A comparison study between sequencing batch reactor and continuous activated sludge system

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The Sequencing Batch Reactor (SBR) is a specific fill and draw version of the activated sludge process. The SBR is characterized by a series of process phases: Fill; React; Settle; Draw and Idle, each lasting for a defined period of time. If no wastewater is available, the SBR can rest in an idle phase. The simplicity of operation, the high COD and SS removal efficiency and the small space requirement make the SBR an attractive treatment option. Particularly in places where land supply is limited and expensive. This study aims to investigate the performance and treatment capability of SBR system under shock organic and hydraulic loads. A comparison study between SBR and activated sludge process has also conducted using pilot plant units. The results of the pilot plant units showed that under steady state conditions, the SBR performed more efficiently than the activated sludge system considering COD removal and SVI. Under organic shock loads, for activated sludge the define $\mu^\wedge_H$ decreased to 1.95 d^{-1} at define F/M ratio = 0.96 d^{-1}. On the other hand, for SBR the $\mu^\wedge_H$ increased to 3.46 d^{-1} at define F/M ratio = 1.0 d^{-1}. These results confirmed that SBR has more capability than activated sludge to handle shock organic loads. This study also showed that increasing the hydraulic shock loading results in decreasing COD removal efficiency.

تعتبر المفاعلات البيولوجية التتابعية أحد تعديلات الحمأة والفارق الرئيسى بين طريقة المعالجة بالمفاعلات البيولوجية التتابعية وطريقة الحمأة المنشطة التقليدية في طريقة التغذية التي يعتمد عليها كل منهما. ففي طريقة الحمأة المنشطة التقليدية تكون التغذية مستمرة بينما في طريقة المعالجة بالمفاعلات البيولوجية التتابعية تكون التغذية بنظام الدفعات بمعنى أن يتم تغذية المفاعل بدفعة من المخلفات السائلة المطلوب معالجتها ثم تتعاقب مراحل المعالجة عليها في نفس المفاعل من عملية التهوية ثم الترسيب ثم تصريف المياه المعالجة و الحمأة الزائدة ثم يتم تغذية المفاعل بدفعة أخرى و هكذا. و يسمى نظام التغذية بهذا الأسلوب بنظام المليء و التفريغ . و يهدف هذا البحث إلى دراسة طريقة المعالجة بالمفاعلات،البيولوجية التتابعية تحت تأثير الأحمال العضوية و الهيدروليكية المفاجئة و كذلك مقارنة هذه المفاعلات مع طريقة الحمأة المنشطة. و لذلك فقط تم إنشاء و تشغيل وحدتين للتجارب الأولى بطريقة الحمأة المنشطة و الثانية بطريقة المفاعلات البيولوجية التتابعية و ذلك بمعمل كلية الهندسة جامعة الإسكندرية . و قد أكدت النتائج التي تم الحصول عليهما من وحدتي التجارب علي أن كفاءة المفاعلات البيولوجية التتابعية أعلي من الحمأة المنشطة في إزالة ال COD في ظروف التشغيل الثابتة (Steady State). و في حالة زيادة الأحمال العضوية أكدت النتائج أيضا أن المفاعلات البيولوجية التتابعية عندها قدرة اعلي من الحمأة المنشطة في العمل بكفاءة تحت تأثير هذه الأحمال. كما تبين أن زيادة الحمل الهيدروليكي تسبب في انخفاض كفاءة إزالة ال (COD) في المفاعلات البيولوجية التتابعية.

Keywords: Activated sludge, Sequencing batch reactor, Biological treatment, Organic shock loads, Hydraulic shock load.

1. Introduction

The activated sludge process has become the most widely used unit process for the treatment of both domestic and industrial wastewater. Sequencing batch reactor (SBR) became popular in the last 20 years for small installations specially where the available space is limited or specific treatment goals are required [1].

Historically activated sludge technology commenced with the investigation of fill and draw reactors. The first activated sludge plant, which was built at Salford, UK [2], was a sequencing batch reactor (SBR) wherein the sewage was introduced batch wise into the reactor for a specified period of time. The contents of the reactor were then aerated for a predetermined period, following which the sludge flocs were allowed to settle and supernatant liquor was decanted. Good effluent quality was achieved, but operation of the SBR was difficult at that time for various technical reasons. The plant was therefore later converted into a continuos flow process.

The sequencing batch reactor SBR is a fill-and-draw type reactor system involving a single complete mix reactor in which all steps of the activated sludge process occur. Mixed liquor remains in the reactor during all cycles. Thereby eliminating the need for separate secondary sedimentation tanks. In contrast to continuous flow systems, the sequencing of processes in a SBR is time rather than space oriented, metabolic reactions and solid / liquid separation takes place at different times in the same reactor.

The SBR system has five basic operating modes; each of the periods is named according to its primary function. The periods are Fill, React, Settle, Draw and Idle in time sequence [3]. The react phase includes aerobic process only or anoxic and aerobic process. The react phase includes only the aerated process if the treatment objective is only to remove organic carbon and suspended solids. But if the treatment objective is to remove nutrient, organic carbon and suspended solids the react phase includes aerated and mixing process.

