original article

Prediction of effluent COD concentration of UASB reactor using kinetic models of monod, contois, second-order Grau and modified stover-kincannon

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ABSTRACT

Aims: The aim of this study is predicting the effluent COD of UASB reactors with flowing mathematical models.

Materials and Methods: Weak industrial wastewater of the township, after passing screening unit, grit removal chamber and equalization tank, entered UASB reactor with volume of 144 m^3 (Length and width: 6 m; useful depth: 4 m). Analyses of laboratory parameters were done in accordance with water and wastewater standards.

Results: The reactor start-up started with hydraulic retention time of 14.4 d and organic loading rate of 0.04 Kg COD/m^3.d or 0.02 Kg BOD_5/m^3.d which in 200 days, hydraulic retention time reached to 0.9 d and organic loading rate reached to 0.85 Kg COD/m^3.d or 0.45 Kg BOD_5/m^3.d eventually, that the highest COD and BOD_5 removal efficiencies were observed up to 70% and 64%, respectively in the hydraulic retention time of 0.9 d. In the kinetic evaluation, the equations for effluent COD concentration prediction were obtained after calculating kinetic coefficients of Y, K_d, K, K_S and μ_{max} in the Monod model; β and μ_{max} in the Contois model; a, b and $K_{2(S)}$ in the second-order Grau model and K_B and U_{max} in the modified Stover-Kincannon model.

Conclusion: The effluent COD concentration of reactor is a function of influent COD concentration of reactor in the modified Stover-Kincannon and second-order Grau models that have highest correlation coefficients while, it is a function of reactor's solids retention time in Contois and Monod models.

Key words: Contois model, modified stover-kincannon model, monod model, second-order grau model, UASB Reactor

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INTRODUCTION

Anaerobic treatment process is a complex process including the degradation of organic compounds to intermediate

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products and finally methane and carbon dioxide.[1] Using anaerobic reactors dates back to over the last century and in recent decades, anaerobic reactors were developed rapidly,[2] including Upflow Anaerobic Sludge Blanket (UASB), Anaerobic Baffled Reactor, Anaerobic Baffled Reactor, Anaerobic Filter Reactor, Anaerobic Sequencing Batch Reactor and Anaerobic Hybrid Reactors.[3] UASB reactor was developed in 1970s by Lettinga *et al*. in Netherland.[4] Today, 87% of UASB reactors are used in wastewater treatment of food, fermentation, wood and paper industry. Other applications of this reactor are wastewater treatment of petrochemical, textile industries and waste landfill leachate. In addition, UASB reactor has been widely applied in tropical countries like India, Brazil and Colombia.[5] Considerable success of UASB reactors due to retention of high concentration of biological solids is due to the formation of granules in these reactors that leads into the accept of high organic loading rate and Solids Retention Time (SRT) in a low Hydraulic Retention Time (HRT) even at environment temperature. Although, it seems that there are some disadvantages in UASB reactors, like high operational cost and special patent design types related vendor.[6] Today, modeling methods are useful tools for description and prediction of the performance of anaerobic treatment systems.[7] There are various models among these models including Monod,[8] Contois,[9] First and Second-Order Grau,[10] Stover-Kincannon Modified,[11] Chen and Hashimoto,[12] Michaelis–Menten,[13] First-Order Substrate Removal Model[14] etc. for prediction of effluent substrate concentration of anaerobic treatment systems. The input data to all these models should be at steady-state condition of reactor performance. In these models, it is assumed that sludge granules are in spherical form in reactor and relative concentrations of acid-forming and methanogenic bacteria are equal in them.[15]

In the last decade, more than 75 active industrial townships in Iran are equipped with industrial wastewater treatment plants and in most of them including Kalat Mashhad, Salmanshahr, Bandarabas, Shahid Rajayi, Islam Abad Qarb, Faraman and Amirkabir of Kashan, there are UASB reactors with various designs. The aim of this study is predicting the effluent COD of UASB reactors with flowing mathematical models. In this study, for predicting the effluent substrate concentration of UASB reactor of Kashan's Amirkabir industrial township wastewater treatment plant, kinetic models of Monod, Contois, second-order Grau and modified Stover-Kincannon were used and the results of the current study were compared with the results of other studies.

