



The Study Effect of Fill and React Period Change on the Performance of the Sequencing Batch Reactor

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Abstract

The operation of the sequencing batch reactor (SBR) can be optimized by controlling the dissolved oxygen concentration, the dosage of external carbon, nitrification and denitrification, and the phase length of aeration (fills and react period). In this work, the analyses and tested with open loop identification the effect of fill and react period change on the performance of the SBR were studied. The process dynamic has been tested to determine the effect of Fill (t_f) and React (t_r) period changes on soluble substrate (S_s), soluble intermediate product (P_s), inert substrate (S_i), particulate organics concentration (X_s), active biomass concentration (X_a), inert biomass concentration (X_i), the total biomass concentration (X_{to}) and the effluent chemical oxygen demand (COD) concentration in the SBR. In all simulations the total Fill and React time were set at 6 h, with the Fill time varied at 0.5 h, 1 h, 1.5 h, 2 h, 2.5 h, 3 h, and the corresponding react time set at 5.5 h, 5 h, 4.5 h, 4 h, 3.5 h, and 3 h, respectively.

Keywords: fill time and reaction time, sequencing batch reactor, wastewater treatment

1. Introduction

Many models for suspended growth processes have been proposed in the wastewater treatment literature but the success of any mathematical model for a system depends mainly on its ability to predict accurately the system performance. Perhaps the most comprehensive was the task group model that detailed the most important events occurring in such systems (Henze *et al.*, 1987). The sequencing batch reactor (SBR) system was also modeled by Orhon *et al.* (1986), depending on Monod kinetics. Ibrahim (1990) developed a structured kinetic model of the SBR. Ibrahim and Abasaeed (1995) introduced a model which was structured upon four processes: substrate associated growth process, product associated growth process, hydrolysis process, and decay processes.

SBR are mainly used for treating wastewater in suspended-growth process. They are suitable for treating wastewater and reducing the effluent COD concentration. In the SBR, all treatments takes place in a single reactor with different phases separated in time. Wastewater is added, simultaneously treated during the fill-period, and then treated during the react-period followed by a settle-period, before finally withdrawn during the withdraw-period (Abasaeed, 1999).

In this paper, the model which was previously developed by Ibrahim and Abasaeed (1995) was used to study the sensitivity of the model predictions to changes in the values of the volumetric flow rate (Q), fill time (t_f) and reaction time (t_r). However, effective control and operation partially depend on understanding the process behavior and the ability to simulate and predict the process dynamics. Therefore, the modeling of activated sludge processes has received considerable attention lately.

2. Methodology

2.1 Sequencing Batch Reactor Process

In the SBR system, all treatment takes place in a single reactor with different phases separated in time. The cycle in a typical SBR is divided into five discrete time periods: Fill, React, Settle, Draw, and Idle. Illustration of SBR process is shown in Fig. 1. The stoichiometric, kinetic parameters and feed conditions used in model simulation are listed in Table 1. The data used in this study were obtained from an instrumented bench scale SBR (Orhon *et al.*, 1986).

In the experimental setups (Orhon *et al.*, 1986), the timer was programmed to allow air into the reactor only during fill and react times, at a rate that would sustain mixed

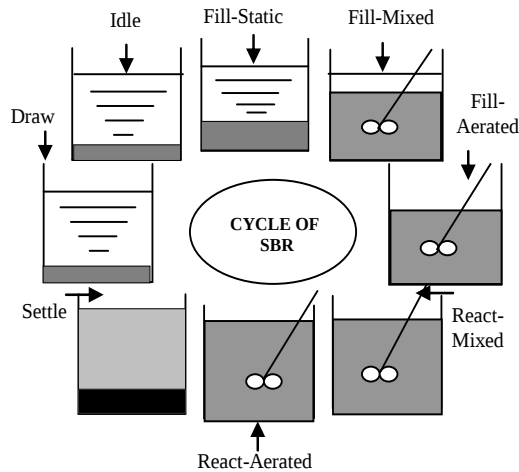


Figure 1. Illustration of a SBR tank during one complete cycle (Orhon, 1986).

liquor dissolved oxygen concentration greater than 2.0 mg/l. Two additional timers controlled the substrate influent and effluent pumps, respectively. The pumps were so adjusted to have a total volume of 6 liter at the end of fill time, and a settling volume of 1.8 liter, so that the incremental substrate flow treated in each cycle was 4.2 liter, value identical to those used by Dennis and Irvine (1979) for comparative evaluation. The system was operated on a four cycles / day basis, so that single cycle duration was 6h, and the total time devoted to fill and react mode was 4h. One hour for settle time and half an hour each for draw and idle times accounted for the remaining 2h.