This study aims to investigate the performance and treatment capability of SBR system under shock organic and hydraulic loads. A comparison study between SBR and activated sludge process has also conducted using pilot plant units.

2. Materials and methods

The experimental work of this study was subdivided into two phases. The first phase (phase I) was carried out on a pilot plant operated as a continuous flow activated sludge. The second phase (phase II) was carried out on a pilot plant operated as a SBR. In each phase of operation the same synthetic sewage was used as a feed influent.

2.1. Pilot plant

The two pilot plants which used in this study were constructed and operated at the laboratory of the Sanitary Engineering Department, Faculty of Engineering, Alexandria University. One was operated as an activated sludge, the other was operated as a sequencing batch reactor.

2.1.1. Activated sludge pilot plant

As shown in fig. 1, the system consists of two basins. The first is a rectangular aeration tank (length = 44.5 cm, width = 39.5 cm, depth of water = 17 cm, volume of aeration tank = 30 litter), the second is a square final settler (length = 40 cm, width = 40 cm, depth of water = 20 cm, volume of settler = 32 litter).

The pilot plant was provided with two peristaltic pumps designed for research purposes (Master Flex -U.S.A, Cole - Parmer Instrument Company). The first pump was used to feed the synthetic sewage into the aeration tank, the second was used to return sludge from the final settling tank to the aeration tank. The aeration tank was provided with two air diffusers in two diagonal corners. The air diffusers were connected to the air compressor with plastic tubes.

The operation conditions of the system were as follows :

- The influent flow rate Q_{in} = 40 l /d which results in a hydraulic retention time in the aeration tank of 9 hours.
- The return sludge flow rate Q_R = 40 l /d (100 % of Q_{in}).
- The waste sludge from the mixed liquor suspended solids = 10 % of volume of the aeration tank per day = 3 l/ d. This results in sludge age θ_c = 10 days.
- The dissolved oxygen in the aeration tank was maintained within (1 - 3 mg/ l).

2.1.2. SBR pilot plant.

The SBR pilot plant consists of one rectangular basin which was operated as both aeration tank and final settler in the time sequence [4]. The SBR reactor dimensions were: length = 44 cm, width = 39 cm, depth of water = 14 cm, and volume of reactor = 24 liter.

As shown in fig. 2, the pilot plant was provided with two peristaltic pumps designed for research purposes (Master Flex -U.S.A, Cole - Parmer Instrument Company).

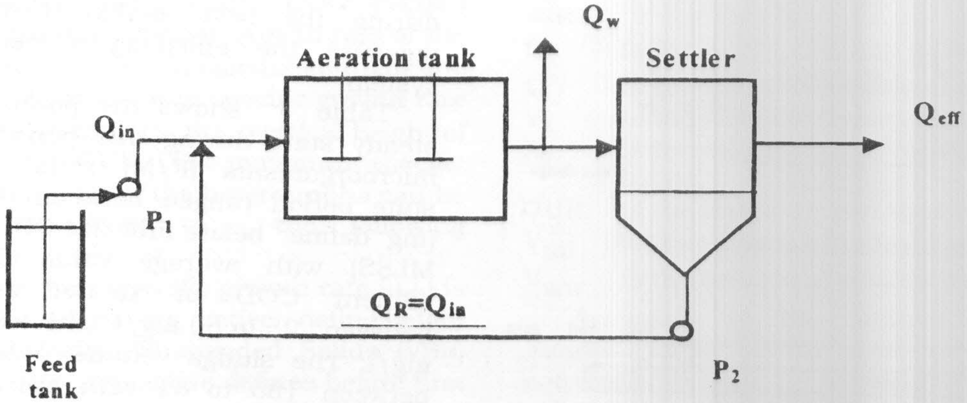

Fig. 1. Activated sludge process.

The first pump was used as a feeding pump in the fill phase of operation. The other one was used to draw treated water at the end of the operation cycle. Air was delivered from an air compressor. The SBR tank was provided with two air diffusers in two diagonal corners. The air diffusers were connected to the air compressor with plastic tubes.

Automatic programmable timer (XT Table Top Timer, Chron Trol Corporation, USA) was also used in order to control cycles of operation. The timer was provided with four controlled circuits. Three of these circuits were required in the cycle operation. The first circuit was connected to the feed pump, the second circuit was connected to the air compressor and the third circuit was connected to the draw pump.

Figure 3 shows the operation cycle of SBR. The operation conditions of the system were as follows:

- Cycle length = 6 hours (4 cycles/day).
- The influent flow rate Q_{in} = 12 l/cycle = 48 l/day.
- The volume of mixed liquor before fill = 12 l.

$$V_E = \frac{\text{volume of feeding wastewaer}}{\text{total volume of the reactor}} = 50\%$$

- Total volume of the reactor = 24 litter.
- Volume exchange = V_E,

Where;

- Hydraulic retention time = 12 hr (Aeration 8 hr & Settling 4 hr).
- The waste sludge from mixed liquor suspended solids = 10 % of volume of the reactor per day = 2.4 l/d to maintain the sludge age θ_C = 10 days.
- The effluent flow rate Q_{eff} = 11.4 l/cycle.
- The dissolved oxygen in the reactor during the react (aerated).
- phase was maintained within (1-3 mg/l).

