The characteristic of the sequencing batch reactor (SBR), anaerobic sequencing batch reactor (ASBR) and sequencing batch biofilm reactor (SBBR)

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Abstract

Improvements in aeration devices and controls have allowed sequencing batch reactor (SBR) to successfully compete with conventional activated sludge systems. SBRs can achieve equalization, primary clarification, biological treatment, and secondary clarification in a single reactor. The processes of SBR system are five or six steps as anoxic fill, aerated fill, react, settle decant. SBR system is shown high removal efficiency for nitrogen, phosphate and heavy metal. But the efficiency of SBR system is affected on salt and heavy metals. The removal efficiency of pollutants between SBR and sequencing batch biofilm reactor (SBBR) shows that the efficiency of SBBR system is higher than SBR system for COD, BOD. Media and granular are used in SBBR system to complement some disadvantages of SBR system such as lots of sludge amount and high sludge volume index.

Keywords : SBR, ASBR, SBBR, nitrification and denitrification, nutrient.

Introduction

The SBR processor that can effectively compete with conventional activated sludge systems such as continuous stirred-tank reactor (CSTR) is not considered in wastewater treatment until the improvements in aeration devices and controls in the late 1950s and early 1960s. (EPA, 1999) Sequencing batch reactor (SBR) systems have benefits to alternative conventional flow systems for the biological treatment of both domestic and industrial wastewater. (Ying-Chih et al., 2007) There are some disadvantages such as lots of sludge amount and high sludge volume index in SBR process. (Sirianuntapiboona, et al., 2007) The Sequencing Batch Reactor (SBR) is operated under non-steady state conditions and same tank with an activated sludge process. The process consists of repetition of a cycle including five separate steps: feed, react, settle, draw and idle. Anaerobic sequencing batch reactor (ASBR) and sequencing batch biofilm reactor (SBBR) system is developed to complement disadvantage of SBR system. (Arnaldo et al., 2007; Li et al., 2003) The using of ASBR is attributed to a growing revaluation of advantages of anaerobic processes and studying about the anaerobic biochemistry and microbiology. Anaerobic sequencing batch reactors (ASBR) are currently used for the treatment of wastewaters with amounts of particulate organic matter such as swine manure, leachate and dairy. (Arnaldo et al., 2007) The sequencing batch biofilm reactor (SBBR) have been shown that it has the high efficiency of nitrogen removal. (Li et al., 2003)

Some advantages and disadvantages of SBRs are listed below: (EPA, 1999)

Advantages of SBRs

- Equalization, primary clarification, biological treatment, and secondary clarification can be achieved in a single reactor vessel.
- Operating flexibility and control.
- Minimal footprint.
- Potential capital cost savings by eliminating clarifiers and other equipment.

Disadvantages of SBRs

- A higher level of sophistication is required especially for larger systems, of timing units and controls.
- Higher level of maintenance associated with more sophisticated controls, automated switches, and automated valves.
- Potential of discharging floating or settled sludge during the DRAW or decant phase with some SBR configurations.
- Potential plugging of aeration devices during selected operating cycles, depending on the aeration system used by the manufacturer.
- Potential requirement for equalization after the SBR, depending on the downstream processes.

Operation of SBR, ASBR and SBBR system

The procedure of operation of SBR

Normally, the process follows basic steps of Fill, React, Settle and Decant. Figure 1 shows the process of SBR worked on one tank. In Figure 1, picture 1, 2 is sorted as fill phases and picture 3, 4, 5, 6 are non-fill phases. The ability to create aerobic or anoxic conditions within the reactor results in flexible operation, better treatment of waste.