MATERIAL AND METHODS

The specifications of UASB reactor of amirkabir industrial township wastewater treatment plant

UASB reactor in Amirkabir industrial township wastewater treatment plant with the volume of 144m^3 (length and width: 6 m, effective depth: 4m) like Clarigestor reactor that is the ancestor of UASB reactors, has no Gas-Liquid-Solid separator system, heating system and baffles to deflect the gas bubbles produced to gas cap. This reactor was designed based on maximum discharge of 350 m^3/d, maximum HRT of 9.87h, maximum up-flow velocity of 0.405m/h and acceptance of maximum organic loading rate of 1.82 Kg COD/m^3.d or 0.972 Kg COD/m^3.d.

Influent wastewater characteristics of UASB reactor

About 65% of wastewater produced in AmirKabir Industrial Township is of sanitary wastewater (human) and the remaining are industrial wastewater that after passing from screening unit, grit removal chamber, Grease removal unit and equalization tank, enter UASB reactor. It can be said that influent industrial wastewater of treatment plant was mostly of textile, carpet weaving, paper making and food industries (dairies and poultry)

Characteristics of influent wastewater of treatment plant UASB reactor during 200 consecutive days were shown in Table 1. As shown in the table, influent wastewater of this reactor is a weak industrial sewage. In this study, by measuring Nitrogen and phosphor concentrations of influent wastewater to reactor, it was defined that the amount of influent wastewater nitrogen and phosphor was more than the required amount for anaerobic treatment and there was no need to add these nutrients materials to reactor. Because in anaerobic treatment process, for wastewater with COD <3000 mg/L, ratio COD: N: P= 350:5:1 is used[16], while the average ratio in the study was 350:28.52:2.59.

Laboratory methods

COD, TSS, SO_4^{-2}, VSS, Ph tests were measured every other day, BOD_5, once in a week and nitrogen and phosphor of influent wastewater at the beginning of applying each new HRT. COD, BOD_5, SO_4^{-2}, TSS, VSS, total nitrogen, total phosphor and Orthophosphate parameters were performed in accordance with standard water and wastewater experiment methods.[17] To measure COD, Aqualytic photometer (AL-250) was used and to measure BOD_5, Aqualytic package (BOD-system Oxi-Direct) was provided and Aqualytic photometer (Muli-Direct) was used to measure SO_4^{-2}, total nitrogen, total phosphor and orthophosphate parameters. It can be said that all Aqualytic devices were made in Germany.

Table 1: Characteristics of influent wastewater to UASB reactor during 200 consecutive days

Parameter	Unit	Concentration *
COD	mg/L	±54.33 704.55
BOD_5	mg/L	±26.59 361.73
TSS	mg/L	±51.63 368.85
SO_4^{-2}	mg/L	±60.71 443.84
pH	-	7.57
Total nitrogen	mg N/L	57.42±8.03
Total phosphor	mg P/L	5.22±0.94
Orthophosphate	mg PO_4/L	17.05±1.36
Parameter		Value
COD: N: P		350: 28.52: 2.59

*The applied concentrations are as mean and standard deviation

In addition, to measure pH, portable pH meter (Jenway, 13145 made in England) was applied. It should be said that sampling method and experiments were double sampling and averaging of two samples.

RESULTS

UASB reactor set up and operation

Table 2 indicates a summary of UASB reactor set up and operation during 200 days. As shown in the table, reactor set up was started with HRT of 14.4 d and organic loading rate of 0.044 Kg COD/m^3.d or 0.023 Kg BOD_5/m^3.d. This loading rate is about 11 times smaller than good loading rate for UASB reactor set up (0.5 Kg COD/m^3.d)[18] and this was due to low discharge of influent wastewater of treatment plant in beginning days of launching. By increasing the discharge of influent wastewater in the following days, HRT reduction to 0.9d and increase of organic loading rate to 0.848 Kg COD/m^3.d or 0.445 Kg BOD_5/m^3.d were occurred at the end of 200 days. As shown in Figure 1 showing removal efficiencies of COD, BOD_5 based on HRT, the highest COD and BOD_5 removal efficiencies were observed 70.2% and 64.5%, respectively in HRT of 0.9 d. As is shown in this figure, by reduction of HRT, removal efficiencies of COD, BOD_5 are increased. Regarding weak industrial wastewater treatment, the reduction of HRT leads into better mass transfer and this is due to better hydraulic mixture and more contact of biomass and influent wastewater. Indeed, dilute wastewaters form low mass transfer force between biomass and food materials and the activity of biomass is reduced based on Monod equation.[19]

FORMULIZATION OF SYNTHETIC MODELS

Monod model

In a UASB reactor with no biomass recycle, changes rate in biomass and substrate concentration are shown by equations 1, 2. Total ratio of the existing biomass in reactor to disposed biomass per time is called cell residence time (solids) that is calculated using equation 3. Equation 4 shows the

