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Development of a WWTP influent characterization method for an activated sludge model using an optimization algorithm

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Abstract. Process modeling with activated sludge models (ASMs) is useful for the design and operational improvement of biological nutrient removal (BNR) processes. Effective utilization of ASMs requires the influent fraction analysis (IFA) of the wastewater treatment plant (WWTP). However, this is difficult due to the time and cost involved in the design and operation steps, thereby declining the simulation reliability. Harmony Search (HS) algorithm was utilized herein to determine the relationships between composite variables and state variables of the model IWA ASM1. Influent fraction analysis was used in estimating fractions of the state variables of the WWTP influent and its application to 9 wastewater treatment processes in South Korea. The results of influent S_s and $Xs+X_{BH}$, which are the most sensitive variables for design of activated sludge process, are estimated within the error ranges of 8.9-14.2% and 3.8-6.4%, respectively. Utilizing the chemical oxygen demand (COD) fraction analysis for influent wastewater, it was possible to predict the concentrations of treated organic matter and nitrogen in 9 full scale BNR processes with high accuracy. In addition, the results of daily influent fraction analysis (D-IFA) method were superior to those of the constant influent fraction analysis (C-IFA) method.

Keywords: ASMs; COD; influent fraction analyzer (IFA); Harmony Search (HS); optimization algorithm; WWTPs

1. Introduction

By the end of 2014, the coverage of wastewater treatment plants (WWTPs) in Korea was at 92.5%. The number of WWTPs in Korea is 597 (treating > 500 cubic meter per day (CMD)) and 3160 (treating < 500 CMD). As the coverage of WWTPs in Korea has nearly reached its limit, the efficient operation and improvement of the existing facilities are becoming important issues.

Since 2012, the water quality criteria for WWTP effluent have been strengthened thereby resulting in more sophisticated operations being required (Pak *et al*. 2012).

IWA Activated sludge models (ASMs) are used, not only for the design of main treatment processes of a plant but also for the improvement of its operational efficiency. Since 1983, activated sludge modeling (ASM), a mathematical modeling for activated sludge process developed by a task group within the International Water Association (IWA) has become widely used for wastewater treatment design and process optimization (Rieger *et al.* 2013, Henze *et al*. 2000, Henze *et al*. 1987).

An ASM is a mathematical model of the microbiological reactions that occur during wastewater treatment. It is capable of obtaining the reaction results of various conditions based on the theoretical kinetic expression. It is also capable of simulating various operational conditions that occur in WWTPs (Flores-Alsina *et al.* 2012, Petersen 2001, Hulsbeek *et al*. 2002, Shuai *et al*. 2015).

The state variables, which are model components of the ASM, are expressed as fractions of chemical oxygen demand (COD), which are composite variables and are the basic and most important data for the application of an ASM (Sin 2004, Kaelin *et al.* 2009, Mannina *et al.* 2011, Marsili-Libelli *et al*. 2001, Henze *et al*. 1999).

To perform a successful simulation, the composite variables must be converted into state variables via the characteristics analysis of a WWTP influent such as systematic calibration protocols (Sin *et al.* 2005). However, due to the tremendous cost and time required for analysis of respiration rate for influent characteristics analysis, most engineers are unable to conduct the COD fraction analysis in the design and operation steps (Fangyue *et al.* 2009). For this reason, it reduces the reliability of the simulation results derived from the ASM.

Therefore, the main objectives of this study are: (1) to reduce the time and cost consumed for the analysis of the COD fraction in the ASM1 model by using an optimization algorithm; and (2) to develop a method and evaluate its applicability in estimating the state variables from the composite variables.

2. Materials and method

2.1 COD composition of IWA ASM1

The COD of domestic wastewater influent in ASM1 is categorized as: (1) biodegradable COD, (2) non-

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biodegradable COD and (3) active biomass. Soluble COD is denoted as S while Particulate COD is denoted as X.

Biodegradable COD consists of soluble, readily biodegradable substrate (S_S) and particulate biodegradable substrate (X_S). The concentration of S_S can be a key factor in the design of a biological nutrient removal (BNR) process. On the other hand, X_S is usually made up of colloidal and suspended COD fractions.