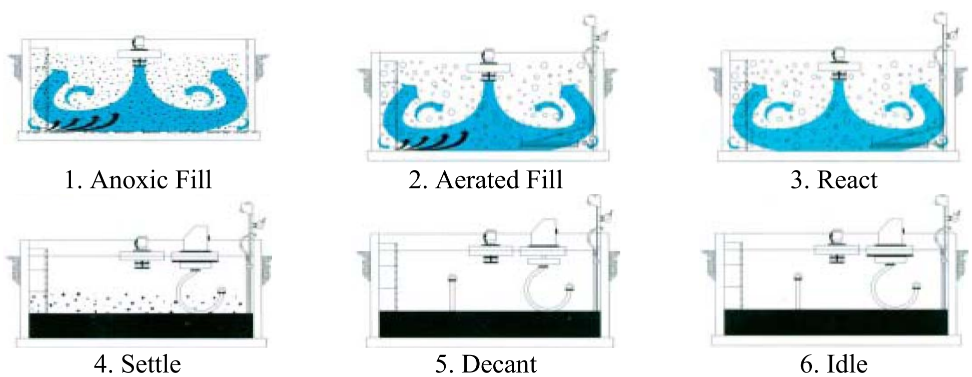


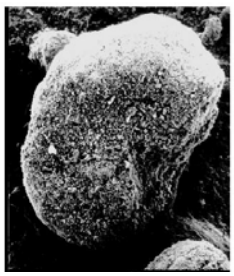
Fig.1. SBR process. (www.liquitek.com)

The below process explain about the each step from fill to idle. (www.liquitek.com)

1. Anoxic Fill - Most of this period occurs without aeration to create an environment that favors the procreation of microorganisms with good settling characteristics.
2. Aerated Fill - Nitrification and denitrification occurs at the beginning of this stage.
3. React - some microorganisms will die because of the lack of food and will help reduce the volume of the settling sludge.
4. Settle – liquids should not enter or leave the tank to avoid turbulence in the supernatant.
5. Decant - This removal must be done without disturbing the settled sludge.
6. Idle - The wasted sludge is pumped to an anaerobic digester to reduce the volume of the sludge to be discarded.

The operation of ASBR and SBBR

Generally, SBR, ASBR and SBBR system have similar procedure for treating pollutants. The process of ASBR consist of five step of fill, react, settle, draw and idle. ASBR system is that in SBR system, anaerobic step is adapted in total process instead of anoxic and aerated step. The different of systems is that ASBR has anaerobic condition in first step and SBBR has a biofilm in SBR system. In anaerobic status, granular biomass has some advantages over processes, including better solids retention, operating control and absence of settling. (Arnaldo et al., 2007; Sirianuntapiboona et al., 2007) As adding the biofilm in SBR, the removal efficiency of pollutants in conventional SBR is increased. The process is not changed in SBR; however, to achieve the ideal operating condition for efficiency of biofilm, the reactor condition such as DO concentration should be considered. (Sirianuntapiboona et al., 2005; Li et al., 2003) Figure 2. illustrates the granular biomass used in ASBR reactor[a] and media adapted in SBBR.[b]



[a]

[b]

Fig. 2 granular biomass in ASBR[a] (Bing et al., 2005) and media included SBBR system.[b] (Sirianuntapiboona et al., 2005)

The comparison among SBR, ASBR and SBBR

Sequencing Batch Reactor (SBR)

Removal about nutrient in SBR system was studied about nitrification, denitrification, biological phosphorous and monitoring and control. (Obaja et al., 2003; Akin et al., 2005; Ahmet, 2006) For nitrification, denitrification, Obaja et al. (2003) studied about nutrients in piggery wastewater with high organic matter, nitrogen (N) and phosphorus (P) content in a sequencing batch reactor (SBR) with anaerobic, aerobic and anoxic stages. The SBR proved to be a very flexible tool, and was particularly suitable for the treatment of piggery wastewater, characterized by high nutrient content.

Nitrification is a two-step reaction: ammonium (NH_4^+) is first oxidized to nitrite (NO_2^-) by autotrophic ammonia oxidizers, nitrite is then oxidized to nitrate (NO_3^-) by autotrophic nitrite-oxidizers (Reactions (I) and (II)). In anoxic denitrification, nitrite/nitrate is reduced to nitrogen gas (N_2) by heterotrophic denitrifiers with the presence of extra carbon source (acid) as electron donor (Reaction (III)). Nitrification can only be successfully operated under low chemical oxygen demand (COD), sufficient dissolved oxygen (DO) and long sludge retention time (SRT), while denitrification needs sufficient COD under anoxic condition. These different requirements pose challenges for nitrogen removal in sequencing batch reactor (SBR) systems, where nitrification and denitrification occur in the same tank:(Le et al., 2007)

- $2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$ (I)
- $2NO_2^- + O_2 \rightarrow 2NO_3^-$ (II)
- $5CH_3COOH + 8NO_3^- \rightarrow 4N_2 + 10CO_2 + 6H_2O + 8OH^-$ (III)