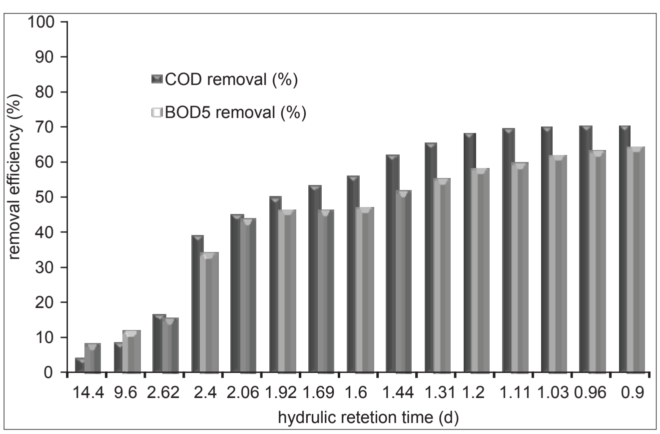

Figure 1: Removal efficiencies of COD and BOD_5 considering hydraulic retention time

Table 2: The summary of UASB reactor performance stages

Solids retention time	Food to micro-organisms ratio	Removal efficiency BOD_5	Removal efficiency COD	Organic loading rate		Influent BOD_5	Influent COD	Performance time	Hydraulic retention time
Day	Kg BOD_5/Kg VSS.d	%	%	Kg BOD_5/m^3.d	Kg COD/m^3.d	mg/L	mg/L	Day	Day
187.9±7.2	0.004±0.0003	5.4 1.9	2.8±1.1	0.023±0.009	0.044±0.001	333.3±13.6	619.7±21.4	21	14.40
172.2±2.4	0.006±0.0002	8.2±4.2	4.5±1.3	0.034±0.002	0.067±0.003	329.0±21.2	640.4±24.4	16	9.60
166.8±0.5	0.023±0.015	14.7±1.1	15.2±1.9	0.129±0.001	0.242±0.013	339.1±1.1	634.5±39.7	5	2.62
152.9±1.6	0.027±0.001	29.6±6.0	28.9±7.4	0.157±0.011	0.285±0.012	381.3±27.1	684.3±28.6	22	2.40
137.4±1.0	0.032±0.009	43.1±2.1	43.8±1.8	0.189±0.015	0.333±0.009	390.0±2.2	685.0±18.4	4	2.06
131.3±2.3	0.033±0.011	45.7±1.1	48.7±1.9	0.195±0.019	0.348±0.010	374.0±4.9	669.1±19.8	5	1.92
113.9±0.4	0.037±0.003	45.6±3.3	51.4±2.9	0.024±0.007	0.0411±0.012	379.0±2.3	679.0±19.8	4	1.69
102.7±1.8	0.033±0.019	46.6±1.1	55.5±0.8	0.201±0.008	0.411±0.007	322.0±5.9	658.0±2.8	4	1.60
89.1±6.1	0.036±0.008	48.7±1.8	60.4±0.9	0.240±0.005	0.480±0.008	346.0±6.8	691.3±12.2	19	1.44
69.9±3.9	0.040±0.004	54.8±4.4	65.2±0.8	0.279±0.014	0.558±0.009	365.0±5.2	730.0±13.1	7	1.31
58.9±2.4	0.042±0.003	55.9±1.6	67.0±1.5	0.296±0.006	0.613±0.019	355.0±6.9	735.2±23.4	15	1.20
47.1±0.8	0.045±002	59.5±0.6	69.1±0.6	0.332±0.002	0.700±0.013	367.5±2.1	775.1±13.9	11	1.11
41.4±1.3	0.049±0.017	61.3±3.2	69.9±0.1	0.366±0.013	0.763±0.001	377.0±7.1	785.0±1.4	3	1.03
36.5±1.8	0.054±0.005	62.6±0.4	70.1±0.2	0.409±0.007	0.810±0.003	393.0±7.2	780.3±1.3	9	0.96
31.8±0.7	0.057±0.006	63.7±0.8	69.8±0.4	0.445±0.002	0.848±0.012	400.3±1.5	763.5±11.2	18	0.90

