PERFORMANCE OF BIOFILM SEQUENCING BATCH REACTOR SYSTEM FOR TREATMENT OF DAIRY WASTEWATER

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ABSTRACT

The dairy industry is one of the most polluting of industries, not only in terms of the volume of effluent generated, but also in terms of its characteristics as well. This study aims to investigate the performance of both conventional sequencing batch reactor (SBR) and biofilm sequencing batch reactor (BSBR) for treatment of dairy wastewater. Two pilot plants of SBR and BSBR systems were operated in parallel for three scenarios with three different hydraulic retention times (HRTs) of 2, 3 and 4 days, respectively. The glucose based synthetic feed was used for both SBR and BSBR systems. The synthetic feed compositions were 7000, 120 and 60 mg/l for COD, TKN and TP, respectively. The COD and TKN removal efficiencies of the SBR system at 2 days HRT were 88.5 and 69.8% respectively. However, the COD and TKN removal efficiencies of the BSBR system at 2days HRT were 94.8 and 73.4% respectively. By increasing the HRT up to 4 days, the difference between the two efficiencies for SBR and BSBR systems was reduced dramatically. The COD and TKN removal efficiencies of the SBR system at 4 days HRT were 97.5 and 76.6 % respectively. However, the COD and TKN removal efficiencies of the BSBR system at 4 days HRT were 99.5 and 85.1% respectively. It was concluded form the performance of BSBR system, the addition of suspended media of only 4% of the reactor volume reduces the reactor volume by 34% to obtain the same removal efficiencies. However, the SS removal of the BSBR system was higher than the SBR system, and the excess sludge producing from the BSBR system is less than the SBR system. Also, the oxygen consumption at the aeration process for the BSBR system was less than the SBR system.

Keywords: Biofilm Sequencing Batch Reactor (BSBR); Dairy Wastewater; Removal efficiencies; Biological treatment.

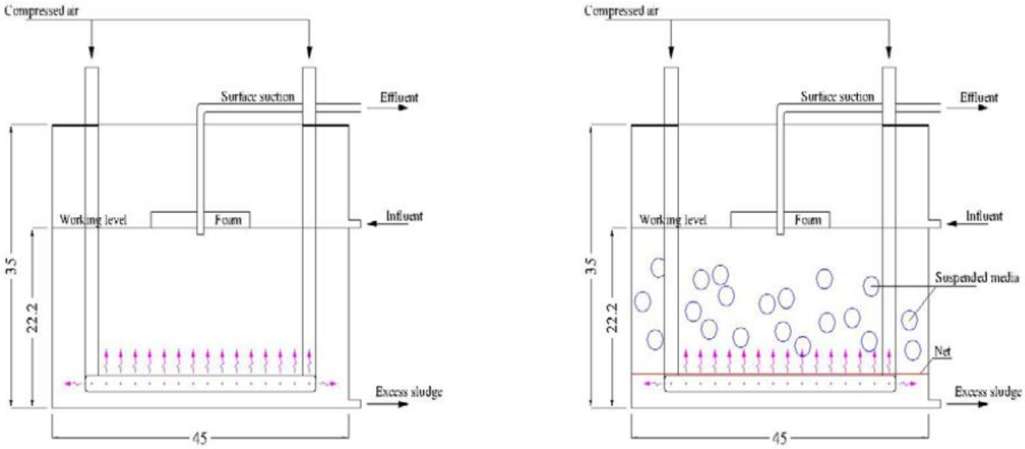
1. INTRODUCTION

The dairy industry is a major enterprise in Egypt, occupying a significant place in food supply. This industry has been identified as an important contributor to the pollution of waterways especially when large industrial establishments are involved [1]. In general, wastes from the dairy processing industry contain high concentrations of organic material such as proteins, carbohydrates, and lipids, high concentrations of suspended solids, high biological oxygen demand (BOD) and chemical oxygen demand (COD), high nitrogen concentrations, high suspended oil and/or grease contents, and large variations in pH, which necessitates "specialty" treatment so as to prevent or minimize environmental problems [2]. The SBR process became more commonly applied from the mid-1980s onwards as an alternative to the more commonly encountered continuous flow systems. It is the only commonly applied activated sludge variant which is designed to operate in a cyclic or intermittent mode. Because of the latter, the operation of SBRs can be matched with the shift nature of factory operations more easily than continuous flow systems. The differences between treatment trains incorporating the continuous flow activated sludge processes and the SBR begin from the aeration vessel onwards. Typically the continuous flow activated sludge process operates with aeration vessels and secondary clarifiers. There would be sludge return from the secondary clarifier to the aeration vessel. The SBR operates without the secondary clarifier and hence would also not have the sludge return from the latter. The SBR system might be suitable to treat dairy wastewater because of its ability to reduce nitrogen compounds by nitrification and denitrification [3-6], but the SBR system still has some disadvantages such as the high excess sludge produced and the high sludge volume index [7-10]. In recent years, the combination of activated sludge and biofilm wastewater treatment processes has been increasingly used worldwide to increase the efficiencies of both organic substrate and nitrogen removals [11-14]. This technology installs either fixed or moving media for biomass natural attachment in the aeration tank of the conventional biological nutrient removal or activated sludge processes. The process primarily focuses on the improvement of nitrification process located in the temperate zone in which slow growing microorganisms could not retain in the system at low temperature. In general, the sludge retention time (SRT) as an operating parameter for the suspended wastewater treatment processes must be increased. In this study, an attached growth system was applied in the conventional SBR reactor by installing suspended plastic media in the SBR reactor to increase the system efficiency, bio-sludge quality and to reduce the excess bio-sludge. The experiments were carried out in both SBR and BSBR systems to observe the performance of the systems and the removal efficiencies and quality of the bio-sludge.

