Original Article

Determination of biokinetic coefficients for an adsorption/bio-oxidation process on municipal wastewater in pilot-scale

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ABSTRACT

Aims: The present study was carried out to determine biokinetic coefficients of a pilot-scale adsorption-bio-oxidation process.

Materials and Methods: The pilot plant was simulated North wastewater treatment plant, Isfahan, Iran. The pilot plant was operated 135 days under different mixed liquor suspended solids (MLSS) concentrations in aeration tank. In each phase, MLSS value was kept constant to reach a steady state condition. B-stage has a higher hydraulic retention time and SRT than A-stage. Also, in order to determine influence of biokinetic parameters on the effluent substrate concentration, a sensitivity analysis was performed.

Results: The coefficients Y, K_d, K_S, and μ_{max} of A-stage were 1.34 mg VSS/mg sCOD, 0.17 d^{-1}, 8.61 mg/L, and 2.78 d^{-1}, respectively. Also, Y, K_d, K_S, and μ_{max} of B-stage were 0.74 mg VSS/mg sCOD, 0.12 d^{-1}, 3.34 mg/L, and 71.94 d^{-1}, respectively. Sensitivity analysis showed that in the A-stage, all coefficients are directly proportional to the effluent sCOD concentration. In the B-stage, K_d and K_S are directly proportional, but μ_{max} was inversely proportional to the effluent sCOD concentration.

Conclusions: All coefficients were in the range of activated sludge coefficients that are mentioned in the literature, except μ_{max} and K_S of B-stage. However, K_S value of B-stage was close to the desired range. Sensitivity analysis showed that μ_{max} and K_S have the most influence on effluent substrate concentration (sCOD).

Key words: A-B process, adsorption-bio-oxidation process, biokinetic coefficients, two-stage activated sludge

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INTRODUCTION

One of the activated sludge process modifications is adsorption-bio-oxidation (A-B) process or two-stage activated sludge process. The A-B system, developed by Böhnke in 1978, has two individual process stages each with a separate sludge recirculation. The A-stage is highly loaded, with a short residence time. Physical and chemical processes, such as adsorption, coagulation and flocculation take place and microbes convert soluble organics, but do not directly degrade all these organics. The A-stage is equipped with an intermediate clarifier, in which excess sludge is separated. The second stage (B) has longer hydraulic retention time (HRT) and solids retention time (SRT). Biological nitrogen removal normally occurs in the second stage. SRT values of A- and B-stage are about 0.5 and 20 days, respectively. Low sludge age operation in A-stage selects fast growing bacteria, which can utilize only part of the readily biodegradable substrate in the raw wastewater. The other part of the substrate remains in the wastewater or, if sludge age is increasing, it is metabolized at a lower rate.[1-5]

The two-stage activated sludge concept for the extension of the main treatment plant of vienna proved to comply with the legal requirements during two years of full-scale operation. All parameters in the case of organic matters, total suspended solids (TSS), and nitrogen were in the range of standard requirements.[3]

Biokinetic coefficients are the basis of a wastewater treatment plant (WWTP) designing.[6] Some of biokinetic coefficients are also used in WWTP operation, such as yield coefficient for calculating sludge production.[5] Biokinetic coefficients used in the design of activated sludge process include maximum specific growth rate (μ_{max}), maximum rate of substrate utilization per unit mass of microorganisms (k), half-velocity (saturation) constant, or substrate concentration at one-half of the maximum specific growth rate (K_S), cell yield (Y), and endogenous decay coefficient (k_d).[7] Typical ranges of μ_{max} and k_d are 2-10 d^{-1} and 0.06-0.15 d^{-1}, respectively. Also K_S and Y range are 10-60 mg/L chemical oxygen demand (COD) and 0.3-0.6 mg VSS/mg COD, respectively.[5]

There are several studies about biokinetic coefficient determination in different processes. Rahman and Al-Malack studied on kinetics of crossflow membrane bioreactor processes (CF-MBR) in the treatment of refinery wastewater. They operated bioreactor under two mixed liquor suspended solids (MLSS) values of 3000 and 5000 mg/L. They changed HRT value and calculated biokinetic coefficients in each MLSS. The values of biokinetic coefficients were within the normal range of the activated sludge process found in the literature, except the values of Y.[8]

