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Investigation, biokinetic calculation, and modelling of a real combined industrial wastewater biological treatment process by activated sludge models

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Abstract

Background: Treatment of combined industrial wastewater from industrial parks is one of the most complex and difficult wastewater treatment processes. Also, the accuracy of biological models for the prediction of the performance of these processes has not been sufficiently evaluated. Therefore, in this study, the International Association on Water Quality (IAWQ(-Activated Sludge Model No. 1 (ASM1) was implemented for the Jey industrial park in Isfahan province, Iran.

Methods: The Jey IPWWTP process is a combination of anaerobic and aerobic biological processes. To evaluate the overall performance of IPWWTP, organic compounds, suspended solids, nutrients, attached biomass, and some operating parameters were measured during 6 months. Then, the biokinetic coefficients of aerobic processes were determined using Monod equations. Finally, the aerobic processes were modeled using ASM1 implemented in STOAT software.

Results: The values of the biokinetic coefficients K, Y, Ks, Kd, and μ_{max} were calculated as 2.7d-, 0.34 mg VSS/mg COD, 133.36 mg/L COD, 0.03d-, and 0.93d-, respectively. Based on the default coefficients and conditions of the ASM model, the difference between the experiments and model prediction was about 2 to 98%. After calibrating the ASM model, the difference between the experiments and prediction in all parameters was reduced to less than 10%.

Conclusion: Investigations showed that the default coefficients and operation conditions of the ASM1 model do not have good predictability for complex industrial wastewaters and the outputs show a low accuracy compared to the experiments. After calibrating the kinetic coefficients and operating conditions, the model performance is acceptable and the predictions show a good agreement with the experiments.

Keywords: Wastewater, Industry, Kinetics, Models, Biological

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Introduction

Today industrial wastewater is one of the main sources of environmental pollution in the world, which often has a high pollution load and toxic and dangerous pollutants. On the other hand, due to the variability of the quantity and quality of industrial wastewater, the methods applied to treat and dispose industrial wastewater are different from municipal wastewater (1). Various processes such as biological, chemical, and physical processes have been applied for the treatment of industrial wastewater (2). One of the most widely used processes for industrial wastewater processes is the activated sludge process. The activated sludge process has expanded for reasons such as high efficiency in achieving existing standards, lack of insect accumulation, and less problems than other methods. Integrated fixed-film activated sludge (IFAS) systems are typically implemented to upgrade and retrofit activated sludge systems (3). Previously, biological wastewater treatment plants (WWTPs) were designed based on the experimental results (4). However, due to the variable quantity and quality of wastewater entering the treatment plants, only the use of experimental results cannot guarantee the quality of effluent. Nowadays, in addition to experimental indicators, mathematic equations based on stoichiometry and biological kinetics equations are used in design (5).

One of the most important factors in biological wastewater treatment processes in municipal and industrial wastewaters are the biokinetic constants such as maximum specific growth rate (μ_{max}, in 1/d), biomass yield (Y, in g VSS/g COD), half velocity constant (Ks, in mg/L), maximum substrate utilization rate (K, in 1/d), and endogenous decay coefficient (K_d, in 1/d) (6). The most important relationships used by experts to determine the kinetic coefficient in biological activated sludge processes are the Monod equations. Another way to determine kinetic coefficient is to optimize them through mathematical models such as activated sludge model (ASM) (7,8). The use of sophisticated mathematical models for simulating and modelling treatment plant performance increased with the advent of computer software such as EFOR, GPS-X, WEST Q AQUASIM, and STOAT. Models are good tools for summarizing and understanding complex interactions in biological systems. The models can be used to predict the dynamic response of the system to sudden changes in order to create a strategy to optimize the operation of wastewater treatment systems (9,10). The use of the relationships provided by the International Water Association for the ASMs has been considered by researchers and operators of WWTPs in recent years. These models, which have been developed for many years, started from ASM1, and finally, reached ASM3 (11). The ASM1 model describes only the reactions performed by heterotrophic bacteria under aerobic and anoxic conditions during the consumption of organic carbonate as well as autotroph nitrifying bacteria that oxidize ammonium to nitrate. A more complex model which includes phosphorus-accumulating organisms (PAOs) with aerobic, anoxic, and anaerobic reactions, was developed as the ASM2 model. This model was modified in 1999 and introduced as the ASM2d model. It is expanded to include the denitrifying activity of the PAOs (12).