Non-biodegradable COD consists of soluble (S_I) and particulate (X_I) COD. S_I is unaffected by the biological reaction and unsettled in the activated sludge. On the other hand, X_I is also unaffected by the biological reaction but can be settled and removed in the clarifier.

Active biomass is divided into heterotrophic biomass (X_{BH}) and autotrophic biomass (X_{BA}). The concentration of X_{BH} and X_{BA} in raw domestic wastewater influent is considered zero for activated sludge simulation. Finally, a variable X_P refers to inert particulate products that can be generated from biomass decay. Generally, the concentration of X_P in influent wastewater is assumed to be zero (Jeppsson 1996).

The reported range of readily biodegradable substrate (S_S) worldwide is from 3% to 35% (with an average of 17.5%) in raw wastewater and 14% to 57% (with an average of 28.9%) in settled wastewater. These values indicate great deviations in the S_S fraction (Pasztor *et al.* 2009). The following Table 1 refers to the result of influent COD fractions from three WWTPs in the city of S of South Korea. The COD components of table 1 is the result of analyzing of the primary settling tank effluent. (measured in September 2008).

In Japan, where the socioeconomic characteristics are similar to Korea, the S_S fraction was approximately 26.7% (Pasztor *et al.* 2009), which is close to 25.6% - the average S_S fraction of the three selected facilities in the city of S in Korea, as investigated in this study.

By contrast, in France and the Netherlands, the numbers ranged from 32% to 57% - about twice as high as those in Korea and Japan (Satoh *et al.* 2000).

The S_S such as volatile fatty acids fraction of the three facilities in the city of S (Korea), as surveyed in this study, ranged from 23% to 27.7% with a relatively low deviation. This is because all WWTPs are being operated within the same city.

Because X_S, in terms of design, consumes the largest amount of oxygen, it is the most influential factor in determining the air flow requirement of the aeration tank (Marquot *et al.* 2006).

Therefore S_S and X_S , are the key factors for determining the capacities of the anaerobic and anoxic zones of a BNR process, determining the S_S and X_S fraction for the activated sludge process simulation is vital in terms of the reliability of the result.

Generally, the X_S range is from 28% to 74% (with an average of 57.9%) in raw wastewater and 24.5% to 65% (with an average of 49.5%) in settled wastewater (Pasztor *et al.* 2009). The result derived from this study is 52.2% on average, which is close to the world average. S_I values ranged from 3% to 14.3% (with an average of 8.7%) in settled wastewater, which is similar to 7.5%, as surveyed in

Table 1 Influent COD fraction of three full-scale WWTPs in Korea during September of 2008

COD components	Ave. (%)	Min. (%)	Max. (%)	domestic wastewater treatment plant		
				Jungrang[a] (%)	Tancheon[b] (%)	Seonam[c] (%)
readily biodegradable substrate, S_S	25.6	23.0	27.7	27.7	23.0	26.0
inert soluble organic matter, S_I	7.5	7.0	8.0	7.4	8.0	7.0
slowly biodegradable substrate, X_S+X_{BH}*	52.2	49.7	55.0	49.7	55.0	51.7
biomass (autotrophs), X_{BA}	0.0	0.0	0.0	0.0	0.0	0.0
inert particulate organic matter, X_I	15.5	14.0	17.2	17.2	14.0	15.4

Note: a) design capacity: 1,710,000 CMD; b) design capacity: 1,100,000 CMD; c) design capacity: 2,000,000 CMD taken from (with permission) basic design report of wastewater treatment plant retrofitting, 2008, S City (Biomass COD is included in the slowly biodegradable substrate fraction)

this study; while X_I ranged from 4% to 20% (with an average of 12.9%) in settled wastewater (slightly lower than 15.5%, the result in this study). If X_I is higher, the primary and secondary sludge generation increases.

X_{BA} was lower than 1% due to a low growth rate of autotrophic microbes. On the other hand, X_{BH} ranged from 3.5 to 25% (with an average of 12%) in settled wastewater, which is relatively high (Pasztor *et al.* 2009). When the biomass fraction using the STOWA (Dutch Foundation for Applied Water Research) protocol is not determined separately, as is often the case, X_{BH} can be measured as X_S (Hulsbeek *et al.* 2002). Moreover, in this study, because the STOWA protocol was used, X_{BH} is included in X_S.