Mardani *et al.* (2011) determined biokinetic coefficients for activated sludge processes such as conventional, extended aeration, and contact stabilization on municipal wastewater. The investigation showed that the yield coefficient (Y), decay coefficient (k_d), maximum specific growth rate, and saturation constant (K_S) for conventional and contact stabilization processes were in the approved range. However, in the extended aeration process, values of Ks and Y in MLSS of 5000 mg/L were out of ranges.[6]

Naghizadeh *et al.* determined biokinetic parameters in municipal wastewater treatment with a submerged MBR using Monod equation. The results showed that Y, k_d, K_S, and μ_{max} coefficients were in the range of Monod equation.[9] Yenkie *et al.* determined biokinetics of wastewater treatment in the high-performance compact reactor using different cell residence times.[10] Zhong *et al.* 2003 used a combinational approach with considering HRT as an evaluation index to discuss factors, such as maximum specific removal rate (K), saturation constant (K_S), maintenance coefficient m, maximum specific growth rate (μ_{max}), and observed yield coefficient (Y_{obs}). They reported values of K and K_S for petrochemical wastewater treatment, as 0.185 h^{-1} and 154.2 mg/L, respectively.[11]

The main objective of this study is the determination of kinetic parameters Y, k_d, μ_{max}, and K_S for a pilot-scale of A-B process. The practical objective is determination of Isfahan North WWTPs biokinetic coefficients. Isfahan North WWTP provides services for about 1.2 million persons.

MATERIALS AND METHODS

Description of the system

Figure 1 shows the schematic of pilot-scale A-B process that used in this study.

The pilot-scale system was designed based on North WWTP Isfahan, Iran. The process is designed for organic matters removal, and SRT of B-stage is about 3.5 days that is not sufficient for nitrogen removal. Also, design SRT of A-stage is about 0.23 day.

Influent wastewater was drawn after fine screen unit of WWTP. For providing and maintaining aerobic condition in the reactors, fine bubble diffusers were fixed in the bottom of basins. The operation of pilot plant was programmed to switch on and off by programming logic controller. The inoculum was collected from South WWTP, Isfahan, Iran.

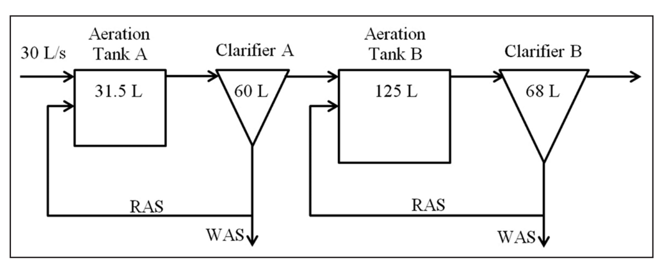

Figure 1: Schematic diagram of pilot-scale A-B process

For achieving biokinetic coefficients, the pilot was operated under four different MLSS concentration in aeration tank named four phases to obtain four different SRTs. In each phase, MLSS value was kept constant to reach a steady state condition.[12] Table 1 shows MLSS values of two stages in four phases. The first 75 days of operation was spent for system start up and acclimatize activated sludge. In the next 60 days, system operated under four different phases.

Analytical methods

Samples was taken from raw wastewater, aeration tanks, clarifier's effluent, wasted sludge, and returned sludge, every 2 or 3 days once. Influent wastewater and effluent samples analyzed for measuring soluble COD (sCOD), COD and TSS. Sludge samples and aeration tank samples analyzed for achieving TSS and volatile suspended solid (VSS) values. All analyzes were done in accordance with the standard methods.[13] Dissolved oxygen of aeration tank was measured daily using a multi-meter and controlled in necessary cases. Microsoft Excel 2010 and SPSS v16.0 software did data analyzing.

By plotting Equation 1, the values of Y and K_d can be calculated from the slope and intercept of the best fit line. The values of μ_{max} and K_S can be computed by plotting Equation 2:[8]

$$\frac{S_i - S_e}{\theta_H X} = \frac{1}{Y\theta_C} + \frac{K_d}{Y} \tag{1}$$

$$\frac{\theta_C}{1 + (\theta_C K_d)} = \frac{K_S}{\mu_{max} S_e} + \frac{1}{\mu_{max}} \tag{2}$$

where:

Y: Yield coefficient, mg VSS/mg sCOD.
K_d: endogenous decay coefficient, d^{-1}.
μ_{max}: Maximum specific growth rate, d^{-1}.
K_S: Half saturation concentration, mg sCOD/L.
S_i: Influent substrate concentration, mg COD/L.
S_e: Effluent substrate concentration, mg COD/L.
X: Biomass concentration, mg VSS/L.
θ_H: HRT, d.
θ_C: SRT, d.