relationship between specific growth rate and growth-limiting substrate concentration. If in steady state condition, influent biomass concentration to reactor is ignored, by substituting equations 3, 4 into equations 1, 2, equations 5, 6 are achieved. Then by arrangement and linearization of the equations, linear equation 7 is obtained and by plotting this equation, synthetic coefficients of Y, K_d are calculated.[13] In Monod model, except equation 2, the concentration changes rate of substrate is expressed by equation 8.[3] By equation 3 and 9 that shows substrate removal rate based on substrate mass balance in a biological reactor, linear equation 10 is obtained, by which synthetic coefficients of K, K_s are achieved. Then, by obtained K, Y coefficients and by equation 11, μ_{max} coefficient can be calculated.[3] Finally, by arranging equation 6, equation 12 is obtained that is used to predict effluent substrate concentration of reactor.[20]

$$\frac{d_x}{d_t} = \frac{Q.X_i}{V} - \frac{Q.X_u}{V} + \mu.X - K_d.X \quad (1)$$

$$-\frac{d_s}{d_t} = \frac{Q.S_i}{V} - \frac{Q.S_e}{V} - \frac{\mu.X}{Y} \quad (2)$$

$$\theta_c = \frac{V.X}{Q.X_e} \quad (3)$$

$$\mu = \frac{\mu_{max-S_e}}{K_s + S_e} \quad (4)$$

$$\mu = \frac{1}{\theta_c} + K_d \quad (5)$$

$$\frac{\mu_{max}.S_e}{K_s + S_e} = \frac{1}{\theta_c} + K_d \quad (6)$$

$$\frac{S_t - S_e}{\theta.X} = \frac{1}{Y}\frac{1}{\theta_c} + \frac{1}{Y}K_d \quad (7)$$

$$\frac{d_s}{d_t} = \frac{K.X.S_e}{K_s + s_e} \quad (8)$$

$$\frac{d_s}{d_t} = \frac{Q}{V}(S_i + S_e) \quad (9)$$

$$\frac{\theta.X}{(s_i - s_e)} = \frac{K_s}{K}\frac{1}{s_e} + \frac{1}{K} \quad (10)$$

$$\mu_{max} = K.Y \quad (11)$$

$$s_e = \frac{K_s(1+K_d.\theta_c)}{\theta_c(\mu_{max} - k_d) - 1} \quad (12)$$

Where, Q is inflow discharge to reactor (L/d), V is reactor volume (L), S_i is influent substrate concentration (g COD/L), S_e effluent substrate concentration (g COD/L), X is total biomass concentration in reactor (g VSS/L), X_i is influent biomass concentration (g VSS/L), X_e is effluent biomass concentration (g VSS/L), Y is yielding coefficient (g VSS/g COD), K_d is endogenous decay coefficient (d^{-1}), μ is specific growth rate (d-1), μ_{max} is maximum specific growth rate (d^{-1}), K_s is half-velocity constant (g COD/L), K is maximum substrate consumption rate per microorganism mass (g COD/g VSS.d), θ is hydraulic retention time (d) and θc is solids retention time (d).

Contois model

Like Monod model, in Contois model, to calculate synthetic coefficients of Y, K_d, linear equation 7 is used. In this model, the relationship between specific growth rate and growth-limiting substrate concentration is shown as equation 13. By substituting equation 5 into equaiton1, equation 14 is obtained and by arranging it, linear equation 15 is obtained, by which β and μ_{max} synthetic coefficients are achieved and finally equation 16 is achieve using it to predict effluent substrate concentration of reactor.

$$\mu = \frac{\mu_{max}.S_e}{\beta.X + S_e} \quad (13)$$

$$\frac{\mu_{max}.S_e}{\beta.X + S_e} = \frac{1}{\theta_c} + K_d \quad (14)$$

$$\frac{\theta_c}{1 + \theta_c.K_d} = \frac{\beta}{\mu_{max}}\frac{X}{S_e} + \frac{1}{\mu_{max}} \quad (15)$$

$$S_e = \frac{\beta.X(1 + K_d.\theta_c)}{\mu_{max}.\theta_c - (1 + K_d.\theta_c)} \quad (16)$$

In these equations, β is synthetic constant of Contois model (g COD/g VSS). Other parameters are already defined.