2.2. Synthetic sewage

Synthetic sewage was used in this study as influent wastewater for both activated sludge and sequencing batch reactor pilot plants. The synthetic sewage was prepared according to Battistoni et al. [5].

The stock solution was prepared first as follows: Dissolve 40 g/ l of glucose; 11.65 g/ l of Na_3PO_4. 12 H_2O; and 8.8 g/ l of $(NH_4)_2SO_4$ in one litter tap water. Synthetic sewage can be prepared by diluting the stock solution with tap water (1-100). The synthetic sewage was daily prepared fresh. The diluted solution has average defined before first use. COD concentration equals to 500 mg/l. All experimental measurements were determined in accordance with the standards methods for the examination of water and wastewater [6].

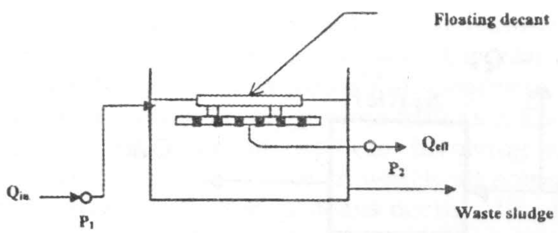

Fig. 2. Sequencing batch reactor SBR.

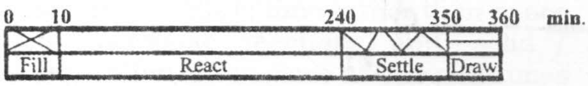

Fig. 3. Operation cycle of SBR

2.3. Start-up procedure

2.3.1. Start-up of the activated sludge pilot plant

Initially the activated sludge system was seeded with sludge wasted from Kafer-El-Dwar wastewater treatment plant (activated sludge treatment plant). The sludge was collected from the return sludge pump. The start up period was 10 days. After that period the sludge was wasted from the aeration tank according to the operation conditions to achieve the desired sludge age θ_c.

2.3.2. Start-up of the sequencing batch reactor pilot plant

Initially the sequencing batch reactor was seeded with sludge wasted from Kafer-El-Dwar wastewater treatment plant (activated sludge treatment plant). The start up period for the SBR system was 7 days. After the start up period sludge were gradually wasted from the sequencing batch reactor to achieve the desired sludge age θ_C [7].

3. Results and discussion

3.1. Continuous flow activated sludge reactor (phase I)

3.1.1. Steady state operation.

After the initial start up, the operation condition of the activated sludge system was controlled to be constant during the steady state operation. The steady state operation period was about three weeks. The performance of the system was recorded during the best period of steady state to measure the efficiency of treatment of the system.

Table 1 shows the performance of the steady state during this period. The food to microorganisms (F/M) ratio during steady state period ranged between 0.20 to 0.24 d^{-1} (mg define before first use COD per day / mg MLSS) with average value 0.22 d^{-1}. The effluent COD of treated sewage ranged between 25 to 50 mg/l with average value 37 mg/l. The sludge volume index (SVI) ranged between 186 to 61 with average value 115 ml/g, and the COD removal efficiency ranged between 90 to 95 with averaged value 92.5 %.

3.1.2. The effect of organic shock load.

In order to study the effect of organic shock loading on the treatment efficiency, aerobic batch tests were conducted using mixed liquor suspended solids taken from the activated sludge system. The maximum specific growth rate ($\hat{\mu}_H$)of the heterotrophs bacteria was measured under several COD concentrations (several organic loading). The maximum specific growth rate ($\hat{\mu}_H$) was used as an indication of the treatment efficiency, any decreasing of the $\hat{\mu}_H$ due to the organic shock loads, will consequently cause a reduction in the treatment efficiency.

In this study the method proposed by Ekama et al. [8] was used to measure the $\hat{\mu}_H$. According to this method, aerobic batch tests were used to obtain and evaluate the OUR profile with different initial substrate using biomass from the main system.

Ekama et al. [8] indicated that the initial high defined before first use. OUR is a consequence of the utilization of the readily biodegradable COD from the wastewater as well as that derived from hydrolysis of the particulate biodegradable COD. The OUR is constant over this period because the concentration of readily biodegradable COD is so high that the growth rate of the heterotrophs is at maximum $\hat{\mu}_H$ in accordance with Monad kinetics [9].

Once the readily biodegradable COD from the influent is depleted, the OUR rapidly drops to the second level which is the rate associated with the utilization of the biodegradable COD.

The readily biodegradable COD fraction and the maximum specific growth rate of the heterotrophs $\mu^{\wedge}_H$ can be calculated using the OUR curve. The maximum specific growth rate ($\mu^{\wedge}_H$) is proportional to the vertical height of the initial high OUR. The maximum specific growth rate ($\mu^{\wedge}_H$) of the heterotrophs can be estimated according to the following assumptions.