2. MATERIALS AND METHODS

2.1. Laboratory wastewater treatment units

Two pilot plant of conventional sequencing batch reactor (SBR) and biofilm sequencing batch reactor (BSBR) systems were operated in parallel, as shown in Fig. 1. Three scenarios were used with three different hydraulic retention times (HRTs) in this study. The two pilot plants were constructed in the laboratory of Sanitary Engineering Department, Faculty of Engineering, Alexandria University. For the BSBR system, plastic media with a total surface area of 2.21 m^2 (Fig. 2, Table 1) was installed on the bottom of the reactor. Both SBR and BSBR reactors were made from Plexiglas (length= width = 45 cm, max. water depth = 22.2 cm, volume of reactor = 45 liters). The two reactors were provided by aeration system at there bases and the air were delivered from an air compressor (DARI – DEC 100/280 – HP 2 – Kw 1.5 – Volt 220, 50 Hz). The BSBR reactor provided with an aluminum grid above the aeration system to retain the media to improve its movement during aeration phase. The two systems was provided by two peristaltic pumps (Master Flex - U.S.A, Cole – Parmer Instrument Company), each pump was used manually as feeding pump in fill phase and as effluent pump in draw phase.

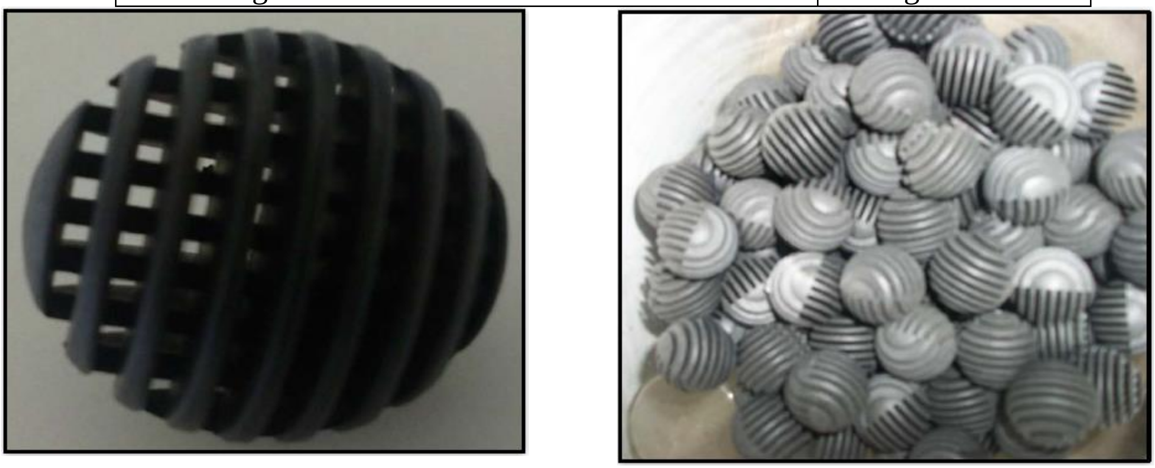


SBR BSBR

Fig.1. BSBR and SBR systems.

Table 1 Properties of the media in the BSBR

Properties	**Value**
Size of each ball	2.5 cm in diameter
Gross volume of each ball	4.6 cm^3
Net volume of each ball	2.37 cm^3
Surface area of each ball	55.206 cm^2
Surface area	1200 m^2/m^3
Weight of each ball	4.40 gm
Density of each ball	0.96 gm/cm^3
Number of balls in reactor	400 balls
Total surface area of balls	2.208 m^2
Total net volume of media in reactor	948 cm^3
Percentage of media gross volume/Reactor volume	4 %
Total weight of media in reactor	1760 gm



Individual media Set of media

Fig.2. Shape of plastic media in BSBR reactor.