Second-order grau model

By linearization of equation 17 that shows substrate concentration changes rate in second-Order Grau model[10], linear equation 18 was obtained. If parameter α equals $Si/K_{2(S)}.X$ and parameter b is considered a constant number, linear equation 19 is obtained [21, 22] that by arranging it, equation 20 is used to predict effluent substrate concentration of reactor.

$$-\frac{d_s}{d_t} = k_{2(s)}.X.\left(\frac{S_e}{S_i}\right)^2 \quad (17)$$

$$\frac{S_i.\theta}{S_i - S_e} = \theta + \frac{S_i}{k_{2(s)}.X} \quad (18)$$

$$\frac{S_i.\theta}{S_i - S_e} = a + b\theta \quad (19)$$

$$S_e = S_i\left(1 - \frac{\theta}{a + b\theta}\right) \quad (20)$$

In these equations, $K_{2(S)}$ is constant of removal rate of second-order substrate in Grau model (d^{-1}), α parameter equals $Si/K_{2(S)}.X$ (g COD.d/g VSS) and parameter b is without unit. Other parameters are defined already.

Modified stover-kincannon model

Changes rate in substrate concentration in modified Stover-Kincannon model is shown in equation 21. By assuming equations 9 and 21 equal and arrangement, linearization and reversing, linear equation 22 is achieved, by which synthetic coefficients K_B, U_{max} are calculated.[23] Then, by this equation, equation 23 is obtained to predict the effluent substrate concentration of reactor.

$$\frac{d_s}{d_t} = \frac{U_{max}\left(\frac{Q.S_i}{V}\right)}{K_B + \left(\frac{Q.S_i}{V}\right)} \tag{21}$$

$$\frac{V}{Q(S_i - S_e)} = \frac{K_B}{U_{max}}\left(\frac{V}{QS_i}\right) + \frac{1}{U_{max}} \tag{22}$$

$$S_e = S_i - \frac{U_{max}.S_i}{K_B + \frac{QS_i}{V}} \tag{23}$$

In these equations, K_B is saturation constant (g COD/L.d) and U_{max} is maximum rate constant of substrate consumption (g COD/L.d). Other parameters are defined already.

APPLYING SYNTHETIC MODELS IN UASB REACTOR

Monod model

Considering linear equation 7, by plotting S_i-S_e/θ.X in front of 1/θ_C, Figure 2 is obtained, by which synthetic coefficients Y and K_d were 0.608 g VSS/g COD and 0.0164 d-1 with correlation coefficient (R2) of 0.928. Also, based on Figure 3 that is plotting θ.X/S_i-S_e in front of 1/Se by linear equation 10, synthetic coefficients K, K_s are 0.0137 g COD/g VSS.d and 0.189g COD/L with correlation coefficient of 0.904. Also, by product of synthetic coefficients K, Y based on equation 11, synthetic coefficient μ_{max} equal to 0.008d-1 was obtained. Then, by equation 12, equation 24 was obtained to predict effluent COD concentration of UASB reactor. In Table 3, the comparison of synthetic coefficients of Monod model in this study with some of the studies performed on UASB reactor is shown. As is shown in this table, there is a considerable difference in synthetic coefficients compared to other studies and this difference is due to reactor characteristics and the type of substrate or influent wastewater.[13]

$$S_e = \frac{0.189\,(1 + 0.0164\theta_c)}{-0.0084\theta_c - 1} \tag{24}$$

Contois model

Like Monod model, to calculate synthetic coefficients of Y, K_d in Contois model, linear equation 7 is used.[13] To calculate synthetic coefficients of β and μ_{max}, by linear equation 15, by plotting θ_C/1+θ_C.K_d in front of X/S_e, that is shown in Figure 4, synthetic coefficients of β and μ_{max} as 0.0212 g COD/g VSS and 0.0132 d-1 with correlation coefficient of 0.975 were achieved. Finally, for prediction of effluent COD concentration of UASB reactor, by equation 16, equation 25 was obtained. The comparison of synthetic coefficients of Contois model in this study with some of the studies on UASB is shown in Table 4. The resulting synthetic coefficients of β and μ_{max} were in line with the values achieved in Hu *et al*. studies [9]. In a study conducted by Martin *et al*. on olive mill wastewater treatment, it was found that Contois model was more suitable and practical compared to Monod model to predict substrate removal rate in UASB reactor.[25]