Obaja et al. (2003) could get some results about treatment of nutrient in SBR system. In working with initial concentrations of 1500 mg/l NH^{+}_{4} –N and 144 mg/l $PO^{3-}{}_{4}$–P, A removal efficiency of 99.7% for nitrogen and 97.3% for phosphate was attained. The ratio C/N must be higher than 1.7 to obtain complete denitrification to molecular nitrogen during the denitrification stage. The SBR can also remove high concentrations of NH^{+}_{4}–N even at temperatures as low as 16 ˚C. (Obaja et al., 2003)

Chiu et al. (2007) told that both the ammonium and the organic loading rates affect the occurrence of the simultaneous nitrification–denitrification (SND) process in the SBR system. The nitrogen removal efficiency decreased gradually with increasing ammonium-loading rates at constant COD loading. Therefore, appropriate control of the carbon source concentration can inspire the SND in a traditional SRB to optimize biological nutrient removal.

Ahmet, (2006) reported that effects of salt concentration (0–6%, w/v) on specific nutrient removal rates from saline wastewater in a sequencing batch reactor (SBR). Specific nutrient (COD, NH_4-N and PO_4-P) removal rates decreased with increasing salt concentration due to adverse effects of salt on microorganisms. Fig . 3 shows the removal rate of COD, NH_4-N and PO_4-P.

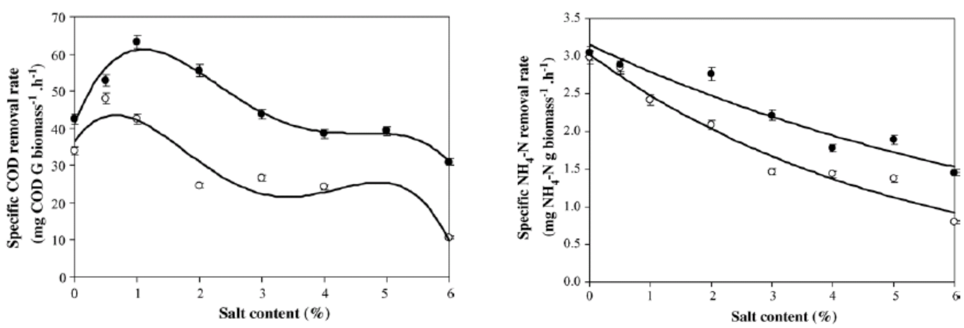


Fig. 3 Variation of specific COD, NH_4-N and PO_4-P removal rate with salt content. (Ahmet, 2006)

Akin et al. (2005), Obaja et al. (2003) and Li et al. (2007) studied to establish control strategies for biological phosphorus and nitrogen removal using Oxidation–reduction potential (ORP), dissolved oxygen (DO) and pH profiles in a Sequencing Batch Reactor (SBR) reactor. To monitor and control biological nutrient removal process, ORP, pH and DO can be used. The ORP can be used as a monitoring parameter to manage biological nitrogen removal in SBR systems. The regulation of ORP allows N of the effluents to be controlled by constantly adapting aeration to the amount of reducing matter present in the sludge. (Obaja et al., 2003) The change in the ORP and pH appears to be related to nitrate concentration and these parameters show a nitrate ''knee'' and the ammonia ''valley'' during the operation. Therefore, the experimental study showed that pH and ORP values can be used as control parameters for denitrification and biological phosphorus removal. However, it is observed that pH profile provide much information during the oxic phase, whereas ORP in the anoxic phase. The pH, ORP, nitrate and phosphate profiles observed in these studies are shown in Fig. 4. The nitrate break point measured by ORP indicates the end of the denitrification period (anoxic to anaerobic conditions), whereas the DO break point indicates the end of the nitrification period. (Akin et al., 2005)