2.2 Dairy industrial wastewater (DIWW)

The chemical compositions of dairy industrial wastewater (DIWW) are depending on the type of dairy industry. Most of there industries produce wastewater compositions as shown in Table 2. According to Battistoni et al. (1993)[15], the synthetic sewage could be used as a influent wastewater to simulate the dairy wastewater. The synthetic sewage prepared by diluting with tape water (1-100) a concentrated stock solution containing 560 g/l glucose ($C_6 H_{12} O_6$), 87.42 g/l $Na_3 PO_4 . 12H_2 O$ and 26.4 g/l $(NH_4)_2 SO_4$ .Table 2 shows the chemical compositions of the daily synthetic sewage.

2.3. Acclimatization of bio-sludge for BSBR and SBR systems

Initially the two pilot plants were seeded with sludge wasted from the treatment plant in factory of yeast and starch, Alexandria, Egypt. The treatment plant was consists of two units. The first was anaerobic reactor and the second was sequencing batch reactor which sludge has been collected from. The anaerobic reactor produce an effluent has COD = 3000 mg/l. So, during the start up period, the initial COD concentration of the synthetic sewage was 3000 mg/l and gradually increases up to 7000 mg/l. The start up period for each reactor was about 10 days of operation.

Table 2 Chemical compositions of dairy industrial and influent synthetic wastewater

Chemical compositions	Dairy industry Wastewater	Influent synthetic Wastewater
COD (mg/l)	5000 – 10000	7000
BOD_5 (mg/l)	3000 – 5000	4000
TS (mg/l)	3000 – 7000	-
Oil & grease (mg/l)	70 – 500	-
TKN (mg/l)	6050 – 150	120
TP (mg/l)	50 – 70	60
pH	4.0 – 7.0	6.0-8.0
Temperature (°C)	34 – 35	25-31

2.4. Operation of SBR and BSBR systems

Table 3 shows the operation parameters of both SBR and BSBR systems. The operation program of both SBR and BSBR systems consisted of five steps: fill, react (aeration), settle, draw and idle. The acclimatized bio-sludge was inoculated in each reactor of both the SBR and SBBR systems, and DIWW was added (final volume of 45 l) within 2 h (fill step). During the feeding of DIWW, the system had to be fully aerated. The aeration was then continued for another 19 h. (react step). Aeration was then shut down for 3 h (settle and draw steps). After the bio-sludge was fully settled, the supernatant had to be removed (the removed volume of the supernatant was based on the operation program as mentioned in Table 3) within 0.5 hr (draw step) and the system had to be kept under anoxic conditions (idle step) for 0.5 h. After that, fresh DIWW was filled into the reactor to the final volume of 45 l and the above operation program was repeated. For the removal of excess bio-sludge to control the stable bio-sludge concentration of the reactor, the excess bio- sludge was wasted from the bottom of the reactor (Fig. 1) during the idle step. The steady state operation period was 20 days for each reactor.

Table 3 Operation parameters of SBR and BSBR systems

Parameters	HRT (d)		
	2	3	4
Working volume of reactor (l)	45	45	45
Flow rate (l/d)	22.5	15	11.25
Operating cycle(times/d)	1	1	1
Operating step (h)			
Fill up (h)	2	2	2
Aeration (h)	19	19	19
Settling (h)	2	2	2
Draw & Idle (h)	1	1	1
Hydraulic loading (m^3/m^3 d)	0.50	0.33	0.25
Hydraulic loading (m^3/m^2 d)[a]	0.0102	0.0068	0.0051
Volumetric organic loading (gCOD/m^3 d)	3500	2333	1750
Surface area-organic loading (gCOD/m^2 d)[a]	71.33	47.55	35.67

[a] They were used for the BSBR system.

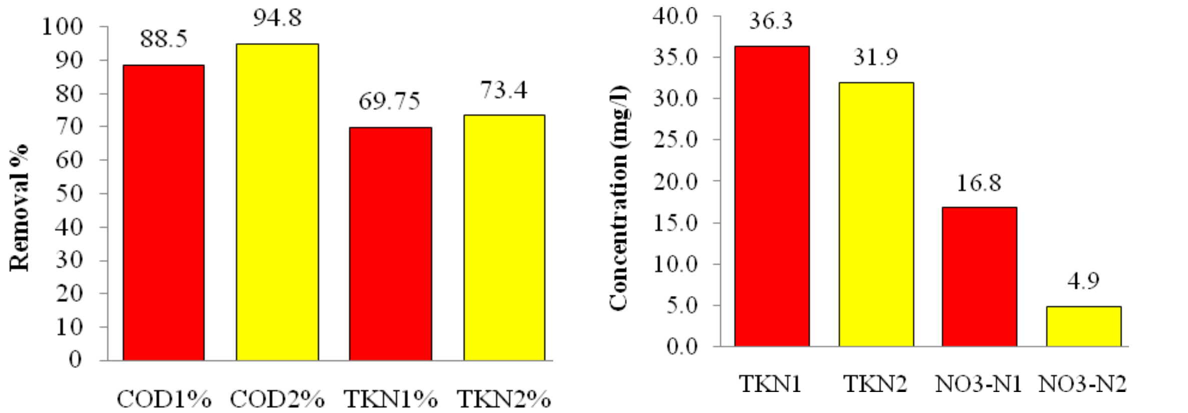
2.5. Chemical analysis

The biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), suspended solids (SS) total kjeldahl nitrogen (TKN), and pH of influent and effluent, mixed-liquor suspended solids (MLSS), excess sludge, and sludge volume index (SVI) were determined by using standard methods for the examination of water and wastewater [16]. Solid retention time (SRT) and sludge age was determined by measuring the average residence time of the suspended microorganisms (suspended bio-sludge) in the system. The F/M was presented as a ratio of COD loading and the total bio-sludge of the system.