The maximum specific growth rate ($\mu^{\wedge}_H$) is usually specified as mg active define before first use. Volatile Suspended Solids (VSS) synthesized per mg active defines before first use. VSS present per day (mg AVSS /mg AVSS/d) or simply d^{-1}. The $\mu^{\wedge}_H$ is related to the maximum readily biodegradable substrate utilization rate K_{ms} in unit mg COD utilized / mg active VSS/d (mg COD/mg AVSS/d) through the yielded coefficient in units mg VSS synthesized /mg COD utilized.

$$\mu^{\wedge}H = K_{ms} \bullet Y_h \text{ (mg AVSS/mg AVSS/d)}. \quad (1)$$

Now K_{ms} (in mg COD/mg AVSS/d) is related to the initial high OUR at the beginning of the batch test OUR_i .

$$K_{ms} = \frac{1}{1 - f_{cv} \cdot Y_h} \cdot OUR_i \cdot \frac{(V_{WW} + V_{ml})}{f_{av} \cdot X_V \cdot V_{ml}} \cdot \quad (2)$$

where;

f_{av} is the Active Fraction of the MLVSS.

f_{cv} is the COD/VSS Ratio of the sludge.

Y_h is the yield coefficient for heterotrophs.

X_V is the mixed Liquor Volatile suspended solids.

OUR_i is the initial oxygen uptake rate.

V_{ml} is the volume of mixed liquor.

V_{ww} is the volume of wastewater.

According to the method proposed by Ekama et al. [8], in order to estimate the constants Y_h and f_{cv} for design purposes for principally domestic municipal wastewaters one may accept Y_h= o.45 mg VSS/mg CODand f_{cv}=1.48 mg COD/mg VSS without a significant loss of accuracy accepting these values. Thus:

$$\frac{1}{1 - Y_h \cdot f_{cv}} = \frac{1}{1 - (1.48)(0.45)}$$

$$= 3.0 \text{ (mg COD consumed /mg Oxygen tilized)}. \quad (3)$$

Table 1
Summary of performance of the activated sludge system in steady state operation (phase I)

Paraeter	COD_{IN}	COD_{eff}	COD_{Rem}	MLSS	pH	T	F/M	SVI	θc	R	Q_{IN}
DAY	mg/l	mg/l	%	mg/l	—	C°	d^{-1}	ml/g	day	%	l/day
1	500	40	92	2737	7	22	0.24	69	10	100	40
2	500	40	92	2792	6.7	21	0.24	61	10	100	40
3	500	35	93	3185	6.9	19	0.21	89	10	100	40
4	500	30	94	3074	7	19	0.22	98	10	100	40
5	500	50	90	3211	6.9	19	0.21	184	10	100	40
6	500	25	95	3378	7	20	0.2	186	10	100	40
7	500	30	94	2873	6.9	20	0.23	184	10	100	40
8	500	50	90	2890	6.9	20	0.21	100	10	100	40
9	500	40	92	2678	7	19	0.22	92	10	100	40
10	500	30	94	2701	7	19	0.22	86	10	100	40
AVE.	500	37	92.5	2952	6.9	20	0.22	115	10	100	40

associated with the utilization of the biodegradable COD.

The readily biodegradable COD fraction and the maximum specific growth rate of the heterotrophs $\mu^\wedge{}_H$ can be calculated using the OUR curve. The maximum specific growth rate ($\mu^\wedge{}_H$) is proportional to the vertical height of the initial high OUR. The maximum specific growth rate ($\mu^\wedge{}_H$) of the heterotrophs can be estimated according to the following assumptions.

The maximum specific growth rate ($\mu^\wedge{}_H$) is usually specified as mg active define before first use. Volatile Suspended Solids (VSS) synthesized per mg active defines before first use. VSS present per day (mg AVSS /mg AVSS/d) or simply d^{-1}. The $\mu^\wedge{}_H$ is related to the maximum readily biodegradable substrate utilization rate K_{ms} in unit mg COD utilized / mg active VSS/d (mg COD/mg AVSS/d) through the yielded coefficient in units mg VSS synthesized /mg COD utilized.

$$\mu^\wedge H = K_{ms} \bullet Y_h \text{ (mg AVSS/mg AVSS/d).} \quad (1)$$

Now K_{ms} (in mg COD/mg AVSS/d) is related to the initial high OUR at the beginning of the batch test OUR_i .

$$K_{ms} = \frac{1}{1 - f_{cv} \cdot Y_h} \cdot OUR_i \cdot \frac{(V_{WW} + V_{ml})}{f_{av} \cdot X_V \cdot V_{ml}} \cdot \quad (2)$$

where;

f_{av} is the Active Fraction of the MLVSS.

f_{cv} is the COD/VSS Ratio of the sludge.

Y_h is the yield coefficient for heterotrophs.

X_V is the mixed Liquor Volatile suspended solids.

OUR_i is the initial oxygen uptake rate.

V_{ml} is the volume of mixed liquor.

V_{ww} is the volume of wastewater.