2.2 Description of target WWTP

To apply and verify the COD influent fraction analyzer (IFA) in this study, nine (9) wastewater treatment processes in the city of S (South Korea) were selected as the targets (P1-P9). The plants collect in urban and industrial wastewaters into combined sewer system.

The plants P1, P2 and P3 are medium-large-scale wastewater treatment facilities and have daily design capacities ranging from 140,000 to 680,000 CMD. While P5, P6 and P7 are medium-small-scale WWTPs with daily design capacities of < 50,000 CMD.

It is also worth noting that one system of P1, uses the modified Ludzack-Ettinger (MLE) process, while the others operated using the A2O and Johannesburg processes.

Since January 2012, when the total phosphorus criteria in Korea was strengthened to < 0.5 mg/L (III regional standard), all seven (7) facilities have been operating tertiary treatment processes. These processes include chemical coagulating precipitation or filtering processes.

During winter, a more sophisticated operation is required due to the low water temperature. Because of this, a simulation of the water quality of the activated sludge was performed. The simulation was based on the primary

Table 2 WWTP influent characteristics of activated sludge process during winter season (November 2014 to February 2015)

Items	Flow rate	BOD	TSS	TN	Alkalinity	Temp.
	(CMD)	(mg·L^{-1})	(mg·L^{-1})	(mg·L^{-1})	(mg·L^{-1})	(degree)
P1-A	74,184	70.2	69.7	24.4	232	18.1
P1-B	68,478	62.4	61.6	23.6	228	18.1
P1-C	73,049	61.5	78.8	25.3	335	24.6
P2	100,680	94.1	49.1	26.7	193	13.3
P3	366,657	104.8	60.6	30.3	201	14.6
P4	455,096	77.7	41.2	23.8	166	11.6
P5	20,105	106.4	70.5	31.2	159	15.0
P6	18,282	31.1	47.1	15.0	201	21.7
P7	35,953	91.0	46.4	25.3	157	14.6
Ave.	134,721	77.7	58.3	25.1	208	16.8
Max.	455,096	106.4	78.8	31.2	335	24.6
Min.	18,282	31.1	41.2	15.0	157	11.6

clarifier effluent from November 2014 to February 2015. The average water quality values of the WWTP influent during winter, in the activated sludge process, were the following: BOD 77.7 mg/L, TSS 58.3 mg/L and TN 25.1 mg/L. These values indicate typical low strength wastewater (Table 2).

As for the internal recycling (IR), the operating condition for the activated sludge process is 139% on average for the internal recycling. This is due to the low organic material concentration in the WWTP influent. For this reason, the dissolved oxygen (DO) concentration in the aeration tank is maintained at a slightly higher level (3.2 mg/L on average). Given the quality of the treated water, full nitrification is being conducted in most plants. In addition, the effluent TN concentration is 9.9 mg/L on average. The value is much lower than the criteria (limit) for WWTP effluent in Korea (20 mg/L). The effluent TSS is 6.3 mg/L on average, which indicates excellent management of settlement efficiency in settled wastewater.

2.3 Optimization algorithm

Influent fraction analysis (IFA) is a method for estimating the state variables of the IWA ASM1 model, using the relationship between the state variables and the TCOD, BOD and TSS of the influent (Alex *et al*. 2008). By adopting the following equation, Harmony Search (HS) optimization algorithm was applied to the IFA in order to calculate the state variables fraction, namely the objective function (Geem 2010). The HS algorithm applied to the IFA basically emulates improvisational notes in music. Starting from the set of optimal solutions that occurred randomly, the algorithm leads to optimum solutions via local search and global search (Fig. 1). The HS algorithm is one kind of meta-heuristic optimization algorithm.

Unlike other algorithms, the HS algorithm does not require a mathematical differential process. It is a method for deriving the optimal harmony value, storing the harmony value (the solution indicated by the respective variables) in the harmony memory and constantly enhancing its priorities. The algorithm is widely used for obtaining minimum cost, minimum error, maximum profit and maximum utility in the fields of structure, water resources and others (Kim and Geem 2015).