3. RESULTS AND DISCUSSION

3.1 First Scenario: Performance of SBR(1) and BSBR(2) systems at HRT=2days

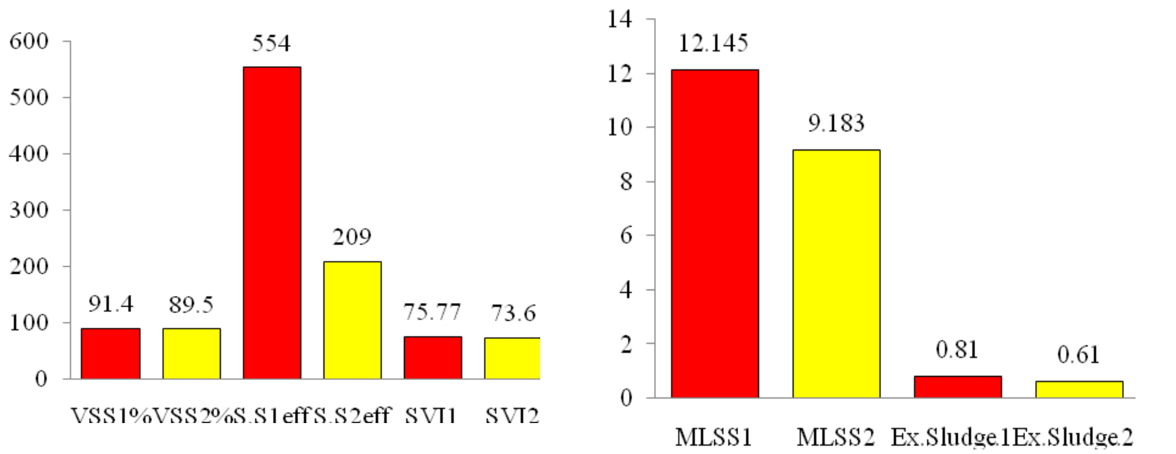
For the 1st scenario, comparison between the average of the removal efficiencies of COD and TKN for both SBR and BSBR was shown in **Fig 3.a**. Also, the effluent TKN and NO_3-N concentrations were shown in **Fig.3.b.** The COD and TKN removal efficiencies of the SBR system were 88.5 and 69.75% respectively. However, the COD and TKN removal efficiencies of the BSBR system were 94.8 and 73.4% respectively. Also, the effluent TKN and NO_3-N concentrations of the SBR system were 36.3 and 16.8 mg/l respectively. However, the effluent TKN and NO_3-N concentrations of the BSBR system were 31.9 and 16.8 mg/l respectively. It can be concluded that, the COD and nitrogen removal of the BSBR system were higher than the conventional SBR system at the 1st scenario (HRT=2 days). Also, the biological nitrogen removal process takes place in the BSBR reactor much better than the SBR reactor.



(a) COD and TKN removal efficiencies % (b) Effluent TKN and NO_3-N concentrations

Fig. 3 Treatment efficiencies and effluent quality for SBR(1) and BSBR(2) at HRT = 2 days

Fig. 4 shows the average of sludge characteristics and effluent SS for SBR (1) and BSBR (2) at HRT= 2 days. The of volatile suspended solids ratio VSS%, effluent SS and SVI of the SBR system were 91.4%, 554 mg/l and 75.77 ml/gMLSS respectively. However, the VSS%, effluent SS and SVI of the BSBR system were 89.5%, 209 mg/l and 73.6 ml/gMLSS respectively. Also, the MLSS and excess sludge of the SBR system were 12.145 g/l and 0.81 g/d/l respectively. However, the MLSS and excess sludge of the BSBR system were 9.183 g/l and 0.61 g/d/l respectively. It can be concluded that, the SS removal of the BSBR system was higher than the conventional SBR system at the 1st scenario (HRT=2 days). Also, the excess sludge producing from the BSBR system was less than the conventional SBR system.



(a) VSS %, effluent SS (mg/l) and SVI (ml/gMLSS). (b) MLSS (g/l) and excess sludge (g/d/l)

Fig.4. Sludge characteristics and effluent SS for SBR (1) and BSBR (2) at HRT= 2 days.