Sensitivity analysis performed and influence of K_d, K_S, and μ_{max} in effluent sCOD concentration determined:[8]

$$S_e = \frac{K_S\left(\frac{1}{\theta_C} + K_d\right)}{\mu_{max} - \left(\frac{1}{\theta_C} + K_d\right)} \tag{3}$$

Raw wastewater characteristics

Table 2 shows average values for characteristics of raw wastewater during the operating period.

RESULTS

A-stage

A-stage operated under four different MLSS values. Operational parameters of this stage are summarized in Table 3. Coefficients calculations were done as shown in Figures 2 and 3. Values of Y, K_d, μ_{max}, and K_S coefficients were 1.34 mg VSS/mg sCOD, 0.17 d^{-1}, 2.78 d^{-1}, and 8.61 mg sCOD/L, respectively.

B-stage

Operational parameters of this stage are summarized in Table 4. Coefficients calculations are presented in Figures 4

Table 1: MLSS values of two stages in four phases

	MLSS, mg/L			
Stages	Phase 1	Phase 2	Phase 3	Phase 4
Stage A	2500	3000	3500	4000
Stage B	3000	3500	4000	4500

MLSS: Mixed liquor suspended solids

Table 2: Characteristics of raw wastewater

Parameter	Value
COD, mg/L	541
sCOD, mg/L	254
sCOD/COD	0.46
TSS, mg/L	324
pH	7.31

sCOD: Soluble chemical oxygen demand, TSS: Total suspended solids

Table 3: Operational parameters of A-stage during four different phases

Operation period	MLSS, mg/L	MLVSS, mg/L	sCOD out, mg/L	SRT, d
1-27	2479	2026	81	0.37
28-48	2981	2401	43	0.44
49-55	3538	2746	63	0.53
56-60	4031	3144	72	0.62

MLSS: Mixed liquor suspended solids, MLVSS: Mixed liquor volatile suspended solids, SRT: Solid retention times, sCOD: Soluble chemical oxygen demand

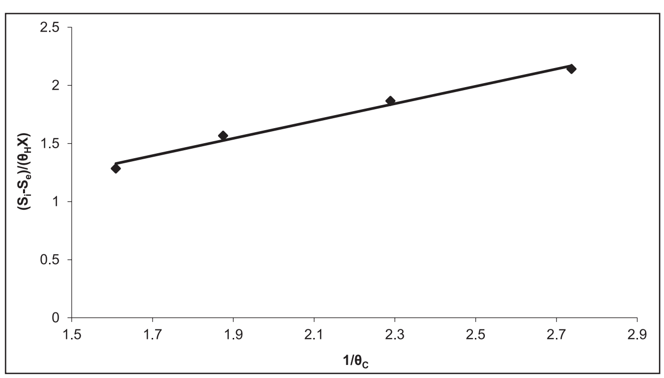

Figure 2: Determination of Y and K_d coefficients in A-stage

and 5. Values of Y, K_d, μ_{max}, and K_S coefficients were 0.74 mg VSS/mg sCOD, 0.12 d^{-1}, 71.94 d^{-1}, and 3.34 mg sCOD/L, respectively.

DISCUSSION

As shown in Table 5, value of Y for A-stage is over than the range given in all references, except Malina. By considering design criteria of A-stage, it is obvious that short HRT in this stage (1 h) raise F/M ratio and make a high-rate bioreactor. Malina studied on a high-rate biological treatment of wastewater and found that Y coefficient based on removed biodegradable oxygen demand and COD is 1.47 and 1.78, respectively.[17,18] These results are compatible to results of present study. High-rate reactors operate in rich food situation and microorganisms have sufficient food to consume. Short HRT causes that microorganisms use rapidly biodegradable COD (rbCOD). Y coefficient is high in such reactors.[17] Naghizadeh *et al*. studied on kinetic coefficients of an MBR. The results of this study showed that the yield of microorganisms (Y) was 0.67 g VSS/g COD.[19] In Mardani *et al*. study, Y coefficient of extended aeration activated sludge process was determined 0.62-1.25 mg VSS/mg sCOD. They related this value to high SRT of extended aeration process and presence of many vorticella coloni, rotifer, and nematode in this SRT.[6] Al-Malack studied on an immersed MBR using municipal wastewater. They found yield coefficient was 0.46–0.6 mg SS/mg COD. This value was in the approved range of other studies.[7]