According to the method proposed by Ekama et al. [8], in order to estimate the constants Y_h and f_{cv} for design purposes for principally domestic municipal wastewaters one may accept Y_h= o.45 mg VSS/mg CODand f_{cv}=1.48 mg COD/mg VSS without a significant loss of accuracy accepting these values. Thus:

$$\frac{1}{1 - Y_h \cdot f_{cv}} = \frac{1}{1-(1.48)(0.45)}$$

$$= 3.0 \text{ (mg COD consumed /mg Oxygen tilized).} \quad (3)$$

Table 1
Summary of performance of the activated sludge system in steady state operation (phase I)

Paraeter	COD_{IN}	COD_{eff}	COD_{Rem}	MLSS	pH	T	F/M	SVI	θc	R	Q_{IN}
DAY	mg/l	mg/l	%	mg/l	---	C°	d^{-1}	ml/g	day	%	l/day
1	500	40	92	2737	7	22	0.24	69	10	100	40
2	500	40	92	2792	6.7	21	0.24	61	10	100	40
3	500	35	93	3185	6.9	19	0.21	89	10	100	40
4	500	30	94	3074	7	19	0.22	98	10	100	40
5	500	50	90	3211	6.9	19	0.21	184	10	100	40
6	500	25	95	3378	7	20	0.2	186	10	100	40
7	500	30	94	2873	6.9	20	0.23	184	10	100	40
8	500	50	90	2890	6.9	20	0.21	100	10	100	40
9	500	40	92	2678	7	19	0.22	92	10	100	40
10	500	30	94	2701	7	19	0.22	86	10	100	40
AVE.	500	37	92.5	2952	6.9	20	0.22	115	10	100	40

It can be concluded from table 2 and fig. 4 that the biological treatment process in the activated sludge system is sensitive to organic shock loads because the $\mu^{\wedge}_H$ decreases fairly rapidly due to slightly increasing in F/M ratio. loads and the $\mu^{\wedge}_H$ represents the efficiency of biological treatment process. This relationship is consistent with the literature [8].

3.2. Sequencing batch reactor SBR (phase II)

3.2.1. Steady state operation.

After the initial start up of the sequencing batch reactor. The operation condition of the system was controlled to be constant during the steady state operation. The performance of the system was recorded during the best period of operation to measure the treatment efficiency of the system.

Table 3 shows the performance of steady state operation during this period. The operation conditions were as follow: The discharge of synthetic feed sewage = 12 l/cycle = 48 l/day, COD influent concentration = 500 mg/l, cycle length = 6 hr., the sludge age was maintained to 10 days, the dissolved oxygen in the reactor during the aeration period was maintained within the desire limits ranged between 1 to 3 mg/l with average value 2 mg/l.

Under such conditions, the food to microorganisms F/M ratio during this period based on (mg COD per day / mg MLSS) ranged between 0.27 to 0.36 with average value 0.31 d^{-1}, the effluent COD of treated

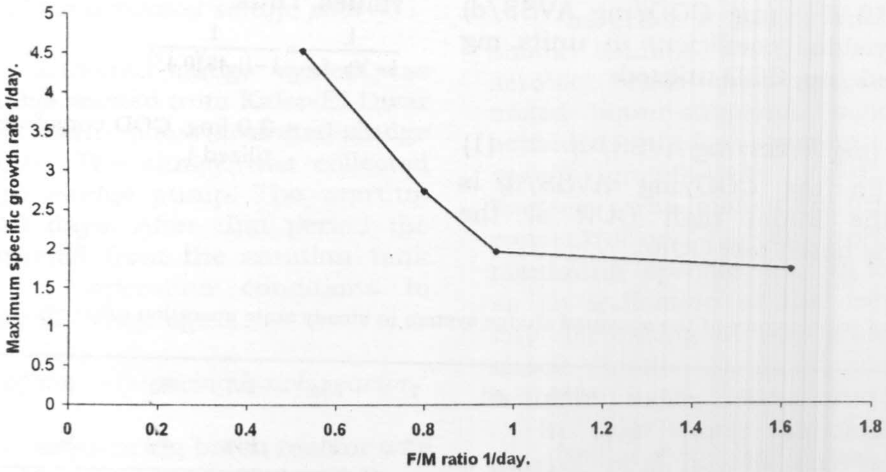

Fig. 4. Relationship between maximum specific growth rate and F/M ratio for activated sludge system.

Table 2
Relation between influent COD_{IN} and $\mu^{\wedge}_H$ (phase I)

Parameter	Influent COD (COD_{in}) mg/l			
	500	650	780	1000
F/M ratio d^{-1}	0.53	0.80	0.96	1.62
OUR_I Mg/l/hr.	40.5	21.0	15.0	10
$\mu^{\wedge}_H$ d^{-1}	4.52	2.73	1.95	1.71

The F/M ratio represents the organic shock sewage ranged between 20 to 40 mg/l with average value 29 mg/l ,the sludge volume index SVI ranged between 103 to 43 with average value 65 ml/g and the COD removal ranged between 92 to 96 % with average value 94 % . Comparing table 1 and table 3, it can be concluded that, the SBR is performing more efficiently than the activated sludge system considering COD removal and SVI.

The suspended solids concentration of treated effluent wastewater (SS_{eff}) could be considered as an indication of the efficiency of SBR system as a final settler tank. The hydraulic retention time of SBR as a final settler was about 4 hours. During the steady state period, 25 samples were collected from effluent wastewater to determine the SS_{eff}. The results of SS_{eff} ranged between 14 to 29 mg/l with average value 23 mg/l. This result proofs that the SBR system is performing efficiently during the settling phase.