Fig.5 shows the comparison between the Residual Dissolved Oxygen (DO_{res}) at the end of the react phase in the reactors for SBR (1) and BSBR (2). The DO_{res} concentrations during the steady state period were ranged between 0.53 to 1.10 mg/l with average value of 0.79 mg/l for the SBR system. However, the DO_{res} concentrations were ranged from 0.96 to 1.80 mg/l with average value of 1.40 mg/l for the BSBR system. It can be concluded that, the DO_{res} concentrations of the BSBR system was higher than the conventional SBR system at the 1st scenario (HRT=2 days). It can be concluded that, the oxygen consumption at the aeration process for the BSBR system was less than the conventional SBR system.

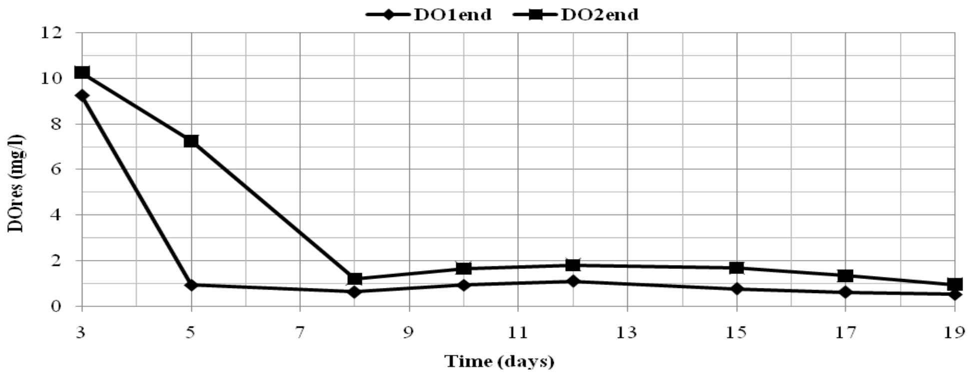
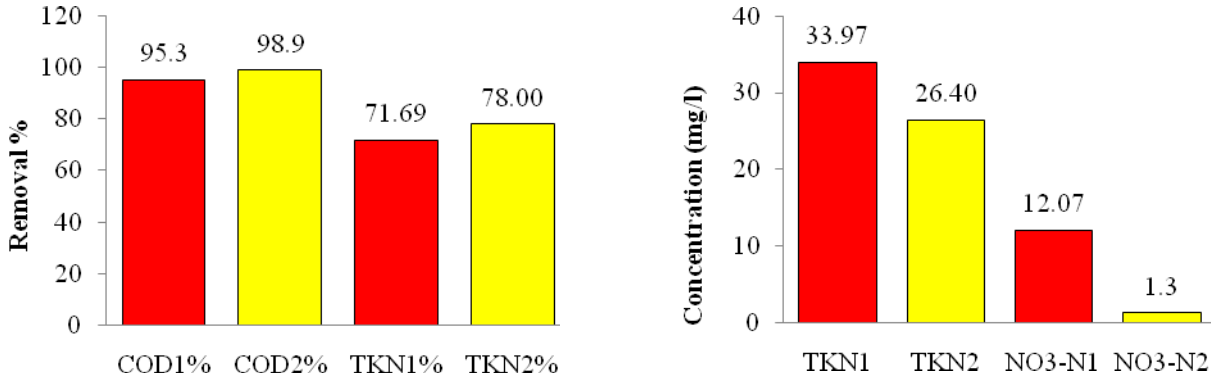


Fig.5 Residual Dissolved Oxygen (DO_{res}) for SBR (1) and BSBR (2) at HRT= 2 days.

3.2 Second Scenario: Performance of SBR(1) and BSBR(2) systems at HRT=3 days

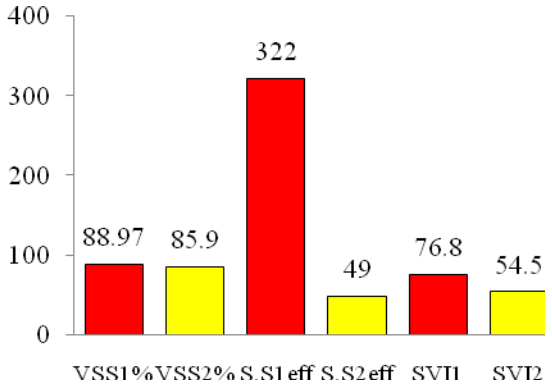
For the 2nd scenario, the comparison between the average of the removal efficiencies of COD and TKN for both SBR and BSBR was shown in **Fig 6.a**. Also, the effluent TKN and NO_3-N concentrations were shown in **Fig.6.b.** The COD and TKN removal efficiencies of the SBR system were 95.3 and 71.69 % respectively. However, the COD and TKN removal efficiencies of the BSBR system were 98.9 and 78.0 % respectively. Also, the effluent TKN and NO_3-N concentrations of the SBR system were 33.97 and 12.07 mg/l respectively. However, the effluent TKN and NO_3-N concentrations of the BSBR system were 26.04 and 1.3 mg/l respectively. It can be concluded that, the COD and nitrogen removal of the BSBR system were higher than the conventional SBR system at the 2nd scenario (HRT=3 days). Also, the nitrification and denitrification process take place in the BSBR reactor much better than the SBR reactor.