2.2 Mathematical Model

This model is based on the work of Ibrahim and Abasaeed (1995) for complete aerobic systems. The model does not include the nitrification and denitrification processes.

The model presented here is, therefore, structured upon four processes. The processes are substrate-associated growth process, product-associated growth process, hydrolysis process, and decay process.

Three soluble components and three particulate materials are considered in the model. The proposed model is presented below in matrix format.

In the proposed model, all biomass (X_{sr} , X_{ar} and X_i) concentrations are based on total volume. The two substrates and the intermediate product (S_{sr} , P_{sr} and S_i) concentrations are based on bulk liquid volume.

The relationship between the bulk volume (V_b) and the total volume (V_t) is given by the following equation.

$$\frac{dV_b}{dt} = Q\left(1 - \frac{X_{to}}{\rho_w}\right) - \frac{V_t}{\rho_w} \frac{dX_{to}}{dt} \quad (1)$$

The mass balance equations for various components are as follows.

Table 1. Process kinetics and stoichiometry (Ibrahim and Abasaeed, 1995).

Component i Process j	C_1 S_s	C_2 S_i	C_3 P_s	C_4 X_5	C_5 X_a	C_6 X_i	Process rate expression, R_j
R1-soluble substrate growth depending process	$-\frac{1}{y_k}$		$\frac{y_p}{y_h}$		1		$\frac{\mu_m S}{S + K_s} X_a$
R2-soluble product growth depending process			$-\frac{1}{y_h}$		1		$\frac{\mu_m P_s}{P_s + K_p} X_a$
R3-hydrolysis of particulate organics		α	$1-\alpha$	-1			$\frac{K_h(X_s/X_a)}{(X_s/X_a) + K_x} X_a$
R4-death of heterotrophs				$1-f_p$	-1	f_p	$B_h X_a$
Stoichiometric parameter f_{pr} y_{hr} y_{pr} α	Kinetic parameter, k_{hr} k_{pr} k_{sr} k_{xr} B_{hr} μ_m α_1						

$$\mu_m = \mu_m \frac{\alpha_1}{\alpha_1 + P_s}; S = S_s - S^*$$

$$\frac{dX_s}{dt} = A_1(X_{sf} - X_s) + (1 - f_p)B_h X_a - \frac{K_h(X_s/X_a)}{(X_s/X_a) + K_x} X_a \quad (2)$$

$$\frac{dX_a}{dt} = A_1(X_{af} - X_a) + \frac{\mu_m S}{S + K_s} X_a + \frac{\mu_m P_s}{P_s + K_p} X_a - B_h X_a \quad (3)$$

$$\frac{dX_i}{dt} = A_1(X_{if} - X_i) + f_p B_h X_a \quad (4)$$

$$\frac{dS_s}{dt} = A_5 S_{sf} - \frac{\mu_m S}{S + K_s} X_a - \beta S_s \quad (5)$$

$$\frac{dP_s}{dt} = A_5 S_{sf} + \frac{1}{A_2} \left(\frac{y_p}{y_h} \frac{\mu_m S}{S + K_s} X_a - \frac{P_s + K_p}{y_h} X_a + (1 - \alpha) \frac{K_h(X_s/X_a)}{(X_s/X_a) + K_x} X_a \right) - \beta P_s \quad (6)$$

$$\frac{dS_i}{dt} = A_5 S_{if} + \frac{\alpha}{A_2} \frac{K_h(X_s/X_a)}{(X_s/X_a) + K_x} X_a - \beta S_i \quad (7)$$

The total Biomass (X_{to}) is the summation of the three concentration ($X_{to} = X_s + X_a + X_i$) and the total Chemical Oxygen Demand (COD).

$$COD = S_s + P_s + S_i \quad (8)$$

$$\text{where } \beta = \left(\frac{dV_b}{dt} \right) \frac{1}{(V_t A_2)}$$

$$A_1 = \frac{Q}{V_t}$$

$$A_2 = 1 - \frac{X_{to}}{\rho_w}$$

Table 2. Kinetic and stoichiometric parameters (Orhon, 1986; Ibrahim and Abasaeed, 1995).