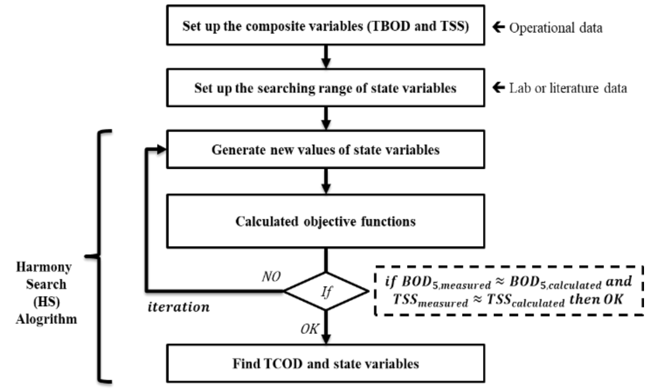

Fig. 1 Optimization procedure for influent characterization using HS algorithm

Objective functions

$$Objective\ function = Minimize \left\{ \left(\frac{|BOD_{measured} - BOD_{calculated}|}{BOD_{measured}} \right) + \left(\frac{|TSS_{measured} - TSS_{ccalculated}|}{TSS_{measured}} \right) \right\}$$

Where

$$TCOD_{calculated} = f_{COD\_BOD} * BOD_{measured}$$

$$S_S = f_{SS\_COD} * TCOD$$

$$S_I = f_{SI\_COD} * TCOD$$

$$X_S = f_{XS\_COD} * TCOD$$

$$X_I = f_{XI\_COD} * TCOD$$

$$BOD_{calculated} = f_{BOD} \times [S_S + X_S + ((1 - f_P)(X_{BH} + X_{BA})]$$

$$TSS_{calculated} = f_{TSS} \times (X_S + X_I + X_{BH} + X_{BA} + X_P)$$

$TCOD$ = Total chemical Oxygen Demand, mg COD/L

$$= S_S + S_I + X_S + X_I + X_{BH} + X_{BA} + X_P$$

BOD = Total Biochemical Oxygen Demand, mg BOD/L

TSS = Total Suspended Solids, mg SS/L

S_S = Finding readily biodegradable substrate, mg COD/L

S_I = Finding inert soluble organic matter, mg COD/L

X_S = Finding biodegradable particulate organic matter, mg COD/L

X_I = Finding inert particulate organic matter, mg COD/L

X_{BH} = Heterotrophic biomass, mg COD/L, assume zero in raw wastewater

X_{BA} = Autotrophic biomass, mg COD/L, assume zero in raw wastewater

X_P = inert particulate products, mg COD/L, assume zero in raw wastewater

f_P = fraction of cell mass remaining as cell debris, unitless

f_{BOD} and f_{TSS} = BOD and TSS modification factor, unitless

f_{SS_COD}, f_{SI_COD}, f_{XS_COD} and f_{XI_COD} = each fraction of S_S, S_I, X_S and X_I over TCOD, unitless

f_{COD_BOD} = ratio of COD over BOD, unitless

Constraints

$0.15 < f_{SS\_COD} < 0.35$ $0.05 < f_{SI\_COD} < 0.12$

$0.4 < f_{XI\_COD} < 0.8$ $0.08 < f_{XI\_COD} < 0.3$ $1.6 < f_{COD\_BOD} < 2.4$

Estimated variables: S_S, S_I, X_S X_I, $TCOD$ (optional)

2.4 Process model

IWA ASM1 model consists of thirteen (13) state variables and eight (8) processes, the biological mechanisms of the activated sludge process are expressed. The reactions in the model were developed based on the Monod equation. The individual reactions also have respective rate equations. The thirteen (13) state variables of the model are expressed by the stoichiometric coefficients of the relevant reactions (Sin 2004). The input variables of the ASM model consist of composite variables such as the COD and state variables, such as fractions. In this study, ASM1 was utilized in calculating the composite variables from the state variables and for the process simulation (Henze *et al*. 2000).