The ASM3 model was also developed in 1999. This model includes carbon removal, nitrification, and denitrification, and is in fact a modified ASM1 model, and the limitations of the ASM1 model in the ASM3 model have been removed (5). Many researches have been done in this field, some of which are mentioned in this study. In 2019, Rafati et al studied the treatment plant in the south of Tehran with the aim of implementing four models of pollution removal and presenting the most appropriate model (13). Arif et al also designed and compared different types of WWTPs in 2018 using a wastewater modelling simulation software (GPS-X) (9). In 1992, Siegrist and Tschui modelled two WWTPs in Switzerland using the ASM1 model (14). In 2005, Nuhoglu et al modelled the Erzincan treatment plant in Turkey based on the ASM1 model (15).

The performance of biological models for urban and sanitary wastewaters has been investigated in several studies. However, the accuracy of the prediction of such models for industrial wastewater, especially combined wastewater from industrial parks has not been evaluated sufficiently. In this study, in the first step, to evaluate the overall performance of the Jey IPWWTP processes, which are ABR + IFAS + EA, the main parameters of the influent and effluent wastewater and operational conditions were measured and evaluated for 6 months. Afterwards, through Monod equations, the biokinetic coefficients of the aerobic section of WWTP were determined. Then, aerobic processes (IFAS + EA) of IPWWTP were modelled using the ASM1 model. Finally, a comparison was made between the model prediction in the mode of default coefficients and operational conditions with the optimized conditions and coefficients, and the accuracy of the model in these two modes was compared.

Materials and Methods

WWTP process description

Jey industrial park with an area of 309 hectares is the first and largest industrial park of Isfahan in the center of Iran. Jey WWTP receives wastewater from a total of industries in the industrial park including electrical and electronics, cellulose, chemical, food, metal, non-metallic minerals, and textiles. Metal industries with a total of 138 industrial units are the largest industry in this industrial park and the food industry is ranked first in water consumption, and consequently, wastewater production. The Jey IPWWTP capacity is 2000 m^3/d. In Figures 1A and B, the geographical location of Jey industrial park and its WWTP are presented.

Also, as shown in Figure 1C, the influent wastewater enters the biological treatment stages after passing through the units of the preliminary treatment consists of screening, oil and grit removal, septage handling, and flow equalization. The biological treatment consists of eight up flow anaerobic baffle reactors (UABRs) with a total volume of 1000 m^3, activated sludge system, which is a combination of 3 IFAS reactors with a total volume of 2025 m^3, and 3 extended aeration reactors and 4 secondary sedimentation tanks with a total volume of 2025 and 600 m^3, respectively.

Data collection

To characterize wastewater, samples were collected once a week at 8-hour intervals in each sampling point, generating 72 grab samples and 24 composite samples for each sampling point.

The sampling points are consisting of influent

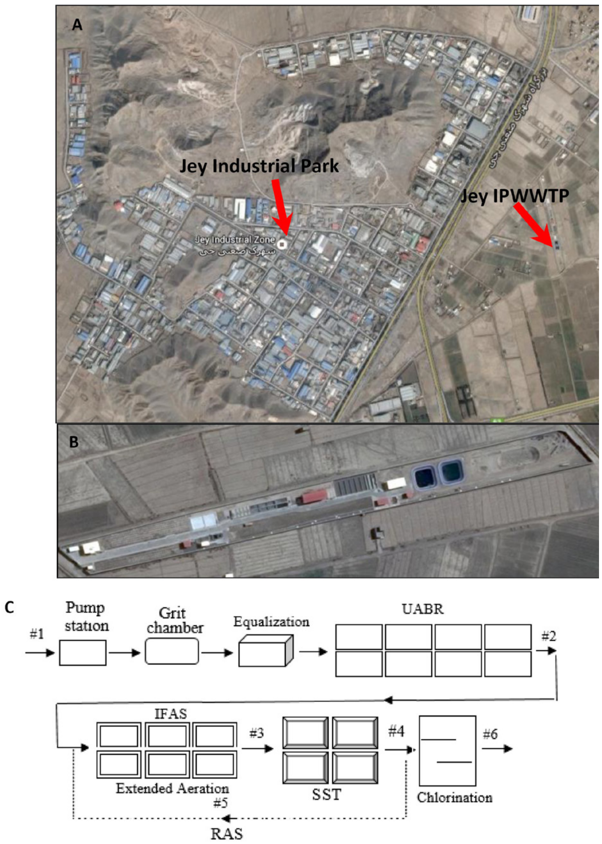

Figure 1. (A) Geographical location of Jey industrial park and its wastewater treatment plant, (B) image of Jey IPWWTP, (C) schematic diagram of the units in the Jey IPWWTP

wastewater (point #1), the outlet of the UABR (point #2), the inlet and outlet of the secondary sedimentation tank (point #3, #4), and the return activated sludge (RAS) (point #5), and effluent wastewater (point #6), which are indicated in Figure 1C. The collected samples were stored in the refrigerator at 4°C. Finally, a total of 144 composite samples were collected and the resulting composite samples were analyzed.