Parameter		Value	Unit
Maximum specific hydrolysis rate:	K_h	0.0916	h^{-1}
Half saturation coefficient for hydrolysis:	K_x	0.15	mgCOD/l
Half saturation constants for substrate growth:	K_s	20.00	mgCOD/l
Half saturation constants for product growth:	K_p	500	mgCOD/l
Death rate coefficient:	B_h	0.052	h^{-1}
Fraction of X_a converted to X_i :	f_p	0.08	dimensionless
Wet density of biomass:	ρ_w	100.000	mg/l
Intermediate product COD formed/cell COD formed:	y_p	0.25	dimensionless
Fraction of X_s hydrolyses to S_i :	α	0.025	dimensionless
Inhibition constant in switching function:	α_1	60	mgCOD/l
Specific growth rates:	μ_m	0.45	h^{-1}
Residual glucose concentration:	S^*	5	mgCOD/l
Cell COD formed/substrate COD consumed:	y_h	0.5	dimensionless
Volumetric flow rate:	Q	3	l/h
Total volume:	V	6	l

$$A_3 = 10 - \frac{X_{tof}}{\rho_w}$$

$$A_4 = \frac{A_3}{A_2}$$

$$A_5 = AA_4$$

The above equations are applicable to reaction period also with modifications. The model given by Equations (1) to (7) is for fill time period in the process. During reaction time in batch SBR process, the volumetric flow rate is nil, the V_t is constant at V_0 , and the initial conditions are different as compared with fill time. Values of kinetic parameters and feed conditions used in model simulation are listed in Table 2 and Table 3.

3. Results and Discussion

3.1 Effect of Fill and React Period Changes on S_{sr} , P_{sr} , S_i and COD profiles

Figure 2 shows the effect of fill time varied at 0.5 h, 1 h, 1.5 h, 2 h, 2.5 h, 3 h, and the corresponding react time set at 5.5 h, 5 h, 4.5 h, 4 h, 3.5 h, 3 h on S_{sr} , P_{sr} , S_i and COD profiles and shows the results of the S_{sr} , P_{sr} , S_i , and COD . It is clear from the figure that the concentration of the soluble substrate (S_s), increased slowly during the fill-period but it fell sharply at the end of it. The figure also reveals that during the fill-period the total rate of formation of the soluble intermediate (from soluble substrate and due to hydrolysis of stored biomass) exceeded its rate of depletion (due to reaction and also because of dilution). The rate of formation of P_s was highest at the early stages of the fill-period and decreased towards the end of the fill-period. The concentration of the intermediate continued to increase slightly till the end of the react-period. The concentration of the inert substrate, S_i ,

increased with time as it was being continuously formed.

The total COD is the summation of the three concentrations (S_{sr} , P_{sr} , S_i), and therefore the shape of the COD curve is indicative of the contributions of the various components, e.g. during the fill-period, the intermediate product and the inert substrate were primarily responsible for the shape of the COD curve.

The COD profile increased during the fill period due to total rate of formation of soluble intermediate exceeding its rate of depletion and dilution (because of filling wastewater), and decreased rapidly in the early part of the react period. After this, it continuously decreased slightly until the end of the react-period.

From Figure 2(A), it can be noted that the reaction period can be terminated at 1h because completed biodegradation is achieved by then. From the Figure 2(B), it can be seen that the completed biodegradation is achieved at 1.5 h. The results for the other periods can be seen in Figure 2(C) to 2(F) and shown in Table 4.

3.2 Effect of Fill and React Period Changes on X_{sr} , X_{ar} , X_i and X_{t0} Profiles

Figure 3 shows the effect of fill time varied at 0.5 h, 1 h, 1.5 h, 2 h, 2.5 h, 3 h, and the corresponding react time set at 5.5 h, 5 h, 4.5 h, 4 h, 3.5 h, 3 h on X_{sr} , X_{ar} , X_i and X_{t0} profiles and shows the results for the X_{sr} , X_{ar} , X_i , X_{t0} . It should be noted that the total biomass concentration is the summation of the three-biomass constituents ($X_s + X_a + X_i$). During the fill-period and because of dilution (and to a lesser extend due to decay process) the concentration of active biomass decreased sharply compared with its decrease after the fill-period (which is due to the decay process alone).