Table 4: Operational parameters of B-stage during four different phases

Operation period	MLSS, mg/L	MLVSS, mg/L	sCOD out, mg/L	SRT, d
1-27	3029	2444	16	4.71
28-48	3488	2842	14	5.57
49-55	4068	3251	35	6.85
56-60	4521	3424	48	7.07

MLSS: Mixed liquor suspended solids, MLVSS: Mixed liquor volatile suspended solids, SRT: Solid retention times, sCOD: Soluble chemical oxygen demand

The K_d and μ_{max} values of A-stage are 0.17 d^{-1} and 2.78 d^{-1}, respectively, and as shown in Table 5, they are in the range of other studies.[5] Comparison between K_S of A-stage and given range in Metcalf and Eddy showed K_S is in the given range, but its value is low. Results of high-rate biological treatment by Malina also show K_S coefficient was lower than conventional activated sludge.[17] Its reason probably related to microbial culture in high-rate reactors. Also, biokinetic coefficients depend on the kind of wastewater, its contents, and temperature.[5]

Table 5: Kinetic coefficients obtained from different studies

Substrate	Y	K_d	μ_{max}	K_S	References
Municipal	0.3-0.8	0.06-0.2	2-10	5-100	Metcalf and Eddy, 2003[5]
Glucose	0.5-0.62	0.025-0.48	7.4-18.5	11-181	Al-Malack, 2006[7]
Synthetic	0.42-0.53	0.05-0.16	0.8-6.3	83-646	Al-Malack, 2006[7]
Municipal	0.46-0.6	0.025-0.075	5.6-8.1	250-3720	Al-Malack, 2006[7]
Industrial	0.3-0.72	0.045	0.77	2980.5	Raj and Anjaneyulu, 2005[14]
Domestic	0.31-0.35	0.016-0.068	1.7	43-223	Pala and Bölükbaş, 2005[15]
Domestic	0.67	0.07	3.75	22	Lawrence and McCarty, 1970[16]
Municipal	0.67	0.5	1.86	65.5	Naghizadeh *et al*., 2008[9]
Municipal	1.78	0.12	0.28	36.6	Malina, 1999[17]
Municipal	1.47	0.25	0.38	1.05	Malina, 1999[17]
Municipal	0.49-0.804	0.019-0.026	0.95-0.98	52-71.12	Mardani *et al*., 2011[6]
Municipal	0.62-1.25	0.02-0.031	1.96-3.17	311.7-508	Mardani *et al*., 2011[6]
Municipal	0.63-0.713	0.017-0.039	0.23-0.42	13.8-50.8	Mardani *et al*., 2011[6]
Domestic	0.4-0.67	0.07-0.09	3.2-3.75	22-60	Pala and Bölükbaş, 2005[15]
Municipal	1.34	0.17	2.78	8.61	Present study (A-stage)
Municipal	0.74	0.12	71.94	3.34	Present study (B-stage)