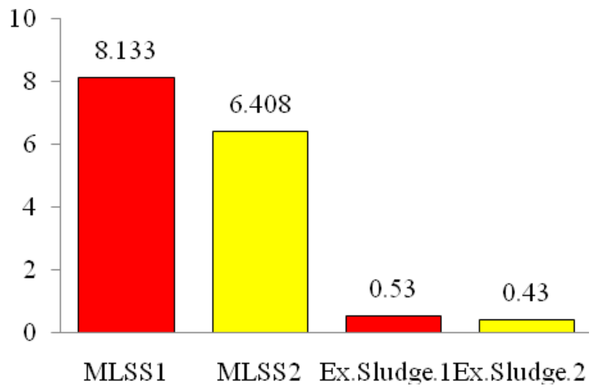
(a) COD and TKN removal efficiencies % (b) Effluent TKN and NO_3-N concentrations

Fig. 6 Treatment efficiencies and effluent quality for SBR(1) and BSBR(2) at HRT = 3 days

Fig. 7 shows the average of sludge characteristics and effluent SS for SBR (1) and BSBR (2) at HRT= 3 days. The of volatile suspended solids ratio VSS%, effluent SS and SVI of the SBR system were 88.97 %, 322 mg/l and 76.8 ml/gMLSS respectively. However, the VSS%, effluent SS and SVI of the BSBR system were 85.9%, 49 mg/l and 54.5 ml/gMLSS respectively. Also, the MLSS and excess sludge of the SBR system were 8.133 g/l and 0.53 g/d/l respectively. However, the MLSS and excess sludge of the BSBR system were 6.408 g/l and 0.43 g/d/l respectively. It can be concluded that, the SS removal of the BSBR system was higher than the conventional SBR system at the 2nd scenario (HRT=3 days). Also, the excess sludge producing from the BSBR system was less than the conventional SBR system.



(a) VSS %, effluent SS (mg/l) and SVI (ml/gMLSS).



(b) MLSS (g/l) and excess sludge (g/d/l)

Fig.7. Sludge characteristics and effluent SS for SBR (1) and BSBR (2) at HRT= 3 days.

Fig.8 shows the comparison between the Residual Dissolved Oxygen (DO_{res}) at the end of the react phase in the reactors for SBR (1) and BSBR (2). The DO_{res} concentrations during the steady state period were ranged between 1.20 to 1.38 mg/l with average value of 1.26 mg/l for the SBR system. However, the DO_{res} concentrations were ranged from 4.50 to 5.50 mg/l with average value of 5.10 mg/l for the BSBR system. It can be concluded that, the DO_{res} concentrations of the BSBR system was higher than the conventional SBR system at the 2st scenario (HRT=3 days). It can be concluded that, the oxygen consumption at the aeration process for the BSBR system was less than the conventional SBR system.

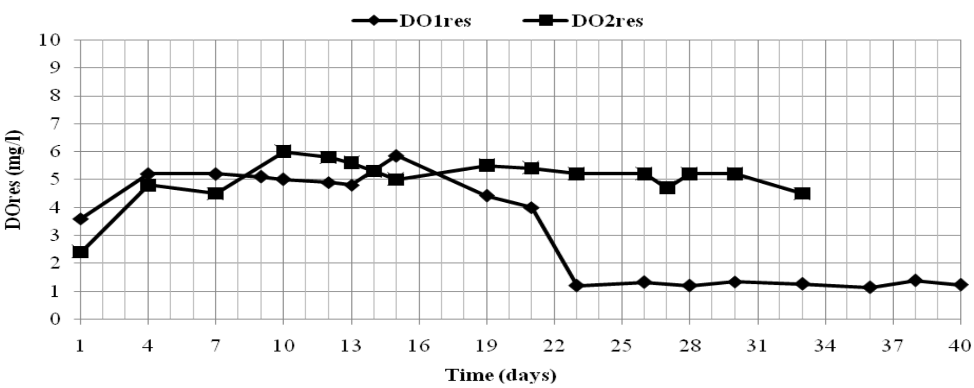
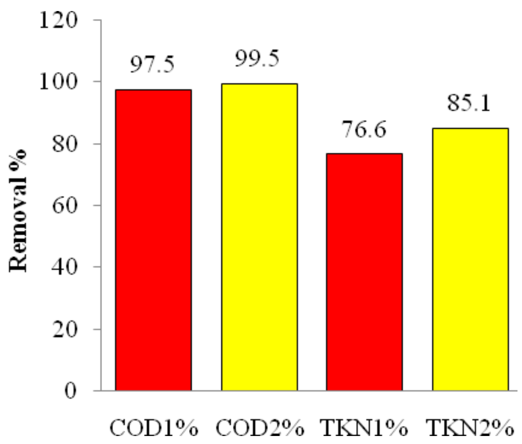