Table 3. Influent characteristics and SBR initial condition (Orhon, 1986; Ibrahim and Abasaeed, 1995).

Parameter		Influent	Initial condition	Unit
Soluble product concentration:	P_s	0	25	mgCOD/l
Soluble inert substrate concentration:	S_i	50	50	mgCOD/l
Soluble substrate concentration:	S_s	1,500	10	mgCOD/l
Chemical oxygen demand concentration:	COD	1,550	85	mgCOD/l
Active biomass concentration:	X_a	0	8,350	mgCOD/l
Inert particulate organics concentration:	X_i	10	1,500	mgCOD/l

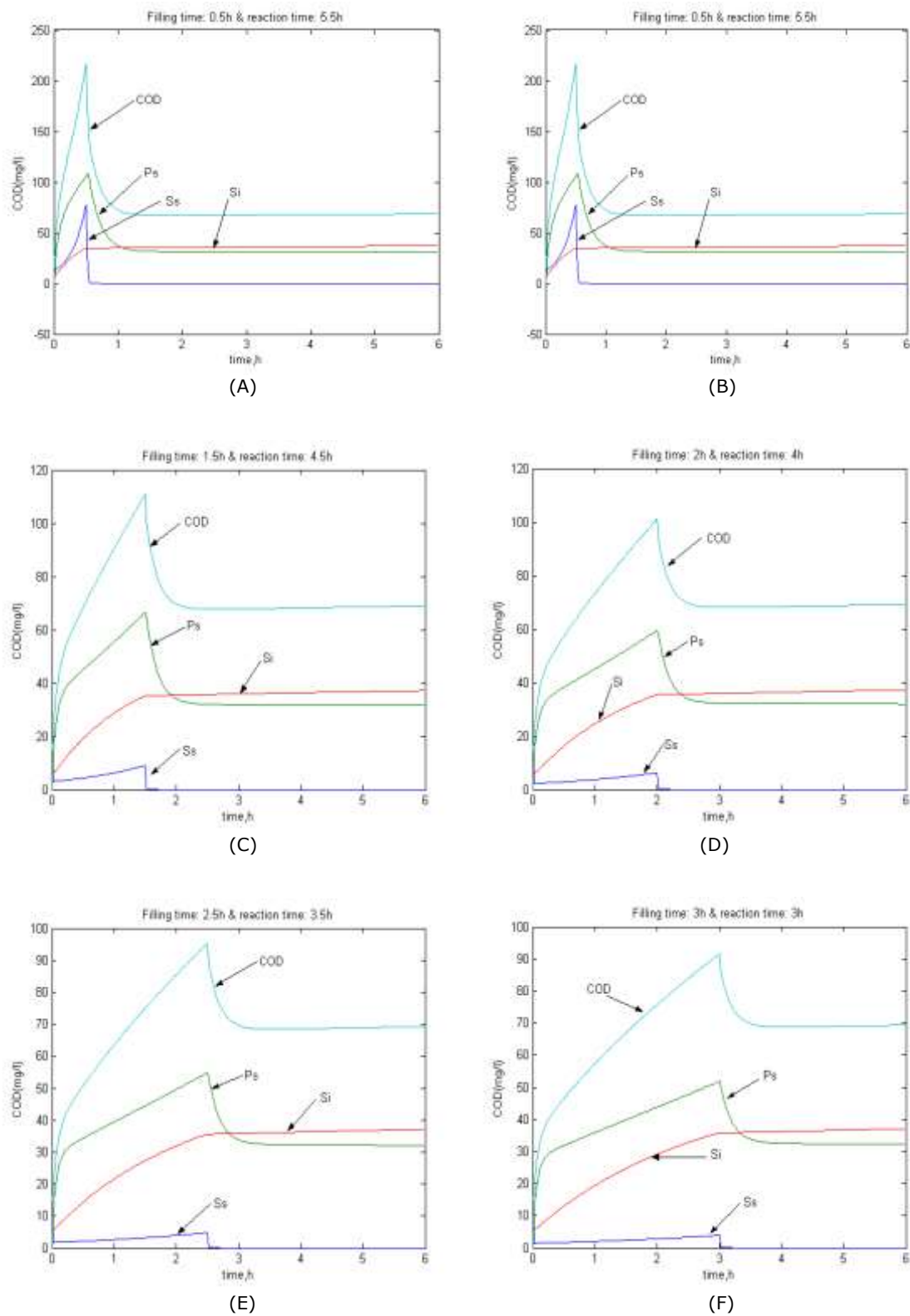


Figure 2. The effect of fill and react period changes with the variation of filling and reaction time on of S_s , P_s , S_i , and COD.