The average characteristics of the influent (point #1) and effluent wastewater (point #6) in the IPWWTP are presented in Table 1.

Wastewater samples were stored in 1000 ml polyethylene bottles, which were previously washed with deionized water and 5 ml of concentrated HNO_3. The samples were transferred to the laboratory in an ice box at 4°C for final analysis. The analysis of the samples was repeated 3 times, and the reagents used were analytical reagent grade.

The parameters analyzed were biological oxygen demand over 5 days (BOD5), chemical oxygen demand (COD), soluble chemical oxygen demand (sCOD), total suspended solids (TSS), volatile suspended solids (VSS), pH, mixed liquor volatile suspended solids (MLVSS), mixed liquor suspended solids (MLSS), temperature, and dissolved oxygen (DO) once a week and parameters PO_4^{-3}-P, NO_3^--N, and NH_4^+-N once a month. The chemical and physical parameters were analyzed using the methods

Table 1. The characteristics of influent and effluent wastewater treatment plant

Parameter	Unit	Average	Min	Max	SD
Influent					
Flow	m^3/d	1231.25	700	1650	286.58
COD	mg/L	1253.79	688	2089	399.09
sCOD	mg/L	926.46	523	1713	303.89
BOD5	mg/L	716	242.88	1590.12	351.42
TSS	mg/L	630.12	140	1400	458.75
VSS	mg/L	301	52	1120	266.56
NH_4^+-N	mg/L	74.67	58	120	23.25
NO_3^--N	mg/L	1.5	0.88	1.98	0.47
PO_4^{-3}-P	mg/L	12.4	10.4	14.4	1.65
pH	-	7.2	5.12	8.13	0.59
Temp	C	22.68	19.8	25.6	2.07
DO	mg/L	0.62	0.4	0.82	0.12
Effluent					
COD	mg/L	117.65	51	180	36.66
sCOD	mg/L	14.88	13	20	2.02
BOD5	mg/L	26.79	11	45	9.2
TSS	mg/L	63.7	16	144	31.51
VSS	mg/L	27.94	7	68	15.59
NH_4^+-N	mg/L	23.17	7	40	13.01
NO_3^--N	mg/L	3.37	1.32	5.06	1.92
PO_4^{-3}-P	mg/L	1.35	0.67	3.2	0.94
pH	-	7.93	7.28	8.36	0.22
Temp	C	21.53	19.2	24.3	1.71
DO	mg/L	0.74	0.48	0.92	0.12

mentioned in the *Standard Methods for the Examination of Water and Wastewater* book (16). Q-EYE MIII portable flowmeter made and designed by German HydroVision Company was used to measure wastewater discharge. Finally, the data were analyzed using Excel 2016 and SPSS version 26 software.

Table 2 shows the average operating and maintenance parameters of the aerobic process in Jey IPWWTP, which was used to calculate the biokinetic coefficients during 6 months.

To measure sludge volume index (SVI), the mixed liquid suspended solids were taken from the aeration tank outlet introduced into a one-liter graduated cylinder, which its retention time was about 30 minutes, and the volume of sediment sludge was recorded at the end. Its formula is as Eq. (1). Eqs 2 and 3 were used for sludge retention time (SRT) and F/M calculations, respectively (17).

$$SVI\left(\frac{ml}{g}\right)=\frac{SV\times 100}{MLSS} \tag{1}$$

$$\frac{F}{M}=\frac{Q\times S_o}{V\times MLVSS} \tag{2}$$

$$SRT=\frac{V\times MLSS}{(Q_W\times X_R+Q_e\times X_e)} \tag{3}$$

Table 2. The parameters of operation and maintenance of biological process in Jey PWWTP

Parameter	Unit	Count	Average	SD	Median	Min	Max
MLSS	mg/L	24	3902.7	1209.04	3569	2358	6150
MLVSS	mg/L	24	3095.4	899.1	2851.5	1886	4758
SVI	mL/g	24	271.8	78.05	273.2	156.3	411.3
HRT	hr	24	1.1	0.24	1.02	0.82	1.77
SRT	d	24	17.3	3.37	17.54	11.96	23.33
Q	m^3/d	24	1231.25	286.58	1300	700	1650
F/M	d^-	24	0.27	0.17	0.22	0.09	0.88

Where Sv, Q, S_0, V, Q_w, X_R, Q_e, and X_e are the volume of sediment after 30 minutes (mL/L), influent wastewater flowrate (m^3/d), influent BOD concentration (mg/L), aeration tank volume (m^3), waste sludge flowrate from the return sludge line (m^3/d), concentration of sludge in the return sludge line (mg/L), effluent flow rate from the secondary clarifier (m^3/d), and effluent TSS concentration (mg/L), respectively (18).