2.5 Simulation software

A commercial simulator developed in Korea, MassFlow™ (UnU Inc., version 2.8.8, http://www.massflow.kr), was used in the WWTP simulations. MassFlow™ provides a modified ASM1; anaerobic digestion, settling tank, thickener, coagulation, biological aerated filter, filtering and dewatering processes for IWA ASM1; and bio-P simulation, for the activated sludge process simulation.

Modified ASM1 is a biological phosphorus removal model that adds S_p (Soluble phosphorus) and X_{pp} (poly-phosphate) to the original ASM1 model. In the modified ASM1 model, two process rates were added to explain anaerobic hydrolysis and lysis of X_{pp}. The equations are as follows.

Process rate for anaerobic hydrolysis

$$\widehat{\mu_H}\eta_{\mathrm{fe}}\left(\frac{K_{O,H}}{K_{O,H}+S_o}\right)\left(\frac{K_{NO}}{K_{NO}+S_{NO}}\right)\frac{X_S/X_{B,H}}{K_X+(X_S/X_{B,H})}X_{B,H}$$

Process rate for lysis of X_{pp}

$$b_{pp}X_{pp}\left(\frac{S_{alk}}{K_{alkh}+S_{alk}}\right)$$

Where

$\widehat{\mu_H}$: Maximum specific growth rate, g VSS / g VSS / d

η_{fe} : Anaerobic hydrolysis reduction factor, unitless

$K_{O,H}$: Oxygen inhibition coefficient, mgO_2 / L

S_o : Dissolved oxygen, mgO_2 / L

K_{NO} : Nitrate half saturation coefficient, L / mgCOD / d

S_{NO} : Nitrate nitrogen, mg/L

K_X : Slowly biodegradable half saturation coefficient, g COD / g COD

$X_{B,H}$: Heterotrophic biomass, mg COD/L

b_{pp} : Rate for lysis of Poly-phosphate, m^3 / g VSS / d

X_{pp} : Poly phosphate, mg P/L

K_{alkh} : Saturation coefficient for alkalinity (HCO3-), mgO_2 / L

S_{alk} : Alkalinity, mg/L as $CaCO_3$

For alkalinity correction, following factors were added to the original ASM1 process rate.

$$\left(\frac{S_{nh}}{K_{n,H}+S_{nh}}\right)\left(\frac{S_{alk}}{K_{alkh}+S_{alk}}\right)\left(\frac{S_p}{K_p+S_p}\right)$$

S_{nh} : Ammonia nitrogen, mg/L

$K_{n,H}$: Half-velocity constant for heterotrophic bacteria, mg NH_4^+-N / L

K_p : Saturation coefficient for poly-phosphate, g VSS / g VSS / d

S_p : Soluble phosphorus, mg P/L

3. Results and discussion

3.1 Comparison of influent fraction analysis with experimental data

To test the performance of the newly developed IFA, the Seonam WWTP in the city of S was selected to measure the

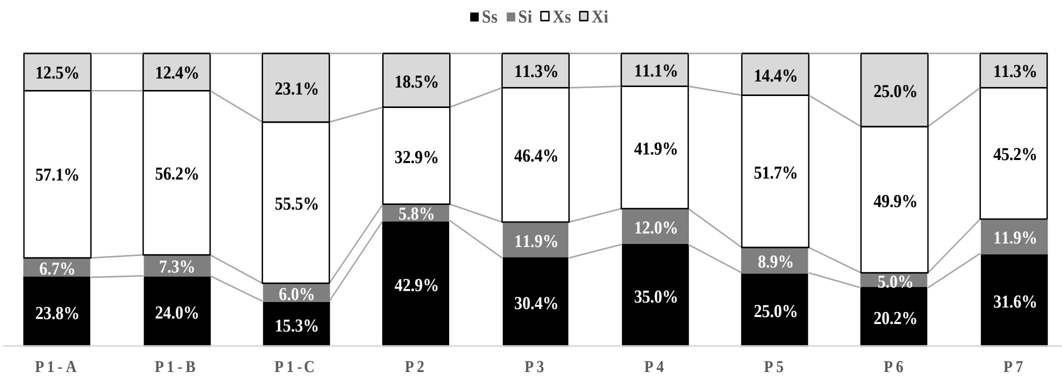

Fig. 2 Influent COD fraction analysis result of each settled wastewater using IFA

COD fraction of its settled wastewater in the primary settling tank. This fraction was then compared with the IFA result.