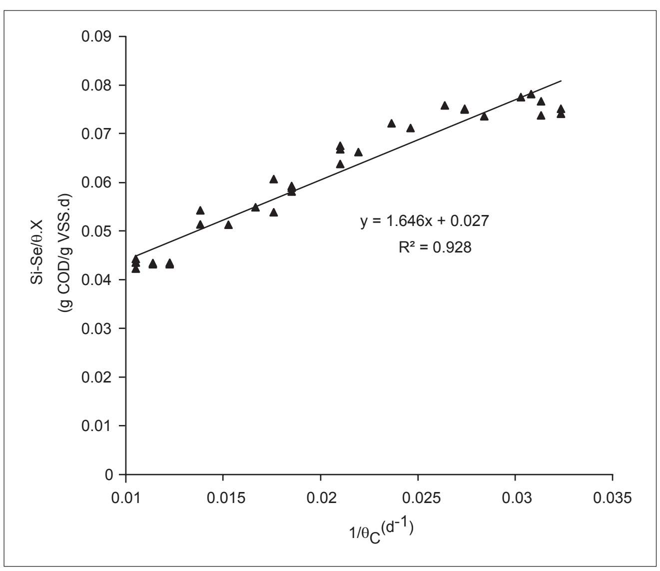

Figure 2: Diagram of determining synthetic coefficients of Y, K_d in Monod model

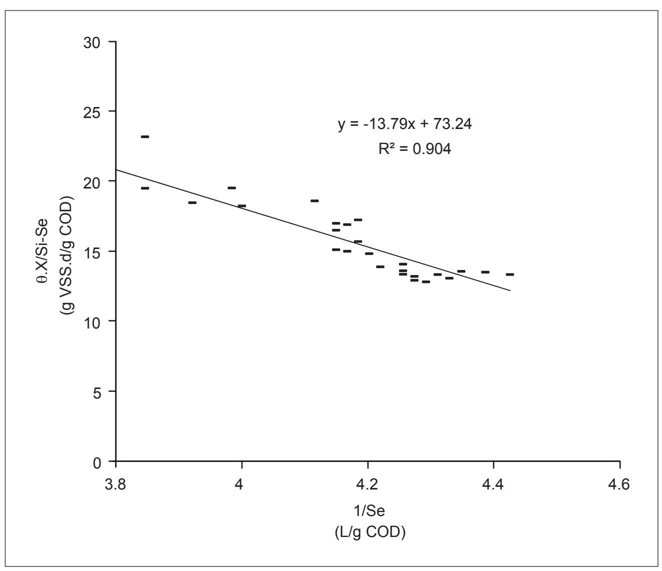

Figure 3: Diagram of determining synthetic coefficients of Y, K_s in Monod model

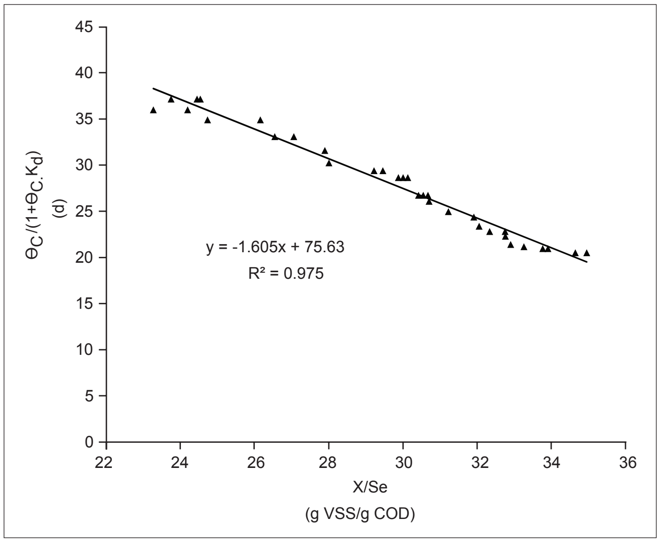

Figure 4: The diagram of determining synthetic coefficients of β and μ_{max} in Contois model

$$S_e = \frac{0.0212X(1+0.0164\theta_c)}{0.0084\theta_c(1+0.164\theta_c)} \quad (25)$$

Second-order grau model

Figure 5 is plot of $S_i.\theta/S_i$-S_e for θ by linear equation 19 and according to it, parameters α, b were achieved 0.583 g COD.d/g VSS and 2.023 with correlation coefficient of 0.981. Then, based on equation 20, equation 26 to predict effluent COD concentration of UASB reactor was used. But as parameter α is equal $S_i/K_{2(S)}$.X and in hydraulic retention time 0.9d that UASB reactor had the highest removal efficiencies of organic matter, average S_i and X was 0.763 g COD/L and 7.808 g VSS/L, synthetic coefficient $K_{2(S)}$ will be 0.168d-1. In Table 5, the comparison of the parameters and obtained synthetic coefficient in this study with other studies on UASB reactor is shown and the results were in line with the results of the studies conducted by Isik and Sponza.[13]

Table 3: The comparison of synthetic coefficients of Monod model with other studies in UASB