Determination of biokinetic coefficients using Monod equations

In this study, considering that in the aerobic section of Jey IPWWTP, a combination of IFAS and EA reactors treats wastewater, then, the effluents are combined with each other and enter the settling tank; for calculation of the kinetic coefficients, it was necessary to measure the suspended and attached biomass. To assign the dry weight of biofilm in attachment of the fixed media, some biofilms were scrapped from the surface, and finally, dried and weighed. The sum of the suspended and attached biomass was considered as MLSS in the IFAS reactor. Also, MLSS was measured in the extended aeration tank. The average MLSS in the IFAS and extended aeration rectors was considered as the MLSS of the aerobic section in the Jey IPWWTP. The biokinetic coefficients of aerobic section in the WWTP, including μ, K, Ks, Y, and Kd were determined using the Monod equations as follows (19).

$$\frac{1}{SRT} = YU - K_d = Y\frac{S_o - S}{\theta X} - K_d \quad (1)$$

$$\frac{\theta X}{S_O - S} = \frac{K_S}{K}\frac{1}{S} + \frac{1}{K} = \frac{1}{U} \quad (2)$$

$$\pi_m = KY \quad (3)$$

Where U, SRT, S_0, S, X, and θ are substrate utilization rate (mg sCOD/mg VSS.d), solids retention time (d), influent substrate concentration (mg sCOD/L), effluent substrate concentration (mg sCOD/L), biomass concentration (mg VSS/L), and hydraulic retention time (d), respectively.

Biochemical modelling

The aim of this study was to model the aerobic section of the IPWWTP, hence, the IFAS and extended aeration processes were modelled using IAWQ Model No. 1, which is known in the software as IAWQ #1, and Generic model was applied for the sedimentation tank. Figure 2 represents the STOAT 5.0 platform model.

The experimental data were introduced to the model as wastewater characterization for 6 months. Also, the specifications and dimensions of the units in the IPWWTP were introduced to the model. The model was evaluated in two modes. In the first mode, the default coefficients of the ASM model and the default operation conditions remained unchanged. In the second mode, the calculated biokinetic coefficients, and also, the operational conditions such as SVI, RAS, and MLSS, duration of operation of waste sludge pumps, and the power of air blowers, and etc. were given to the model, and the results were compared in these two modes.

Results

Determination of biokinetic coefficient

To determine the biokinetic coefficients using Monod equations, Figure 3A and B were plotted using the data gathered during 6 months of operation. The values of the biokinetic coefficients were found to be as follows: K = 2.7d^-, Y = 0.34 mg VSS/mg COD, K_s = 133.36 mg/L COD, K_d = 0.03 d^-, and μ_{max} = 0.93 d^-.

In Table 3, a summary of obtained kinetic coefficients using the Monod model in a number of studies conducted in recent years along with the results of the present study is presented.

Model calibration

The model was run in two modes, once with default coefficients and operating conditions and once with calculated coefficients. The results of modelling are presented in Table 4. In this table, the results of the experiments as well as the percentage of differences between the modelling and the experimental results for carbon compounds, suspended solids, and nitrogen and phosphate compounds are given.

The model output for the modified model, effluent carbon compounds, effluent suspended solids, and effluent nitrogenous compounds is presented in Figure 4.

Optimization of nitrification-denitrification process

By measurement of ammonia nitrogen and nitrate nitrogen concentrations and performing mass balance on them, it is possible to evaluate the nitrification and denitrification rate in Jey IPWWTP. The results of the nitrification and denitrification process are presented in Table 5.

Discussion

The application of biological modelling in the design and operation of treatment plants has increased significantly. To implement these models, it seems necessary to have