In Korea, since CODmn is used for design and operation instead of CODcr, only the TBOD and TSS can be used to measure the organic matter that can be applied to the ASM1. Therefore, among the input variables of the IFA, the composite variables were evaluated using only TBOD and TSS to evaluate the TCOD, VSS and state variables (Case-1). As shown in table 3, the calculation results using the IFA and the results from the experiment showed the absolute errors of 1.5% in TCOD, 1.6% in VSS, 14.2% in S_S, 24.9% in S_I, 6.4% in $X_S + X_H$ and 3.1% in X_I. All predictions were precise, with the exception of S_I.

Case-2 of Table 3 is a simulation result based on the assumption that the TCOD can be measured. In Case-2, the prediction errors of S_S, S_I and $X_S + X_H$ were 8.9%, 22.9% and 3.8% respectively. These values are lower compared to the values in Case-1. The prediction error of X_I, however, was 12.0%, which shows a slight increase compared to the Case-1 value. Considering the analysis errors of our test in the laboratory, both cases can be used for the ASM1 simulation. If the COD can also be measured, the errors could be further decreased. In the case of S_I, the reason the errors were significant in both cases is because the measured value was lower compared to the other state variables; the errors were therefore relatively exaggerated. The absolute errors in Case-1 and Case-2 were 3.3 mg/L and 3.0 mg./L respectively; both of which are low and are about 1.8% and 1.6% of the TCOD. Therefore, their influence on the simulation result is thought to be less.

3.2 Evaluation by steady-state simulation

The steady-state simulation during winter season regarding the nine activated sludge processes of seven WWTPs was conducted using IFA (Table 4). The influent COD fraction was obtained as seen in Fig. 2, while NH_4^+-N (S_{NH}) was applied as total nitrogen (TN) with the exception of biodegradable organic nitrogen (X_{ND}). The fraction of X_{ND} calculated from X_s and X_I, 0.04, was applied (Henze *et al*. 2000) while the soluble nitrate nitrogen NO_3^-N (S_{NO}) as well as soluble biodegradable organic nitrogen (S_{ND}) were assumed to be '0'.

For the steady-state simulation, IWA ASM1 was used. Only the default values were used for the kinetic

Table 3 Comparison of influent fraction analyzer with experimental data of settled wastewater

Items		Measured (mg·L^{-1})	Simulated (mg/L)		Error (%)	
			Case-1 a)	Case-2 b)	Case-1	Case-2
Composite variables	TCOD	188.0	185.1	**	*1.5*	-
	TBOD	79.9	79.9	80.0	*0.0*	*0.1*
	TSS	100	99.9	100.0	*0.1*	*0.0*
	VSS	77.2	78.4	78.4	*1.6*	*1.6*
State variables	S_S	48.9	42.0	44.5	*14.2*	*8.9*
	S_I	13.2	9.9	10.2	*24.9*	*22.9*
	X_S+X_H	97.2	103.4	107.0	*6.4*	*3.8*
	X_I	29.0	29.9	32.4	*3.1*	*12.0*

Note: a) TCOD was calculated using IFA; b) TCOD was applied as measured data (Measured June 2006, Method: OUR test using batch reactor, Applied measured TCOD data for IFA)

parameters. As a result of the simulation, TSS showed an absolute error from the actual data of as much as 0.7%, TN 3.3%, NH_4^+-N <0.1 mg/L and NO_3^-N <3.9%, which are acceptable. Like the simulation result, only the adjustment of the influent COD fraction and the adjustment of aerobic simultaneous denitrification can result in a fine steady-state simulation.

3.3 Evaluation by dynamic simulation

To evaluate the IFA performance, S-wastewater was conducted with a dynamic simulation based on the condition D-IFA, where the IFA was applied every day for 122 days from September to December 2014 and under the condition C-IFA, by which the COD fraction is assumed to be constant. The S-WWTP is operated as the Johannesburg process with a design capacity of 520,000 CMD. The amount of WWTP influent per day during the simulation period was 420,634 CMD, about 81% of the design capacity.