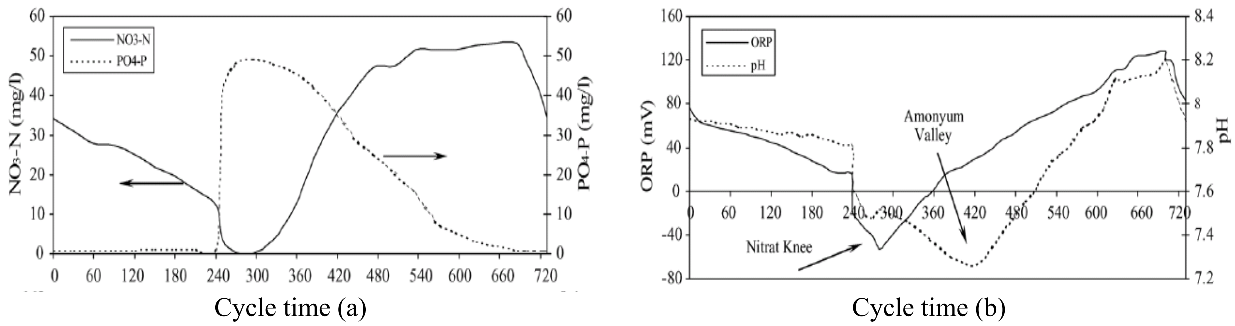


Fig. 4. (a) Nitrate and phosphate, (b) ORP and pH profiles. . (Akin et al., 2005)

Li et al. (2007) reported that both alkalinity and ORP exhibited clear variations in a SBR cycle under different operating conditions (COD, DO, and HRT), but alkalinity presented a better indication for effluent nitrogen concentration than ORP did. The involvement of COD and DO in ORP hindered its clear correlation with effluent nitrogen concentration. Alkalinity exhibited a linear reverse correlation with effluent nitrogen concentration (Alk =−4.26[N] + 216, R^2 = 0.92). Alkalinity lower than 100 mg/L indicated insufficient denitrification, while alkalinity higher than 200–250 mg/L was related with insufficient nitrification. (Li et al., 2007)

Sirianuntapiboona, et al. (2007) studied about removal of Zn^{2+}, Cu^{2+}, Pb^{2+} and Ni^{2+} by bio-sludge in sequencing batch reactor and granular activated carbon-SBR (GAC-SBR) systems. In this study, Sirianuntapiboona, et al. (2007) used both resting (living) and autoclaved (dead) bio-sludge. The results are that The maximum adsorption capacities of Zn^{2+} and Cu^{2+} were about 17–19 mg/g of bio-sludge. The results show that the bio-sludge could adsorb Zn^{2+} and Cu^{2+} from the wastewater, independently. The resting bio-sludge showed COD and BOD_5 removal abilities while dead bio-sludge did not. Cu^{2+} and Zn^{2+} could reduce COD and BOD_5 removal abilities of the bio-sludge, because they masked the adsorption site on the bio-sludge, in competition with organic matters. The heavy metals adsorption efficiency of the system increased with the increase of MLSS concentration of the system. Table 1 shows the efficiency of the removal of heavy metals (Zn^{2+}, Cu^{2}) by bio-sludge in sequencing batch reactor.

The SBR system with short SRT operation was found to be suitable to treat the wastewater containing heavy metals especially Pb^{2+} and Ni^{2+}, because, it could remove both organic matter and heavy metals form the wastewater with high efficiency. The heavy metals (Pb^{2+}, Ni^{2+}) removal efficiency of both SBR and GAC-SBR systems were increased with the increase of hydraulic retention time (HRT), or the decrease of organic loading. The SBR system showed higher heavy metals removal efficiency than GAC-SBR system at the same organic loading or HRT. Both organic and heavy metals (Pb^{2+} and Ni^{2+}) adsorption abilities of bio-sludge were 10–30% reduced by autoclaving at 110 ˚C for 10 min. However, the dead bio-sludge was more suitable to use as the adsorbent of metal ions even the heavy metals adsorption capacity of dead bio-sludge was 10–30% lower than that of living bio-sludge. (Sirianuntapiboona, et al., 2007)

Table 1. The effluent concentration and removal efficiency of wastewater in SBR system (Sirianuntapiboona, et al., 2007)