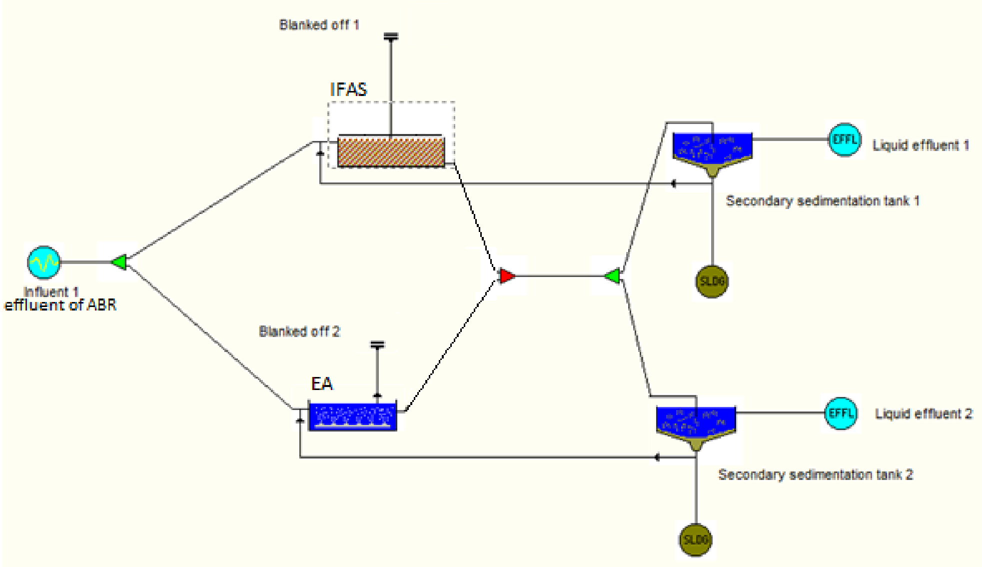

Figure 2. The general plan entered into the STOAT software to start modeling

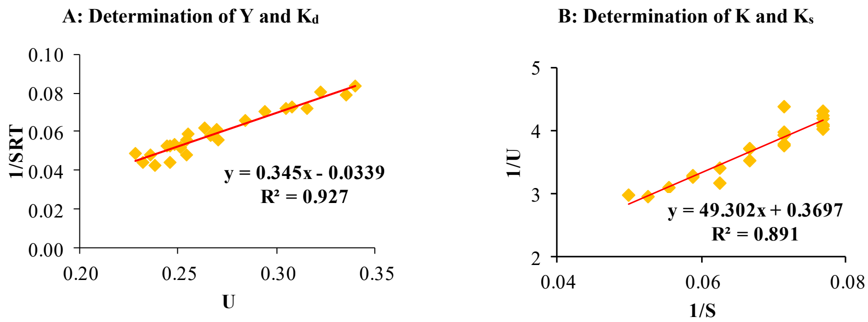

Figure 3. Determination of kinetic coefficients based on the Monod equations

Table 3. Comparative evaluation of the studies performed in determining kinetic coefficients with the findings of the present study

References	Type of Wastewater	μ_{max}(d⁻)	K_d(d⁻)	Y (mg VSS/mg COD)	K_s (mg COD/L)	K(d⁻)
Present study	Industrial	0.93	0.03	0.34	133.36	2.7
Tchobanoglous et al (2003)	Municipal	0.16-7.2	0.06-0.15	0.4-0.6	5-30	4-12
Pala and Bölükbaş (2005)	Municipal	1.28-2.51	0.016-0.068	0.4-0.6 7	43-223	3.2-3.75
Seyedi et al (2016)	Industrial	0.188	0.25	0.6	0.146	-
Al-Malack (2005)	Municipal	1.28-6.46	0.026-0.151	0.49-0.58	289-2933	-
Suman Raj and Anjaneyulu, (2005)	Industrial	0.77	0.045	0.3-0.72	2980.5	-
Mardani et al (2011)	Municipal	1.96-3.17	0.0198-0.0309	0.617-1.251	311.7-508	-
Mohammadi et al (2015)	Municipal	8.424	0.984	0.411	71.12	20.496
Qasim (2017)	Municipal	0.06-0.56	0.03-0.07	0.2-0.5	20-80	2-8

sufficient knowledge about the characteristics of the influent wastewater. The information required for modelling is much more accurate and detailed than what is normally required for the operation of treatment plants. Combination with industrial effluents can lead to significant changes in the properties of wastewater so that it is significantly different from purely domestic wastewaters. In this study, the influent wastewater characterisation and biokinetic coefficients in Jey IPWWTP were investigated. In Table 3, the kinetic coefficients obtained in this study correspond to the proposed values of kinetic coefficients with valid references. The biomass yield (Y, mg VSS/mg COD) is in the range provided by a valid reference (20), which is less than the value obtained in other references. In the process design, Y is important because it represents an estimate of the amount of sludge produced from the treatment process (21). One of the reasons for the low level of Y is considered to be the composition of wastewater. In a study by Liwarska-Bizukojc et al, the treatment of aerobic biomass of pentachlorophenol with very low Y was

