) (2) 6-8 hours/cycle, 10-30 min/Sub-cycle (HRSD)
(3) Integer expressed in minutes vector (max. 480)
(4) 40% <Filling cycle volume size <100%, min. 10% or more Filling
(5) Filling must be unconditional at first and cannot come last
(6) Always Aeration after Filling

2.4. Objective: Minimum Cost (Minimum Aeration Time)

The sequence set that can be generated according to the above sequence constraint is prioritized based on the condition that the operation time becomes the minimum, and then aeration time having minimum value (it is advantageous that the energy cost can be reduced as the aeration time is shortened). Select the most optimal sequence set. Simulation is performed to determine if the selected set is valid for the process. Determine whether the sequence set that performed the simulation satisfies the operation / target constraint condition. In this case, the operation / target restriction condition means, for example, whether or not the nitrogen content in the effluent after the SBR reaction satisfies 20 ppm or less. If the constraint is not satisfied, go back to the previous step of selecting the sequence set and select the next sequence set and repeat the simulation. If satisfied, apply the selected sequence set to the actual process.

2.5. Sub-optimal for $|A_t - T_t| > \varepsilon$

If the error between the profile value created by the simulator and the actual operation data value deviates from the specified error range (|At-Tt|), return to the previous step of selecting a sequence set and repeat the process of selecting a different sequence set. At this time, even if the driving progresses to the subordinate level, there is a slight difference in aeration time, and the risk is very low. When the profile value of the simulator and the actual operation data value satisfy the specified error range value, effluent discharge occurs. In the process, the error correction value is compared with the actual value of the pH sensor, which is already known to be robust, and the value of the profile is corrected.

2.6. Model Update

In the SBR reactor, the process is completed if the process has been running at one time by the sequence set with the highest optimization. However, if the process driven by a sequence set that is not the most optimal sequence set, updating the used simulation model is required.
The updated model will be applied and operated when the next batch is started.

2.7. Expected Effects

(1) It is possible to minimize the risk of sensor fault and error by using EQ tank concentration data with lower variability than SBR.
(2) Optimal operation and cost saving according to raw water condition by control of variableness cycle
(3) Reduce sensor investment cost and O & M cost for stable operation
(4) The possibility to respond to uncertain raw water and environmental conditions
(5) O & M optimization scheduling for effluent condition
(6) The same effect can be applied to mainstream in the future
(7) Alternatives to uncertainty can be presented