Parameter	Unit	Substrate			
		Industrial waste including 2 4 dichlorophenol	Synthetic waste including Sucrose	Textile waste (cotton production)	Weak industrial waste of Amirkabir industrial township
Influent COD	mg/L	3000	778.25 602.08	4214±241	54.33±704.55
Hydraulic retention time	h	20-2	8-5.33	100-6	345.6-21.6
Solids retention time	d	646-38	150.86 213.17	736-47	187.9-31.8
Y	g VSS/g COD	0.780 R^2=0.982	0.083 -	0.125 R^2=0.912	0.608 R^2=0.928
K_d	d^{-1}	0.093 R^2=0.982	0.006 -	0.0065 R^2=0.912	0.164 R^2=0.928
K	g COD/g VSS.d	0.954 R^2=0.943	0.699 -	0.84 R^2=0.967	0.0137 R^2=0.904
K_S	g COD/L	0.560 R^2=0.943	0.226 -	4 R^2=0.967	0.189 R^2=0.904
μ_{max}	d^{-1}	0.213	0.058	0.105	0.008
Reference		[24]	[20]	[13]	This study

Table 4: The comparison of synthetic coefficients of Contois model with other studies in UASB reactor

Parameter	Unit	Substrate		
		Diaries waste (ice cream production)	Textile waste (cotton production)	Weak industrial waste of Amirkabir industrial township
Influent COD	mg/L	5500	4214±241	704.55±54.33
Hydraulic retention time	h	178.8-71.76	100-6	345.6-21.6
Y	g VSS/g COD	0.0212 R^2=0.942	0.125 R^2=0.912	0.608 R^2=0.928
K_d	d^{-1}	0.0131 R^2=0.942	0.0065 R^2=0.912	0.0164 R^2=0.928
β	g COD/g VSS.d	0.0482 R^2=0.193	0.465 R^2=0.967	0.0212 R^2=0.975
μ_{max}	d^{-1}	0.0213 R^2=0.0913	0.105 R^2=0.967	0.0132 R^2=0.975
Reference		[9]	[13]	This study

Table 5: The comparison of synthetic coefficients of second-Order Grau model with other studies in UASB reactor

Parameter	Unit	Substrate			
		Municipal waste	Landfill leachate	Textile waste (cotton production)	Weak industrial waste of Amirkabir industrial township
Influent COD	mg/L	230-445	9000-25000	4214±241	54.33±704.55
Hydraulic retention time	h	0.25-1.00	2.7-2.8	100-6	345.6-21.6
α	g COD.d/g VSS	0.002 R2=0.932	0.013 R2=0.911	0.562 R2=0.950	0.583 R2=0.981
b	-	1.346 R2=0.932	1.066 R2=0.911	1.095 R2=0.950	2.023 R2=0.981
$K_{2(S)}$	d-1	0.954	38.5	0.337	0.168
Reference		[26]	[27]	[13]	This study

Table 6: The comparison of synthetic coefficients of modified stover-kincannon model with other studies

	Substrate				
	Paper waste	Melasse waste	Industrial waste including 2 4 dichlorophenol	Textile waste (cotton production)	Weak industrial waste of amirkabir industrial township
Anaerobic reactor	AF	AHR	UASB	UASB	UASB
Influent COD (mg/L)	2701±641	2000-15000	3000	4214±241	54.33±704.55
Hydraulic retention time (h)	12-23.7	6-24	20-2	100-6	345.6-21.6
K_B (g COD/L.d)	3.86	186.23	0.035	8.211	2.924
U_{max} (g COD/L.d)	0.80	83.3	0.008	7.501	1.502
R^2	0.997	0.987	0.991	0.995	0.990
Reference	[28]	[21]	[24]	[13]	This study