Table 4. Wastewater characterization and calibrated and Kinetic parameters in STOAT 5.0

Parameter		Experiment	Model (calibration)	Difference Calibrated Model with Experiments%	Model (Default)	Difference Default Model with Experiments%
COD_{out} (mg/L)		117.654	107	9.06	23.12	80.35
$sCOD_{out}$ (mg/L)	$sbCOD_{out}$ (mg/L) $snbCOD_{out}$ (mg/L)	14.88	16.00	7.53	12.18	18.15
$pCOD_{out}$ (mg/L)	$pbCOD_{out}$ (mg/L) $pnbCOD_{out}$ (mg/L)	102.774	97.8	4.84	10.48	89.80
TSS_{out} (mg/L)		63.7	59	7.38	3.34	94.76
VSS_{out} (mg/L)		27.94	30.52	9.23	2.59	90.73
$nVSS_{out}$ (mg/L)		35.76	32.78	8.33	0.75	97.90
TKN_{out} (mg/L)	NH_4^+-N_{out} (mg/L)	23.17	23.95	3.37	1.68	92.75
	org-N_{out} (mg/L)	-	-	-	-	-
NO_3^--N_{out} (mg/L)		15.33	13.98	8.81	11.52	24.85
PO_4^{-3}-P		1.35	1.32	2.22	1.32	2.22

sbCOD, slowly biodegradable COD; nbCOD, Soluble non-biodegradable COD; pCOD, Particulate COD; pbCOD, particulate biodegradable COD; pnbCOD, Particulate non-biodegradable COD; nVSS, Non-VSS; TKN, Total Kjeldahl nitrogen.

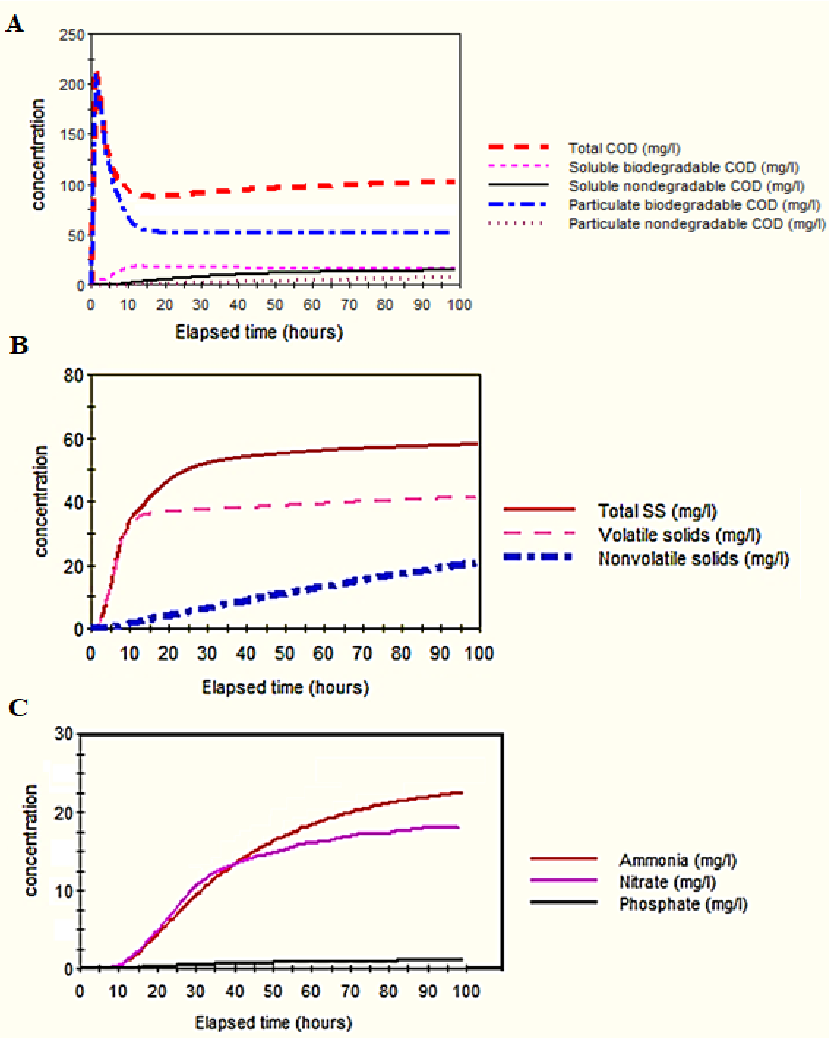

Figure 4. The results of the modified model for A) effluent carbon compounds, B) effluent suspended solids, and C) effluent nitrogenous compounds

approximately 0.05 (22). Endogenous decay coefficient (K_d, 1/d), is almost in the range obtained by other researchers, which shows that microorganisms have a high ability to remove COD (23). $k_d = 0.03$ d^{-} indicates that