3.2.2. *The effect of organic shock load.*

In order to study the effect of organic shock load on the sequencing batch reactor system respirometric analysis (OUR curve) was also conducted. The aerobic batch test was used to determine the relation between OUR and time for different influent COD concentrations. These results were used to calculate the maximum specific growth rate of heterotrophs biomass does this mean $\mu^{\wedge}_{H}$ for each influent COD [8]. All assumptions proposed for the batch tests of the activated sludge system are valid here. Table 4 shows influent COD concentrations, food to microorganisms' ratio F/M and maximum specific growth rate of heterotrophs $\mu^{\wedge}_{H}$ of the previous tests.

Fig. 5 shows the relationship between the F/M ratio and the maximum specific growth rate $\mu^{\wedge}_{H}$. The $\mu^{\wedge}_{H}$ slightly decreases due to slightly increasing in F/M ratio. After that, the $\mu^{\wedge}_{H}$ increases due to increasing of F/M ratio. It can be concluded from table 4 and fig. 5 that, the biological treatment process in the sequencing batch reactor system is more capable to carry the organic shock loads. The F/M ratio represents the organic shock load and the $\mu^{\wedge}_{H}$ represents the efficiency of biological treatment process. Comparing results of table 2 and table 4, it is obvious that for activated sludge system, increasing organic shock loading causes shape decrease in $\mu^{\wedge}_{H}$, for example $\mu^{\wedge}_{H}$= 1.95 d^{-1} at F/M ratio = 0.96 d^{-1}. On the other hand for SBR system increasing organic shock loading dose not

Table 3
Summary of performance of the sequencing batch reactor in steady state operation (phase II)

Parameter	COD_{IN}	COD_{eff}	COD_{Rem}	MLSS	pH	T	F/M	SVI	θc	Q_{IN}
DAY	mg/l	mg/l	%	mg/l	—	C°	l/day	ml/g	day	l/day
1	500	30	94	3349	6.6	22	0.29	51	10	48
2	500	25	95	3328	7	22	0.3	60	10	48
3	500	20	96	3418	6.5	21	0.29	64	10	48
4	500	30	94	3120	6.4	21	0.32	43	10	48
5	500	30	94	3044	6.3	22	0.33	49	10	48
6	500	20	96	2764	6.2	22	0.36	72	10	48
7	500	30	94	3659	6.5	22	0.27	79	10	48
8	500	40	92	2807	6.6	22	0.36	103	10	48
9	500	35	93	3655	6.2	22	0.27	67	10	48
10	500	30	94	2834	6.3	23	0.35	60	10	48
AVE.	**500**	**29**	**94**	**3198**	**6.5**	**22**	**0.31**	**65**	**10**	**48**

cause a sharp decrease in $\mu^{\wedge}_{H}$. The $\mu^{\wedge}_{H}$ =3.4 d^{-1} at F/M ratio = 1.0 d^{-1}. Accordingly, it is clear that, the SBR has more capability than activated sludge to handle shock organic load.

3.2.2.1.The bench scale sequencing batch reactor method

Because little information is available in literature on the effect of increasing organic shock loading on the SBR treatment efficiency, bench scale sequencing batch reactor experiments were carried out. In these experiments four beakers, one litter each were used as a bench scale. All operation conditions were maintained typically the same as the main SBR (pilot plant) except the concentration of influent COD in each beaker. To confirm the results of these tests, each test was repeated for two runs and average results were recorded.

Table 5 shows the average values of results from these tests. Also table 5 shows the effect of organic shock load on the sequencing batch reactor SBR. F/M ratio represents the organic shock load and, the COD_{eff} is considered as an indication of the efficiency of the biological treatment process.

Fig. 6 shows the relationship between COD removal and F/M ratio. The COD removal increases due to slightly increasing of F/M (mg COD per day / mg MLSS). After that, the COD removal decreases due to any increase in F/M ratio.

It can be concluded from table 5 and fig. 6 that, increasing the organic shock loads (i.e. F/M ratio) causes reduction in the efficiency of the biological treatment process (i..e. COD removal). The best COD removal efficiency could be obtained at F/M ratio at about 0.46 d^{-1}.

Table 4
Relation between influent COD_{IN} and $\mu^{\wedge}_{H}$ (phase II)

Parameter	Influent COD (COD_{in}) mg/l			
	500	650	780	1000
F/M ratio, d^{-1}	0.57	0.75	0.78	1.00
OUR_I ,Mg/l/hr.	24.0	21.0	34.5	33.0
$\mu^{\wedge}_{H}$, d^{-1}	2.90	2.55	3.61	3.46

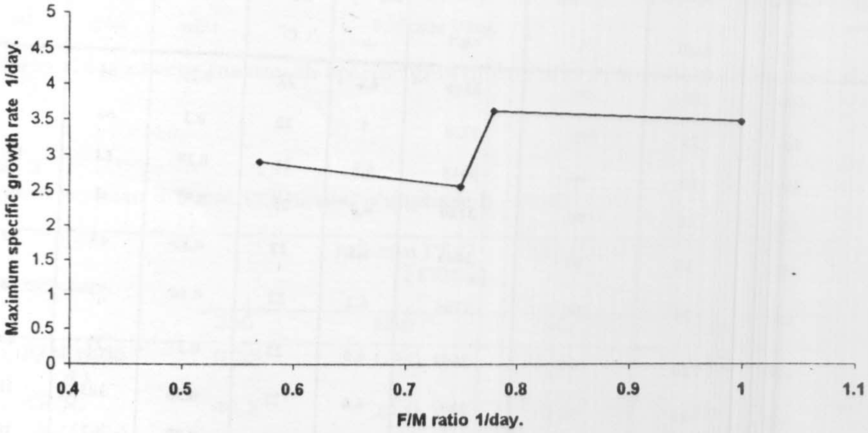

Fig. 5. Relationship between maximum specific growth rate and F/M ratio for sequencing batch reactor (SBR) system.