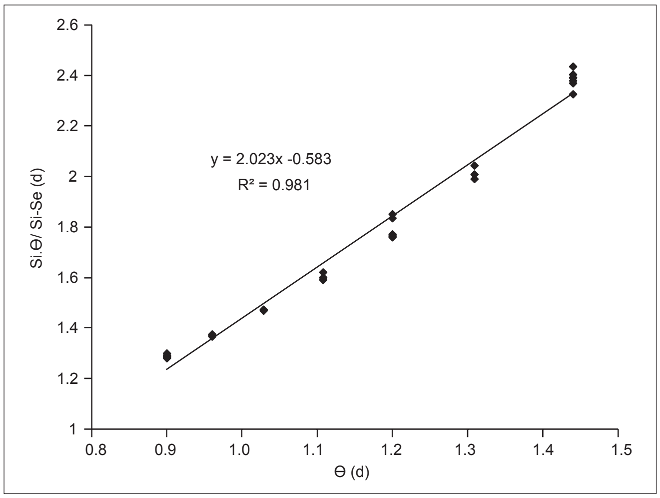

Figure 5: The diagram of determining α, b parameters in second-Order Grau model

$$S_e = S_i\left(1 - \frac{\theta}{0.583 + 2.023\theta}\right) \quad (26)$$

Modified stover-Kincannon model

Synthetic coefficients K_B and U_{max} were achieved based on linear equation 22 by plotting V/Q (S_i-S_e) for V/Q.Si in Figure 6 as 2.924 g COD/L.d and 1.502 g COD/L.d with correlation coefficient 0.990. Thus, based on equation 23, equation 27 can be obtained and it can be used to predict effluent COD concentration of UASB reactor. In Table 6, the comparison of the resulting synthetic coefficients in this study with other studies on some of anaerobic reactors is shown and the results were in line with the results of Yilmaz *et al*. studies.[28]

$$S_e = S_i - \frac{1.502S_i}{2.924 + \frac{QS_i}{V}} \quad (27)$$

DISCUSSION

In the current study, removal efficiency of organic materials in UASB reactor was increased with reduction of hydraulic retention time and it can be predicted that by increasing inflow discharge to UASB reactor in future days, more reduction of hydraulic retention time will increase confusion, reduction of half-velocity constant coefficient (K_S) and increasing efficiency of UASB reactor. By synthetic investigation of this reactor, the highest correlation coefficient was related to modified Stover-Kincannon model, Second-Order Grau model, Monod model, Contois and Monod, respectively. Also, the equations for predication of effluent COD coefficient of UASB reactor showed that in modified Stover-Kincannon and Second-Order Grau models, effluent COD concentration of reactor (S_e) was a function of influent COD concentration to reactor (S_i), while in Contois and Monod models, Se is a function of solids retention time (θ_C).

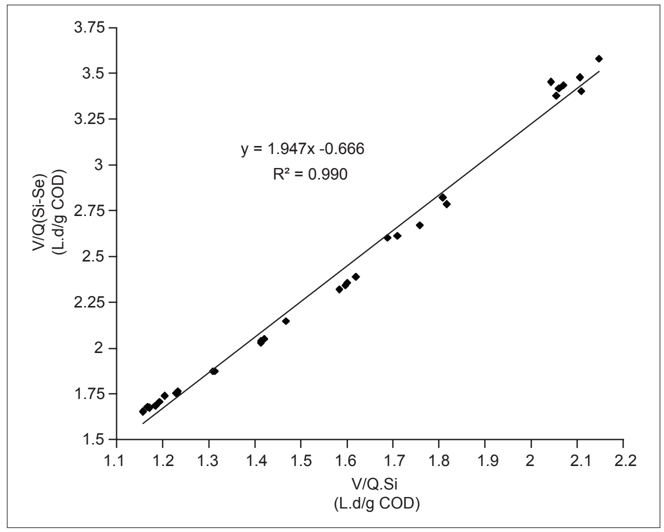

Figure 6: The diagram of determining synthetic coefficients K_B and U_{max} in Modified Stover-Kincannon model

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ABBREVIATIONS

Q: Inflow discharge to reactor (L/d)
V: Reactor volume (L)
S_i: Influent substrate concentration

S_e: Effluent substrate concentration
X: Total biomass concentration in reactor (g VSS/L)
X_i: Influent biomass concentration (g VSS/L)
X_e: Effluent biomass concentration (g VSS/L)
θ: Hydraulic retention time (d)
θ_C: Solids retention time (d)
Y: Yielding coefficient (g VSS/g COD)
K_d: Endogenous decay coefficient (d^{-1})
μ: Specific growth rate (d^{-1})
μ_{max}: Maximum specific growth rate (d^{-1})
K_s: Half-velocity constant (g COD/L)
K: Maximum substrate consumption rate in microorganism mass (g COD/g VSS.d)
β: Synthetic constant of Contois model (g COD/g VSS)
$K_{2(S)}$:Substrate removal rate of second-Order Grau model, Monod model
α: Equals $S_i/K_{2(S)}.X$ (g COD.d/g VSS)
b: Without unit
K_B: Saturation constant (g COD/L.d)
U_{max}: Maximum substrate consumption rate (g COD/L.d)

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