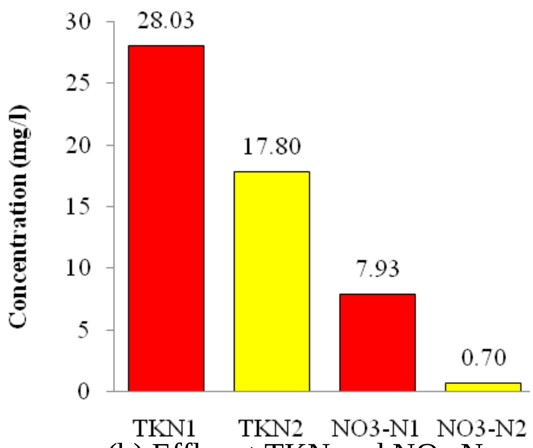
Fig.8 Residual Dissolved Oxygen (DO_{res}) for SBR (1) and BSBR (2) at HRT= 3 days.

3.3 Third Scenario: Performance of SBR(1) and BSBR(2) systems at HRT=4 days

For the 3rd scenario, the comparison between the average of the removal efficiencies of COD and TKN for both SBR and BSBR was shown in **Fig 9.a**. Also, the effluent TKN and NO_3-N concentrations were shown in **Fig.9.b.** The COD and TKN removal efficiencies of the SBR system were 97.5 and 76.6 % respectively. However, the COD and TKN removal efficiencies of the BSBR system were 99.5 and 85.1 % respectively. Also, the effluent TKN and NO_3-N concentrations of the SBR system were 28.03 and 7.93 mg/l respectively. However, the effluent TKN and NO_3-N concentrations of the BSBR system were 17.80 and 0.7 mg/l respectively. It can be concluded that, the COD and nitrogen removal of the BSBR system was higher than the conventional SBR system at the 3rd scenario (HRT=4 days). Also, the nitrification and denitrification process take place in the BSBR reactor much better than the SBR reactor.



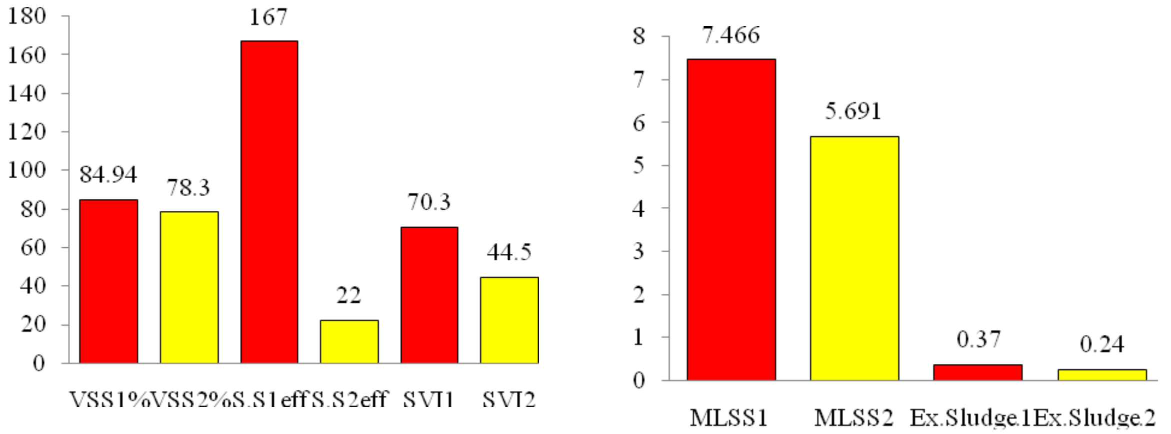
(a) COD and TKN removal efficiencies %



(b) Effluent TKN and NO_3-N concentrations

Fig. 9 Treatment efficiencies and effluent quality for SBR(1) and BSBR(2) at HRT = 4 days.

Fig. 10 shows the average of sludge characteristics and effluent SS for SBR (1) and BSBR (2) at HRT= 4 days. The of volatile suspended solids ratio VSS%, effluent SS and SVI of the SBR system were 84.94 %, 167 mg/l and 70.3 ml/gMLSS respectively. However, the VSS%, effluent SS and SVI of the BSBR system were 78.3%, 22 mg/l and 44.5 ml/gMLSS respectively. Also, the MLSS and excess sludge of the SBR system were 7.466 g/l and 0.37 g/d/l respectively. However, the MLSS and excess sludge of the BSBR system were 5.691 g/l and 0.24 g/d/l respectively. It can be concluded that, the SS removal of the BSBR system was higher than the conventional SBR system at the 2nd scenario (HRT=4 days). Also, the excess sludge producing from the BSBR system was less than the conventional SBR system.



(a) VSS %, effluent SS (mg/l) and SVI (ml/gMLSS).