Table 5. Operational samples and results

Sample	SRT Day	DO	Effluent Quality (mg/L)				Removal %		Aeration Tank	
			COD	BOD	NH_4-N	NO_x-N	Nit	De-nit.	MLSS (g/L)	MLVSS (g/L)
1	22.57	0.89	107	30					6140	4700
2	20.37	0.9	95	25					6150	4758
3	18.73	0.82	84	29					5625	4500
4	19.09	0.8	70	35	8	3.74	48.2	80.36	5875	4500
5	17.84	0.88	51	11					3284	2620
6	19.19	0.89	97	15					3546	2830
7	17.25	0.78	150	31					3105	2482
8	16.41	0.72	106	21	29	3.96	43.89	57.09	3479	2680
9	20.72	0.78	115	27					4844	3622
10	16.92	0.92	133	15					5766	4450
11	17.95	0.9	145	15					3886	3152
12	16.08	0.8	134	25	28	5.06	37.88	53.37	4315	3567
13	14.25	0.69	80.1	25					2358	1886
14	11.96	0.7	81.2	19					2652	2121
15	12.65	0.62	83.2	20					2782	2332
16	13.95	0.63	81.2	16	27	4.62	37.11	53.98	3302	2734
17	13.93	0.75	166	35					3356	2720
18	15.26	0.7	173	38					3640	2934
19	13.74	0.72	177	34					2386	1966
20	12.47	0.68	112	43	40	1.54	79.75	65.74	2506	2004
21	19.04	0.56	135	24					3592	2873
22	20.89	0.48	180	45					4064	3250
23	22.50	0.56	152	34					3166	2532
24	23.33	0.58	116	31	7	1.32	50.76	85.89	3846	3077

there is no growth inhibitory factor in the raw wastewater entering the biological treatment system (24). K_s in this study was 133.36 mg/L. μ_{max} is inversely related to K_s so that the higher the K_s, the lower the amount of biological activity or μ_{max} and the lower the treatment efficiency (25). Also, the value obtained for μ_{max} was 0.93 d^{-}. In the process of anaerobic digestion of abattoir wastewater in Nigeria, the value of μ_{max} was 1.073 d^{-} (26). Swamy and Anjaneyulu inferred that in wastewater that creates a competitive environment (such as industrial wastewater) for microorganisms, their growth rate will decrease and the next definite reason for this is the inhibitors in the wastewater (27). The toxicity of industrial wastewater is a possible reason that will have a negative effect on μ_{max} (28). Also, Jablonski et al considered the reduction of μ_{max} to be due to the availability of biodegradable organic matter as a carbon source for aerobic microorganisms (29). This difference in values and discrepancies can be attributed to the fact that this research was conducted on a full scale and on real wastewater.

Carbon compounds such as non-degradable sCOD, degradable sCOD, and value of pCOD obtained from the difference between TCOD and sCOD, at the input model were considered to be about 14.88, 911.58, and 327.33 mg_{TCOD}/L of, respectively, that as expected, the non-degradable sCOD did not change a lot. The model output is visible in Figure 4A. In a study by Alemu et al, in the field of tannery wastewater treatment for reuse for irrigation, the concentrations of BOD and COD in the treated effluent were 56 and 170 mg/L, respectively (30). Suspended solids, according to the results of experiments performed at the input of the activated sludge section, for TSS, VSS, and nVSS, which is obtained from the difference between VSS and TSS, the values of the input model were 630.25, 301, and 329.125 mg/L, respectively. The model output is represented in Figure 4B. As shown in Table 2, the results of the experiments as well as the model predictions are given in the state of default coefficients and modified coefficients, which shows a significant difference in the value of nVSS. In the study of Cristóvão et al, which was performed for reuse of canning industry effluent with conventional activated sludge process with reverse osmosis system and UV process, TSS removal efficiency was reported to be 94.8% (31). In terms of nitrogen compounds, it can also be stated that the total output nitrogen includes nitrate nitrogen and total Kjeldahl nitrogen (TKN), which itself contains organic nitrogen and ammonia nitrogen. Since the wastewater is industrial and most of the organic nitrogen is transformed to ammonia nitrogen during the treatment process, its amount was considered insignificant and neglected in this study. Also, TKN was considered equal to ammonia nitrogen. The model output is presented in Figure 4C. On the other hand, modifying the default coefficients had no effect on changing the phosphate concentration, and the predicted values of phosphate in the state of the default coefficients and the modified coefficients were equal. In a study by Zhang et al with the aim of determining the effect of solids retention time on the performance of membrane photobioreactors for industrial wastewater treatment, it was found that the highest amount of total nitrogen removal (19.26 ± 4.58%) and total phosphorus (54.95 ± 4.36%) were 20 and 30 days in cell retention time, respectively (32).