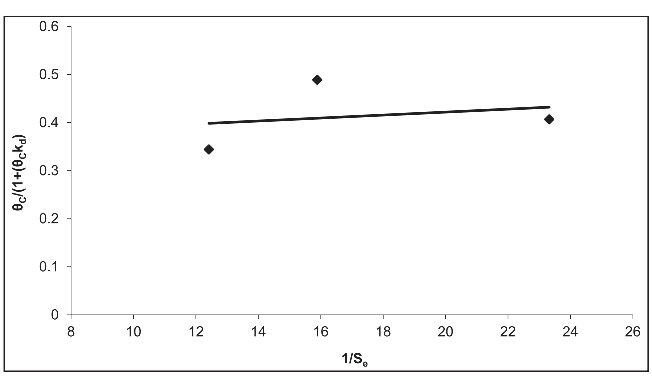

Figure 3: Determination of μ_{max} and K_S coefficients in A-stage

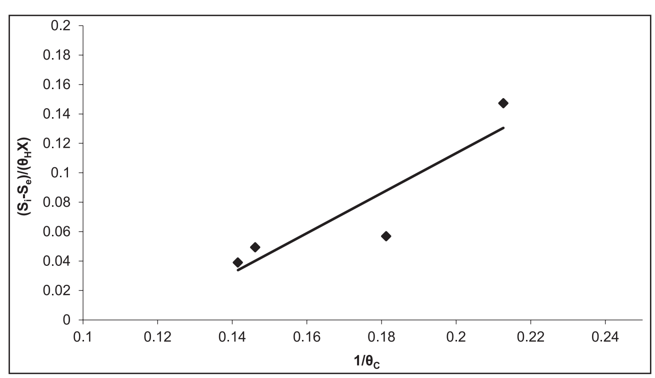

Figure 4: Determination of Y and K_d coefficients in B-stage

Yield coefficient (Y) of B-stage was 0.74 mg VSS/mg sCOD. This amount is compatible to Metcalf and Eddy. The results showed that Y in B-stage was less than Y in the A-stage. It is related to high female/male ratio in A-stage and rbCOD consumption in the first stage.[5] It is also in the reported range of Mardani *et al*. study.[6]

Values of K_d, μ_{max}, and K_S of B-stage are 0.12 d^{-1}, 71.94 d^{-1}, and 3.34 mg sCOD/L, respectively. K_d is totally in the range. However, μ_{max} is out of range and higher than other studies. Also, K_S was less than the given range in Metcalf and Eddy. The reason is probably due to consumption of most of sCOD in A-stage. As shown in Tables 3 and 4, outlet sCOD of first stage is 63-81 mg/L, while outlet sCOD of the second stage is 16-48 mg/L. These results indicate most of biodegradable sCOD consumed in the A-stage and theoretically, there are low amounts of available sCOD in the aeration tank of B-stage, so, K_S was decreased.

Haider *et al*. reported that the K_S values of both stages had to be small enough to allow the complete degradation of readily biodegradable organics in stage A and B (SS_A and SS_B), respectively. They assumed by modeling that K_S value equal to 1 mg/L is fit to kinetics of A-stage of an A-B process.[2]

By considering coefficients of A- and B-stages, we found that there are some differences. Of course, this difference did not follow any particular pattern to draw a straightforward conclusion. This difference might be attributed to the character of the system itself, as the system could be a selective process and kinetic coefficient obtained might represent different species.[8] This is supported by the performance investigation of the unit during the study period. For an instance, after A-stage operated for 20 days in MLSS concentration of 2500 mg/L, It was increased to 3000 mg/L and sCOD of effluent decreased, while it was supposed to be increased. Nevertheless, after increasing MLSS to 3500 mg/L, sCOD of effluent increased. The same occurrence happened for B-stage.

Rahman and Al-Malack investigated biokinetic coefficients in CF-MBR in the treatment of refinery wastewater and found values of coefficients are within the normal range of the activated sludge process that found in the literature, except the values of Y. The reason for the relatively low value of Y might lead to the oxidation state of the carbon source and nutrient elements.[8]

Mardani *et al*. determined biokinetic coefficients for activated sludge processes such as conventional, extended aeration, and contact stabilization on municipal wastewater. In the extended aeration process, values of K_S and Y in MLSS of 5000 mg/L were out of ranges.[6]

In order to determine influence of biokinetic parameters on the effluent substrate concentration, a sensitivity analysis was performed. The values of the k_d, μ_{max}, and K_S were individually varied by ± 50%, while the other parameters were kept constant.[8] During the sensitivity analysis, SRT of A- and B-stages were kept at 0.45 and 6 days, respectively. The sensitivity was studied by simulating the effluent COD using Equation 3. The results of the sensitivity analysis are shown in Figures 6 and 7.

In the A-stage, all coefficients are directly proportional to the effluent sCOD concentration. In the B-stage, K_d and K_S are directly proportional to the effluent substrate concentration, but μ_{max} was inversely proportional to the effluent sCOD concentration. The effluent substrate concentration was found to be more sensitive to μ_{max} when compared to K_d and