Table 5
Average results of bench scale SBR experiments

Parameter		No of beaker 1	2	3	4
COD_{in}	mg/l	460	610	735	935
V_w	l	0.25	0.25	0.25	0.25
V_{ml}	l	0.25	0.25	0.25	0.25
V_E	%	50 %	50 %	50 %	50 %
MLSS	mg/l	2613	2613	2613	2613
F/M ratio	d^{-1}	0.355	0.465	0.56	0.72
COD_{eff}	mg/l	32.5	37.5	65	112
$COD_{Removal}$	%	93 %	94 %	91%	88 %
OUR_F	mg/l/hr	0.0	0.2	1.2	3.5

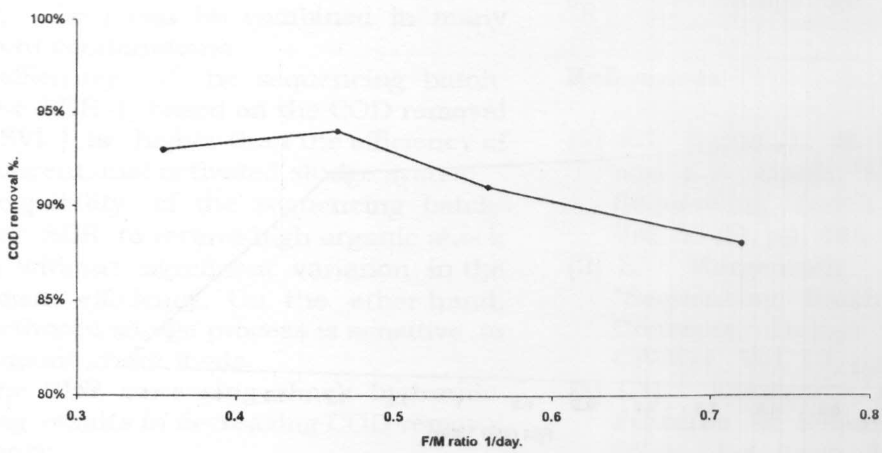

Fig. 6. Relationship between COD removal and F/M ratio of organic shock loads for sequencing batch reactor (SBR) system.

3.2.3. The effect of hydraulic shock load

The bench scale sequencing batch reactor experiment was also used to study the effect of hydraulic shock loads on SBR. In this test four beakers one litter each were used as a bench scale SBR.

All operation conditions were maintained typically the same as the main SBR (pilot plant) except the volume of feed influent synthetic wastewater in each beaker. The influent COD concentration was constant and the same as the influent COD of main SBR system. To confirm the results from these tests, each test was repeated for two runs and the average was recorded.

Table 6 shows the effect of hydraulic shock loads on the sequencing batch reactor SBR. fig. 7 shows the relationship between COD removal and F/M ratio. In these experiments, because COD_{in} is constant the F/M ratio changed according to the hydraulic shock loading only. The COD removal slightly decreases due to any increase of F/M (mg COD per day / mg MLSS). After that, the COD removal rapidly decreases due to any increase of F/M ratio. It can be concluded from fig. 7 that, in the SBR system increasing hydraulic shock loading results in decreasing COD removal efficiency.

Table 6
Average results of bench scale SBR experiments

Parameter		No of beaker 1	2	3	4
COD_{in}	mg/l	480	480	480	480
V_w	l	0.25	0.40	0.60	0.75
V_{ml}	l	0.25	0.25	0.25	0.25
V_E	%	50 %	62 %	71 %	75 %
MLSS	mg/l	1943	1495	1143	971
F/M ratio	d^{-1}	0.49	0.81	1.22	1.52
COD_{eff}	mg/l	37.5	42.5	50	92.5
$COD_{Removal}$	%	92 %	91 %	90%	81 %
OUR_P	mg/l/hr	0.0	1.1	1.1	2.2