The model indicated high compliance with the measured parameters, such as COD, sCOD, pCOD, TSS, VSS, nVSS, PO_4^{-3}-P, NO_3^-N, and TKN. The average relative deviation (ARD) between the simulated parameters and the measured parameters for the whole six months was computed where ARD values were 9.06, 9.82, 4.84, 7.38, 8.45, 8.33, 2.22, 8.81, and 3.26% for COD, sCOD, pCOD, TSS, VSS, nVSS, PO_4^{-3}-P, NO_3^-N, and TKN, respectively. The ARD values were lower than 10% and considered admissible according to the study of Suman Raj and Anjaneyulu (33). The results showed that when the model was calibrated, the differences of calibrated model with measured data were less than 10%, which indicates that the first model should be calibrated, and finally, used. Also, the results showed that trusting only the coefficients and the default setting of the model is not correct and may cause errors in the operation of the treatment plant. According to the mentioned information, the output of the model with calibrated kinetic coefficients is acceptable and shows a good agreement and compatibility with the experimental results.

Nitrification is an aerobic process in which ammonia is changed by nitrifying bacteria to nitrite and nitrate (34). A number of parameters affect the growth of nitrifiers such as DO, temperature, pH, RAS ratio, and SRT (35). According to the results of sample No. 20, it had the highest nitrification rate (79.75%). The results showed that the amount of MLSS and MLVSS was provided to the desired level by performing RAS. One of the important parameters that affects the growth of nitrifying bacteria, is the sludge age. When the sludge age is low, nitrifying bacteria are washed out of the system, and also, grow very slowly (36).

The second aim was to perform the denitrification process in the effluent and reduce nitrate and transform it to nitrogen gas. Denitrification is an anoxic process performed by denitrifying bacteria (nitrifiers) during which oxidised forms of nitrogen, such as NO_3^- and NO_2^-, are changing to nitrogen gas (N_2) (37). The results of the denitrification process are presented in Table 5. According to the results of sample No. 24, it had the highest denitrification rate (85.89%), in which the highest SRT rate was observed. SRT is an important factor which affects not only the performance of nutrient removal and sludge characteristics but also helps improve the denitrification process, and thus, convert more ammonia to nitrate, and thus, provide a basis for denitrification (38). In sample No. 12, the nitrate concentration was 5.06 mg/L, but with increasing SRT and sludge return and providing the time required for denitrification, the nitrate concentration in the effluent decreased, so that in sample No. 24, the nitrate concentration in the effluent reached 1.32 mg/L. Since nitrate can act as the final electron receptor for nitrifying bacteria, this factor reduces aeration costs. On the other hand, it effectively reduces COD because 1 gram of nitrate is equivalent to 2.86 g of oxygen in COD removal (39). In the study of Elawwad et al, which was performed to optimize nitrogen removal and achieve the highest quality effluent, the percentages of nitrification and denitrification were 94% and 62.4%, respectively, by increasing the cell retention time from 2.7 to 7 days (25).

Conclusion

In this study, successful IAWQ #1 and Generic modelling were performed for Jey IPWWTP. This model was validated with the obtained data for 6 months, and the results showed that when the model was calibrated, the differences of calibrated model with measured data, were less than 10%. This verifies the good calibration of the model. The values of the biokinetic coefficients were found to be as follows: K = 2.7d$^-$, Y = 0.34 mg VSS/mg COD, Ks = 133.36 mg/L COD, Kd = 0.03 d$^-$, and μ_{max} = 0.93 d$^-$. Different DO, RAS, and SRT parameters were different for optimizing nitrogen removal. The results showed that the rate of nitrification and denitrification are 79.75% and 85.89%, respectively. These values in the SRT were observed for about 12 to 13 days. Finally, the output of the model with calibrated kinetic coefficients is acceptable and shows a good agreement and compatibility with the experimental results.

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Ethical issues

This study was approved by Isfahan University of Medical Sciences (Ethical Code: IR.MUI.RESEARCH.REC.1398.757).

Competing interests

All authors were actively involved in all stages of the samples collection and analysis as well as the manuscript preparation. In addition to plagiarism, forgery of data and sending and republishing this work were not observed and approved by the authors.

Authors' contributions

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