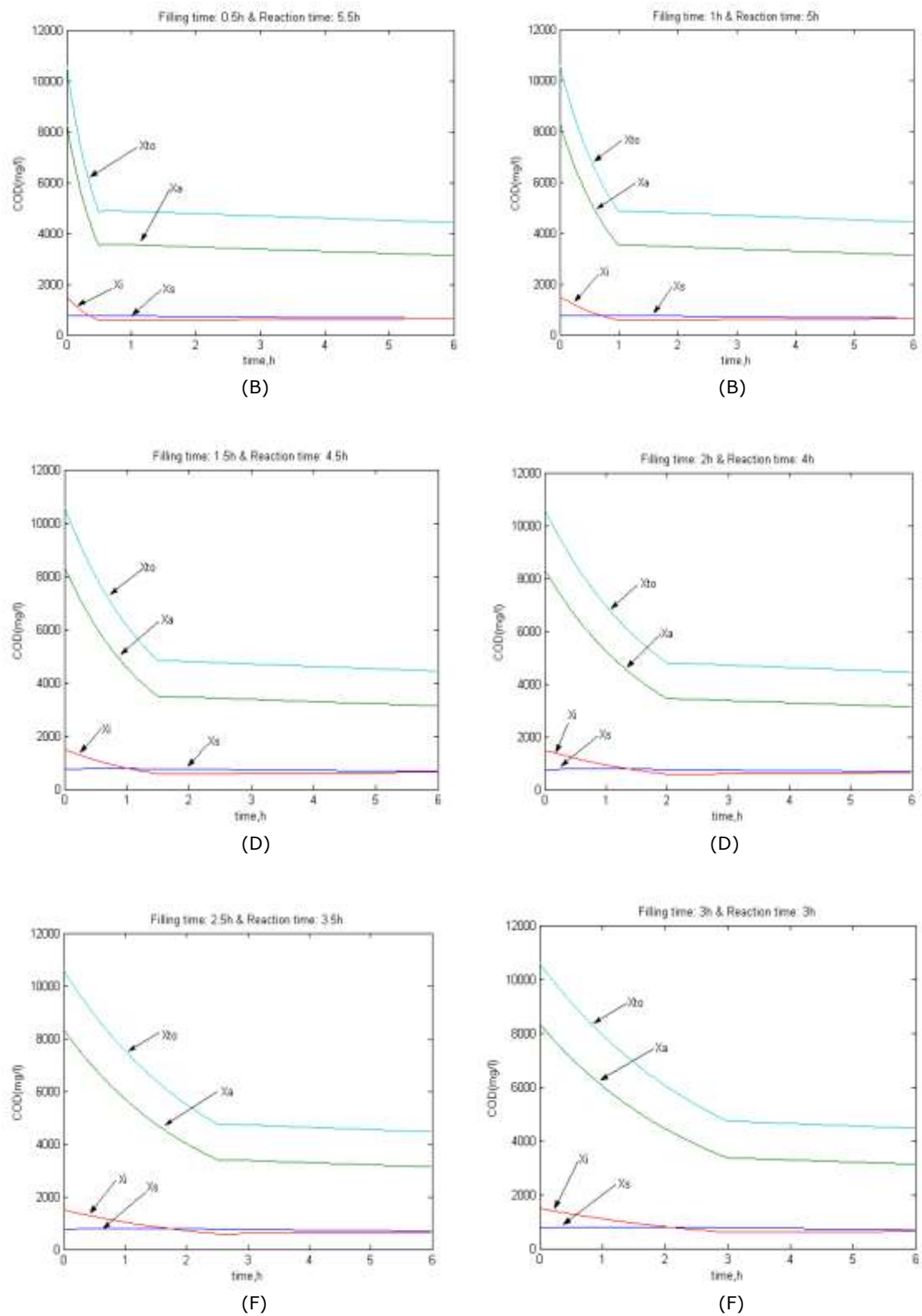
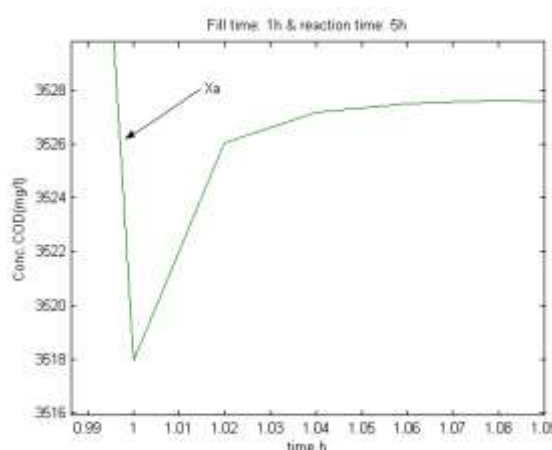