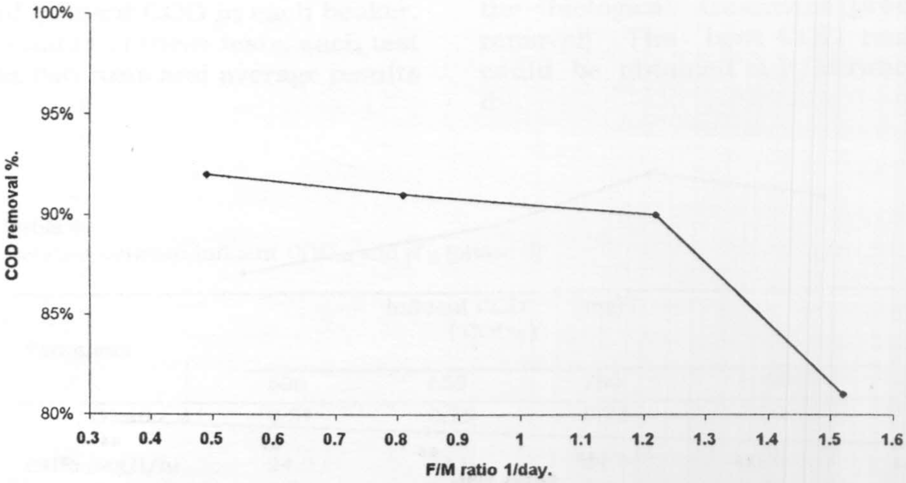

Fig. 7. Relationship between COD removal and F/M ratio of hydraulic shock loads for sequencing batch reactor (SBR) system.

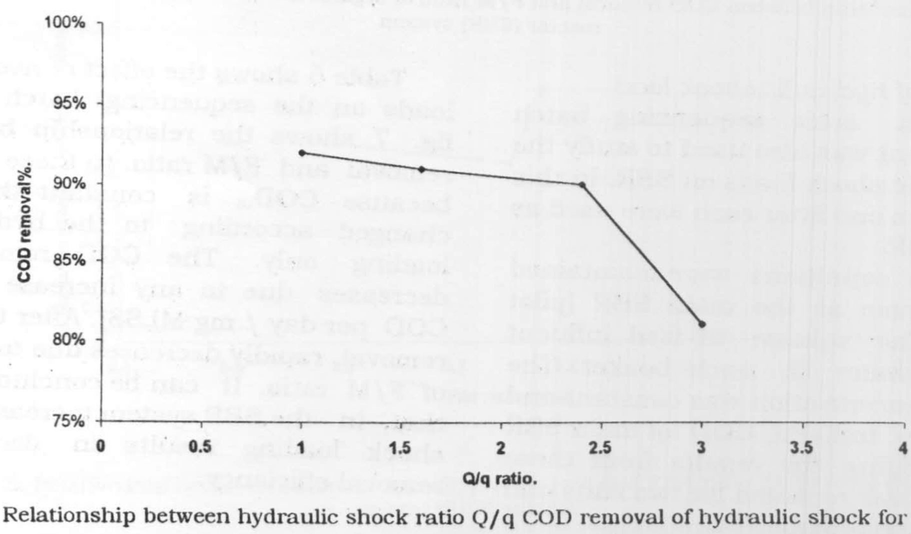

Fig. 8. Relationship between hydraulic shock ratio Q/q COD removal of hydraulic shock for SBR.

Fig. 8 shows the relation between hydraulic shock load ratio Q/q and the COD removal. Where Q = shock load discharge, q = normal discharge. This figure also confirms that, increasing the hydraulic shock loads (i.e. Q/q) causes reduction in the efficiency of the biological treatment process (i.e. COD removal). More results can be found in [10].

4. Conclusions

Based on the observations and the results obtained from this study the following points are concluded.

1- The SBR offers considerable flexibility in the operation of sewage treatment plants where different phases (fill, react, settle, draw, idle) can be combined in many different combinations.
2- The efficiency of the sequencing batch reactor SBR (based on the COD removal and SVI) is higher than the efficiency of the conventional activated sludge system.
3- The capability of the sequencing batch reactor SBR to receive high organic shock loads without significant variation in the treatment efficiency. On the other hand, the activated sludge process is sensitive to the organic shock loads.
4- For the SBR increasing shock hydraulic loading results in decreasing COD removal efficiency.

Nomenclature

AVSS	Active Volatile Suspended Solids.
COD	Chemical Oxygen Demand.
COD_{in}	Influent Chemical Oxygen Demand.
F/M	Food to Microorganisms Ratio.
f_{av}	The Active Fraction of the MLVSS.
f_{cv}	COD/VSS Ratio of the Sludge.
K_{ms}	The Maximum Readily Biodegradable Substrate Utilization Rate.
MLSS	Mixed Liquor Suspended Solids.
MLVSS	Mixed Liquor Volatile Suspended Solids.
OUR	Oxygen Uptake Rate.
OUR_i	Initial Oxygen Uptake Rate.
Q_{eff}	Effluent Flow Rate.
Q_{in}	Influent Flow Rate.
Q_R	Return Sludge Discharge.
Q_W	Waste Sludge Discharge.
SBR	Sequencing Batch Reactor.
SS	Suspended Solids.
SS_{eff}	Effluent Suspended Solids.
SVI	Sludge Volume Index.
T	Temperature.
V_E	Volumetric Exchange Ratio.
V_{ml}	Volume of Mixed Liquor.
V_{ww}	Volume of Wastewater.
VSS	Volatile Suspended Solids.
Y_h	Yield Coefficient for Heterotrophs.
$\hat{\mu}_H$	Maximum Specific Growth Rate of Heterotrophs Biomass.
θ_c	Sludge Age.

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