As the result of dynamic simulation for both conditions, D-IFA condition showed better RMSE value, as well as BOD, TSS, TN and MLSS (Table 5). BOD and TSS did not show significant differences under both conditions. However, in terms of TN and MLSS, condition D-IFA was better.

Table 4 Comparison with operational data and steady-state simulated results of the activated sludge process effluent (November 2014 to February 2015)

Items	TSS			Total nitrogen			NH_4^+-N			NO_3^--N		
	Meas. ($mg\cdot L^{-1}$)	Simul. ($mg\cdot L^{-1}$)	Err. (%)	Meas. ($mg\cdot L^{-1}$)	Simul. ($mg\cdot L^{-1}$)	Err. (%)	Meas ($mg\cdot L^{-1}$).	Simul. ($mg\cdot L^{-1}$)	Err. ($mg\cdot L^{-1}$)	Meas. ($mg\cdot L^{-1}$)	Simul. ($mg\cdot L^{-1}$)	Err. (%)
P1-A	8.72	8.72	0.0	10.79	10.76	0.3	0.22	0.13	< 0.1 mg/L	9.83	9.65	1.8
P1-B	7.46	7.43	0.4	9.57	9.80	2.4	0.24	0.24	< 0.1 mg/L	8.96	8.78	2.0
P1-C	8.72	8.76	0.5	10.79	10.80	0.1	0.24	0.22	< 0.1 mg/L	9.63	9.64	0.1
P2	2.39	2.39	0.1	9.30	9.43	1.4	0.52	0.49	< 0.1 mg/L	8.43	8.13	3.6
P3	3.37	3.38	0.2	11.64	11.39	2.2	0.52	0.57	< 0.1 mg/L	8.93	8.92	0.1
P4	5.22	5.25	0.7	11.30	11.65	3.1	0.73	0.70	< 0.1 mg/L	10.19	10.14	0.5
P5	4.76	4.74	0.5	7.67	7.73	0.8	0.51	0.56	< 0.1 mg/L	6.45	6.42	0.5
P6	11.58	11.59	0.1	10.40	10.05	3.3	0.36	0.34	< 0.1 mg/L	6.37	6.12	3.9
P7	4.38	4.39	0.2	7.85	7.98	1.6	0.43	0.45	< 0.1 mg/L	6.06	6.21	2.5

In the case of TN, the C-IFA simulation result rapidly increased within the two initial days, as compared to the past data. This is because, in the C-IFA, the COD/BOD was fixed at 1.766 - which was calculated using the IFA in the steady-state condition. The proper COD/BOD ratio in this period, as derived from the D-IFA, was 1.633, while the value derived from the C-IFA was 1.766. This discrepancy led to an exaggeration of the influent COD. The heightened COD reduced the nitrification efficiency and in turn, rapidly increased the TN concentration of the effluent.

On the other hand, in the case of D-IFA, where the calculation of influent fraction was conducted every day because the influent COD concentration was re-calculated based on the BOD and TSS concentrations, the result resembled the actual operational data (Fig. 3). For the same reason, in both cases, the RMSE value was 0.32 mg/L, which showed no difference. However, in the case of the R-square values, D-IFA was 0.68, while the C-IFA was 0.47, which shows that D-IFA is more acceptable.

In the case of the MLSS, the D-IFA simulation result showed a trend similar to the operational data, while the C-IFA showed a constant decrease (Fig. 4). This is because the influent S_S fraction, which is sensitive to the MLSS concentration, was 30% on average for the first 23 days, but further decreased to about 20%, after constant decrease continued to the 40th day. In the case of C-IFA, because the average (25.6%) was applied to S_S, the MLSS was bound to decrease constantly.

4. Conclusions

In this study, IFA was proposed for its capability of estimating the state variables fraction of the WWTP influent. It was performed by utilizing the relationship between the state variables of the ASM1 model (and the HS optimization algorithm) and the composite variables (BOD, TSS).

For the WWTP in the city of S in Korea, the IFA was applied to compare the simulated COD with the measured COD. As a result, the S_S fraction of the WWTP influent (which is sensitive to the biological nitrogen removal) could be predicted with an error of about 14.2%. In the case where the influent TCOD could be measured, the error decreased to 8.9%. In the case of $X_S + X_H$, which takes up the largest part of the influent COD, the estimation could be performed with error ranging from 3.8% to 6.4%.