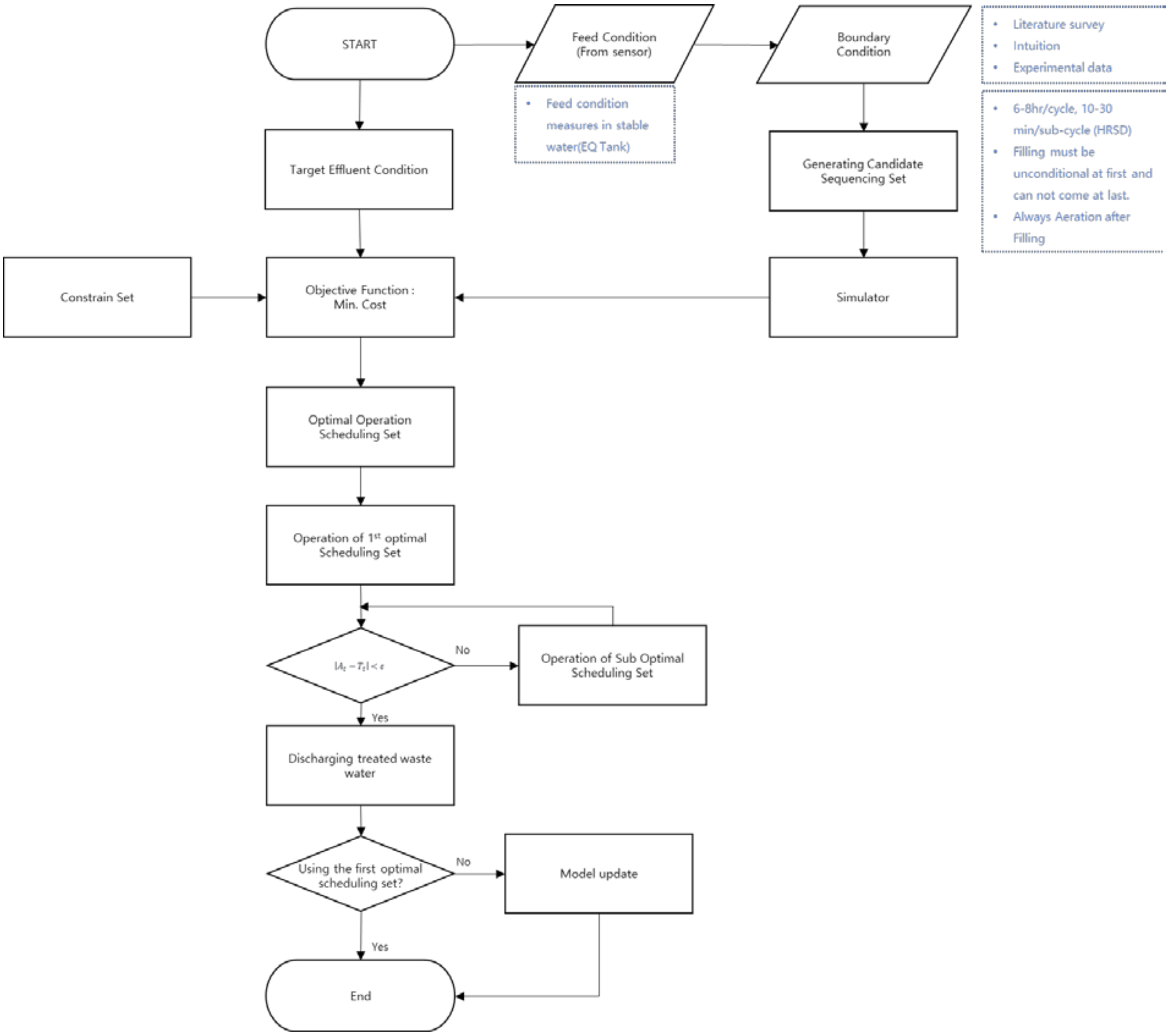
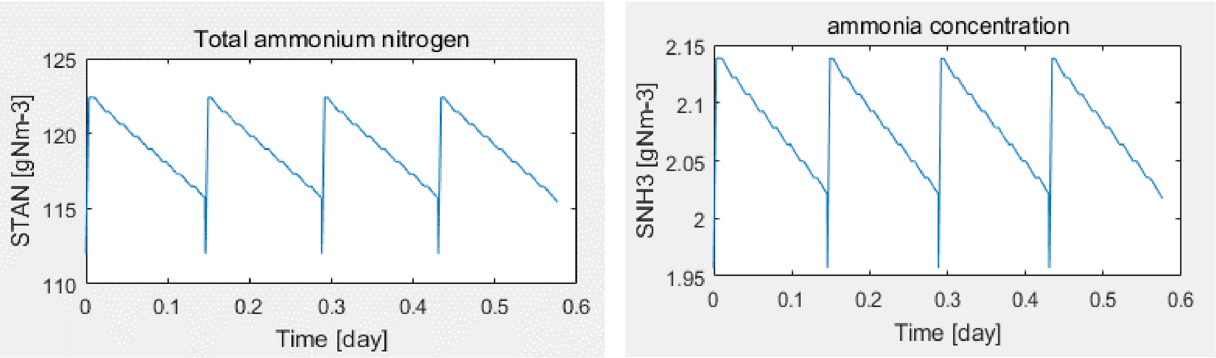


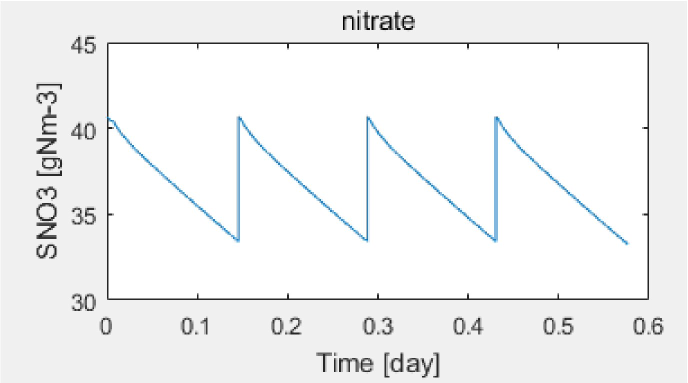
Fig. 2 Flowchart of proposed control.

3. Results

The result obtained by applying the method mentioned in the flowchart in Fig. 2 by simulating the data from the actual pilot plant. This experiment used one batch and consisted of a total of four sub-cycles in one cycle. It can be seen that the concentration increases as the raw water flows in each sub-cycle. Increased concentrations are reduced by batch reactions over time. It can be seen that all of the sub-cycles exhibit similar behaviors, indicating that the process is stable.



(a) total ammonium nitrogen (b) ammonia



(c) nitrate

Fig. 3 Results of the simulation.

Referring to Fig. 3, it can be seen that the values decrease with time. From this simulation results, it can be inferred that the theory is applicable to the actual process.

4. Conclusions

The authors proposed a new control system for Anammox process called "proactive scheduling". The method is to measure the concentration of the influent water and to study how the operation (Filling, Aeration, Mixing, etc.) should operate to satisfy the effluent concentration condition. We use a scheduling method to generate a sequence that satisfies the effluent condition. The generated sequence has several candidate groups. When the simulation is run using the first priority sequence, if the runoff condition is not satisfied, the simulation using the second priority sequence proceeds. If the simulation result is satisfactory, the sequence is applied to the actual process to perform the wastewater treatment process. To verify this, a model was made, and the simulation was run through the created model. After running the simulation using the actual pilot plant data, we confirmed the validity of the process. With the new control method, it is expected that Anammox process will use less energy and cost compared to the existing wastewater treatment plants.

Acknowledgements

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