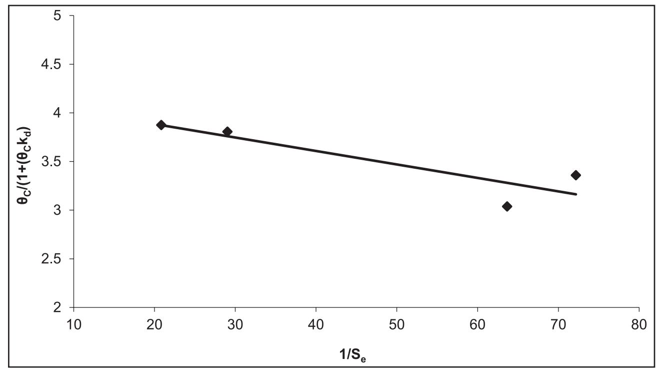

Figure 5: Determination of μ_{max} and K_S coefficients in B-stage

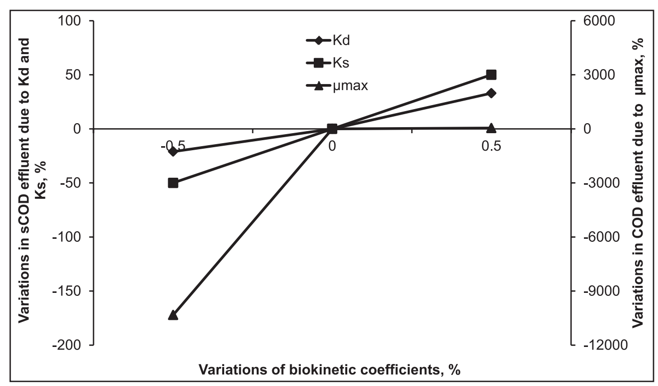

Figure 6: Sensitivity analysis of biokinetic coefficients of A-stage

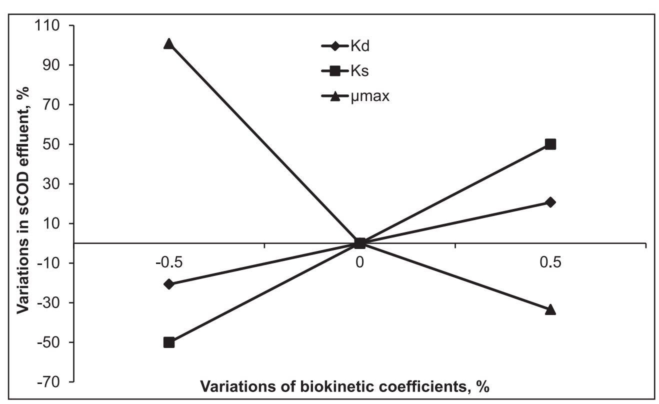

Figure 7: Sensitivity analysis of biokinetic coefficients of B-stage

K_S. Also, effluent sCOD concentration was more sensitive to K_S rather than K_d. It is obvious that caution should be in mind when using Monod model for designing A-B process, especially in the case of μ_{max} in A-stage and K_d in B-stage. Small variations in the mentioned coefficients can result in significant changes in the values of the effluent substrate concentration.

Rahman and Al-Malack performed sensitivity analysis and seen that k_d and K_S are directly proportional to the effluent substrate concentration while μ_{max} was inversely proportional to the effluent substrate concentration. Regardless of the MLSS concentration, the effluent substrate concentration was found to be more sensitive to μ_{max} when compared to K_d and K_S. Also, the effluent substrate concentration showed almost the same level of sensitivity to both K_d and K_S.[8]

Mardani *et al*. studied the sensitivity of the various biokinetic coefficients of conventional, extended aeration and contact stabilization activated sludge process. They found that K_d and K_S are directly proportional to the effluent substrate concentration while μ_{max} was inversely proportional to the effluent substrate concentration. Regardless of the MLSS concentration, the effluent substrate concentration was found to be more sensitive to μ_{max} when compared to K_d and K_S.[6]

CONCLUSIONS

Biokinetic coefficients of an A-B process (two-stage activated sludge) using a steady state method determined. The Y, K_d, K_S, and μ_{max} of A-stage were 1.34 mg VSS/mg sCOD, 0.17 d^{-1}, 8.61 mg/L, and 2.78 d^{-1}, respectively. The Y, K_d, K_S, and μ_{max} of B-stage were 0.74 mg VSS/mg sCOD, 0.12 d^{-1}, 3.34 mg/L, and 71.94 d^{-1}, respectively. All coefficients were in the range of activated sludge coefficients that are mentioned in the literature, except μ_{max} and K_S of B-stage. However, K_S value of B-stage was close to the range. Sensitivity analysis to determine the most affecting coefficient on effluent sCOD concentration was performed. The μ_{max} had the most influence on effluent substrate concentration. After it, K_S was more influencing. In the A-stage, all coefficients are directly proportional to the effluent sCOD concentration. In the B-stage, K_d and K_S are directly proportional to the effluent substrate concentration while μ_{max} was inversely proportional to the effluent sCOD concentration.

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Conflicts of interest
There are no conflicts of interest.

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