By utilizing the estimated influent COD fraction, the organic material and nitrogen concentrations in the nine BNR processes derived from the seven facilities under the steady-state simulation could be obtained at high precision.

Along with this, in evaluating the IFA under dynamic simulation conditions, the S-wastewater treatment facility in the city of S was simulated for 122 days. The simulation of everyday IFA (D-IFA) showed better results than the simulation in which the COD fraction was set as a constant value (C-IFA). The C-IFA showed relatively high error values as the WWTP influent COD fraction changed during the simulation period. This indicates that, unlike the steady-state simulation, the dynamic condition requires WWTP influent fraction analysis during the simulation period.

If the range information of the state variables from areas with similar characteristics of WWTP influent of BOD, TSS and TCOD is known, the suggested IFA can be utilized to estimate the WWTP influent COD fraction of the ASM1 model. This is also expected to reduce the time and cost needed for the COD fraction analysis experiment. Moreover, if the organic matter concentration of the WWTP influent cannot be measured during the construction of a new WWTP, the IFA can be utilized as an alternative to improve the reliability of simulation.

Table 5 Dynamic simulation result for S-wastewater treatment plant for 122 days

RMSE (Root Mean Square Error)	BOD	TSS	TN	MLSS
daily IFA$^{a)}$	1.00	1.20	1.05	154
constant IFA$^{b)}$	1.13	1.25	1.37	365

Note: a) IFA was applied daily depending on the quality of WWTP influent; b) Influent fluent fraction was continuous during the simulation period

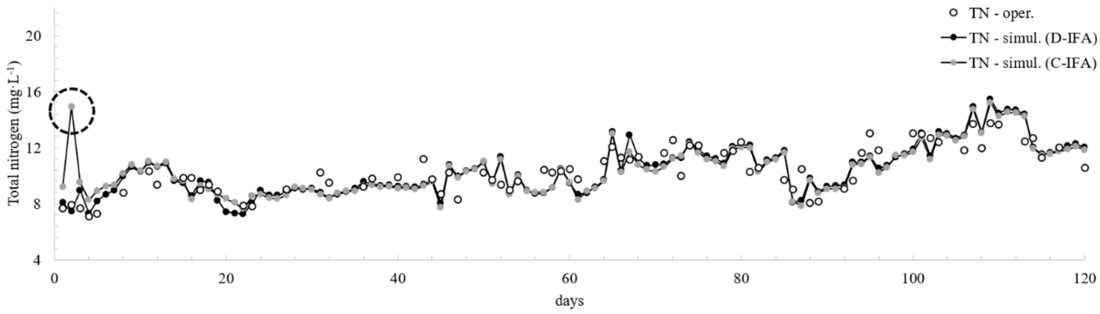

Fig. 3 Dynamic simulation result of WWTP effluent total nitrogen

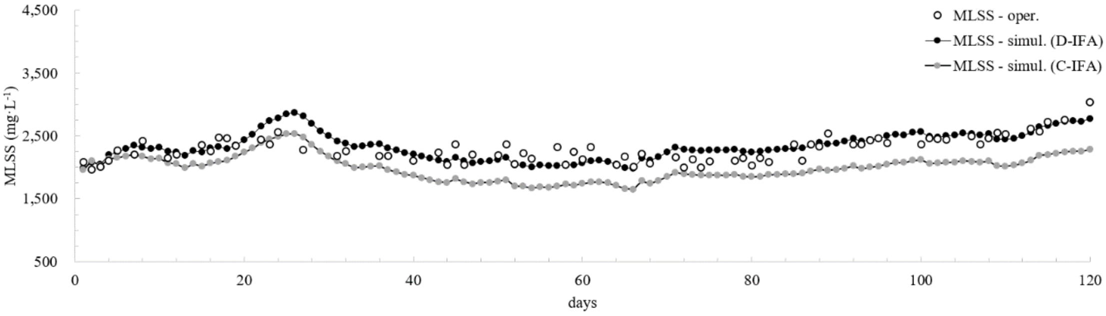

Fig. 4 Dynamic simulation result of MLSS

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