(b) MLSS (g/l) and excess sludge (g/d/l)

Fig.10. Sludge characteristics and effluent SS for SBR (1) and BSBR (2) at HRT= 4 days.

Fig.11 shows the comparison between the Residual Dissolved Oxygen (DO_{res}) at the end of the react phase in the reactors for SBR (1) and BSBR (2). The DO_{res} concentrations during the steady state period were ranged between from 3.34 to 5.33 mg/l with average value of 4.38 mg/l for the SBR system. However, the DO_{res} concentrations were ranged from 5.54 to 9.92 mg/l with average value of 7.56 mg/l for the BSBR system. It can be concluded that, the DO_{res} concentrations of the BSBR system was higher than the conventional SBR system at the 3rd scenario (HRT=4 days). It can be concluded that, the oxygen consumption at the aeration process for the BSBR system was less than the conventional SBR system.

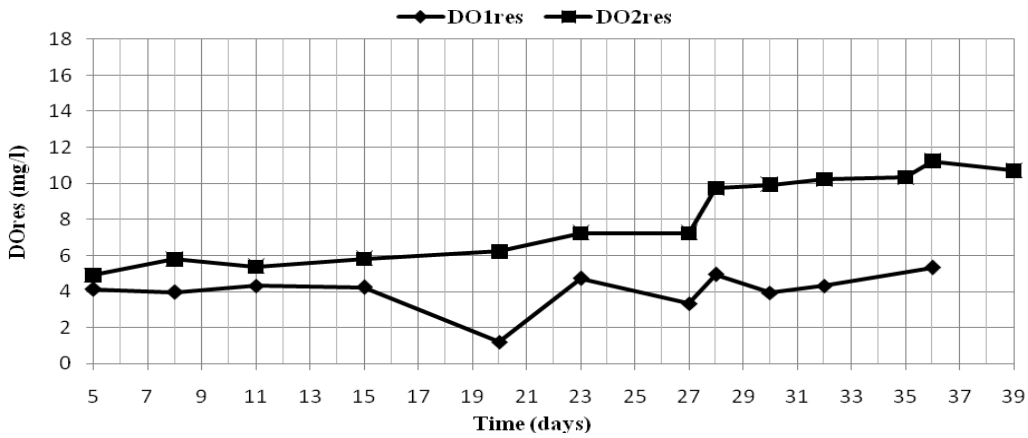


Fig.11 Residual Dissolved Oxygen (DO_{res}) for SBR (1) and BSBR (2) at HRT= 4 days..

3.4 Summary of results of the performance of SBR and BSBR system for all scenarios.

The summary of the results of steady state operation for the SBR and BSBR pilot plants in the three scenarios was shown in table 4. For all scenarios, the COD % and TKN% removal for the BSBR pilot plant were higher than the SBR pilot plant. However, the effluent SS and excess sludge for the BSBR pilot plant were smaller than the SBR pilot plant. Also, the effluent DO_{res} for the SBR pilot plant was less than the BSBR pilot plant.

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Table 4. The summary of results for SBR and BSBR pilot plants in the three scenarios.

HRT (d)	**2**		**3**		**4**	
Reactor	**SBR**	**BSBR**	**SBR**	**BSBR**	**SBR**	**BSBR**
Organic loading ($gCOD/m^3d$)	3500	3500	2333	2333	1750	1750
Hydraulic loading (m^3/m^3d)	0.50	0.50	0.33	0.33	0.25	0.25
Sludge age(d)	15	15	15	15	20	20
COD %	88.52	94.8	95.34	98.9	97.46	99.52
TKN %	69.75	73.4	71.69	78	76.64	85.14
SS_{eff} (mg/l)	554	209	322	49	167	22
DO_{res}(mg/l)	0.79	1.40	1.26	5.10	4.38	7.56
Excess sludge (g/d/L)	0.81	0.63	0.53	0.43	0.37	0.24

4. CONCLUSIONS

Based on the observations and the results obtained from this study, the following points could be concluded:

- Biofilm Sequencing Batch Reactor (BSBR) had a higher COD and TKN removal efficiencies, and lower excess sludge compared with Sequencing Batch Reactor (SBR).
- Increasing the HRT enhanced the performance of both SBR and BSBR. However, it was noticed that, increasing the HRT from 2 to 3 days made a big enhancement comparing with increasing the HRT from 3 to 4 days.
- Adding Suspended media in the SBR enhanced the biological nitrogen removal process, which was noticed by low NO3-N concentrations in BSBR comparing with the SBR.
- Adding plastic suspended media of just 4% of the working reactor volume saved about 34% of the reactor s' volume to reach the same efficiencies.
- The oxygen consumption at the aeration process for the BSBR system was less than the SBR system, which makes it economic to use tapered aeration system.
- The SS removal of the BSBR system was higher than the conventional SBR system, and the excess sludge producing from the BSBR system was less than the conventional SBR system.
- The most effective Sludge Retention Time (SRT) for both SBR and BSBR systems was ranged from 15 to 20 days.

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