Figure 3. The effect of fill and react period changes with the variation of filling and reaction time on of X_s , X_a , X_i , and X_{t0} .

Table 4. Effect of Volumetric (Q), fill time (t_f), and reaction time (t_r) on the effluent COD , P_s , S_i , S_s , X_{a0} , X_{i0} , and X_s in SBR.

(Q) (l/h)	t_f (h)	t_r (h)	t_{opt} (h)	COD (mg/l)	P_s (mg/l)	S_i (mg/l)	S_s (mg/l)	X_a (mg/l)	X_i (mg/l)	X_s (mg/l)
12	0.5	5.5	1	68.69	31.38	37.31	0	3,129	641.7	653.21
6	1	5	1.5	68.83	31.56	37.27	0	3,130	641.0	661.56
4	1.5	4.5	2	68.97	31.74	37.23	0	3,131	640.3	670.07
3	2	4	2.5	69.11	31.92	37.19	0	3,131	639.6	678.76
2.4	2.5	3.5	3	69.25	32.10	37.14	0	3,132	638.9	687.65
2	3	3	3.5	69.39	32.29	37.10	0	3,132	638.2	696.74
1.5	4	2	4.5	69.68	32.66	37.02	0	3,132	636.7	715.54
1.2	5	1	5.5	70.14	33.16	36.99	0	3,123	632.8	735.03

The concentration of the inert biomass (X_i) decreased during the fill-period (dilution effects were more pronounced than its rate of formation from the active biomass) and it increased after the end of the fill-period due to its formation from X_a (Figure 4).

**Figure 4.** The effect of fill time of 1 h and react time of 5 h on active biomass (X_a).

4. Conclusion

The analyses and tested with open loop identification to study the effect of fill time (t_f) with the varied at 0.5 h, 1 h, 1.5 h, 2 h, 2.5 h, 3 h and reaction time (t_r) set at 5.5 h, 5 h, 4.5 h, 4 h, 3.5 h, and 3 h, respectively on SBR to the effluent of COD concentration, soluble intermediate product (P_s), inert substrate (S_i), soluble substrate (S_s), active biomass (X_a), inert biomass (X_i) and stored biomass (X_s) concentration were studied. From these results, it can be seen that the optimum condition is got at a value of volumetric 12 l/h, fill time at 0.5 h and reaction time at 5.5 h. An adequate model

enhances the understanding of biological phenomena and it can be a basis for better process design, control, and optimization of the reactor system.

Nomenclature

- B_h = death rate coefficient (h^{-1})
 f_p = fraction of X_a converted to X_i
 K_h = maximum specific hydrolysis rate (h^{-1})
 K_p = half saturation constants for product growth (mg COD/l)
 K_x = half saturation coefficient for hydrolysis (mg COD/l)
 K_s = half saturation constants for substrate growth (mg COD/l)
 P_s = soluble product concentration (mg COD/l)
 Q = volumetric flow rate (l/h)
 S^* = residual glucose concentration (mg COD/l)
 S_i = soluble inert substrate concentration (mg COD/l)
 S_s = soluble substrate concentration (mg COD/l)
 V_b = liquid phase volume (l)
 V_t = total volume (l)
 X_a = active biomass concentration (mg COD/l)
 X_i = inert particulate organics concentration (mg COD/l)
 X_s = particulate organics concentration (mg COD/l)
 X_{to} = total biomass concentration [mg(organic COD)/l]
 Y_p = gm intermediate product COD formed/gm cell COD formed.

Greeks Letters

- α = fraction of X_s hydrolyses to S_i
 α_1 = inhibition constant in switching function (mg COD/l)

μ_m = specific growth rates (h^{-1})

ρ_w = wet density of biomass (mg/l)

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