Types of wastewater	Concentration of heavy metal in the wastewater	Parameters										
		Cu^{2+}		Zn^{2+}		BOD_5		COD		TKN		SS
		Effluent (mg/L)	% Removal	Effluent (mg/L)	% Removal	Effluent (mg/L)	% Removal	Effluent (mg/L)	% Removal	Effluent (mg/L)	% Removal	Effluent (mg/L)
SIEWW containing Cu^{2+}	10	1.52 ± 0.04	84.9 ± 0.4	–	–	23 ± 11	98 ± 1	130 ± 26	92 ± 2	13.9 ± 2.6	72.4 ± 5.5	89 ± 2
	20	4.33 ± 0.70	78.4 ± 3.5	–	–	60 ± 14	94 ± 2	352 ± 27	78 ± 2	31.5 ± 1.4	37.4 ± 3.6	168 ± 3
	30	10.06 ± 0.76	66.5 ± 2.5	–	–	98 ± 53	90 ± 6	348 ± 31	78 ± 2	33.5 ± 2.2	33.5 ± 3.5	3332 ± 4
	40	20.34 ± 1.40	49.2 ± 3.5	–	–	130 ± 14	87 ± 1	328 ± 28	79 ± 2	33.3 ± 3.6	33.8 ± 6.2	409 ± 4
	50	29.50 ± 0.68	41.1 ± 1.4	–	–	143 ± 11	86 ± 1	328 ± 38	79 ± 3	34.2 ± 0.8	32.1 ± 0.7	470 ± 21
SIEWW containing Zn^{2+}	10	–	–	1.31 ± 0.10	87.0 ± 1.1	16 ± 1	98 ± 1	22 ± 2	99 ± 1	10.0 ± 0.2	80.0 ± 0.1	14 ± 1
	20	–	–	3.70 ± 0.47	81.6 ± 2.3	25 ± 5	98 ± 1	37 ± 5	98 ± 1	17.6 ± 1.8	64.8 ± 3.3	25 ± 1
	30	–	–	8.62 ± 1.70	71.3 ± 5.6	28 ± 3	97 ± 1	54 ± 9	97 ± 1	22.0 ± 0.8	55.8 ± 1.9	36 ± 1
	40	–	–	20.22 ± 6.19	49.4 ± 15.5	83 ± 10	92 ± 1	118 ± 6	93 ± 1	26.1 ± 2.4	47.5 ± 5.2	89 ± 1
	50	–	–	25.25 ± 8.17	49.5 ± 16.3	95 ± 13	91 ± 1	194 ± 6	88 ± 1	27.1 ± 1.2	45.6 ± 2.8	108 ± 1

He et al. (2007) studied about influence of the addtion of zeolite powder in SBR system. The results show that the addition of zeolite powder could improve the activity of the activated sludge in SBR reactor, and COD, NH_3-N, TN and TP could be removed in a shorter cycle time and could also improve the nitrification rate and settling property of activated sludge, which is helpful to inhabit the sludge bulking and to enhance the performance of biological nitrogen removal.

Anaerobic sequencing Batch Reactor (ASBR)

Anaerobic sequencing batch reactor (ASBR) is a newly developed technology and has been extensively studied due to its advantages: (Xiangwen et al., 2007)

- No short circuit, as in the case of fixed-bed continuous systems.
- High efficiency for both COD removal and gas production.
- No primary and secondary settles.
- Flexible control.

Despite its operational advantages, the ASBR has not been used as widely in the wastewater treatment industry as other anaerobic processes. One of the reasons is its low performance efficiency if overloaded. (Cheong et al., 2007)

Gregor et al. (2007) reported that about the treatment of brewery slurry, the process phases were adapted to fit the brewery slurry discharge schedule. ASBR experiments were conducted under different organic loading rates (OLR) from 3.23 to 8.57 kg of COD/m^3 day of reactor and control was conducted with OLR of 3.0 kg of COD/m^3 day. The ASBR COD degradation efficiency was from 79.6% to 88.9%, control experiment efficiency was 65%. ASBR VSS removal efficiency was from 78.5% to 90.5%, control experiment efficiency was 54%. The ASBR methane production yield was from 371 to 418L/kg COD inserted, control experiment methane yield was 248L/kg COD inserted.

Combined ASBR–UASB treatment can increase the biogas yield compared to conventional up-flow anaerobic sludge blanket (UASB) treatment for all brewery wastewater. Combined ASBR–UASB treatment can also reduce overall reactor volume by 25% compared to conventional UASB treatment. (Gregor et al., 2007)

Sarti et al. (2007) told that pioneering efforts in reactors design have led to the development of new high rate reactors that can operate at higher loadings than conventional digesters, and systems capable of treating medium to low-strength wastewaters. Therefore, (Sarti et al., 2007) studied that the comparative performance of three pilot-scale anaerobic sequencing batch reactors treating domestic sewage, and the removal efficiencies in the two ASBR1 and ASBR2 reactors operated under mixed liquor recirculation show mean values of COD and TSS removals efficiencies of 40% and 65%, and average removal efficiencies of 60% and 80% for COD and TSS, respectively. Fig. 5 shows the result of the experiment of (Sarti et al., 2007).

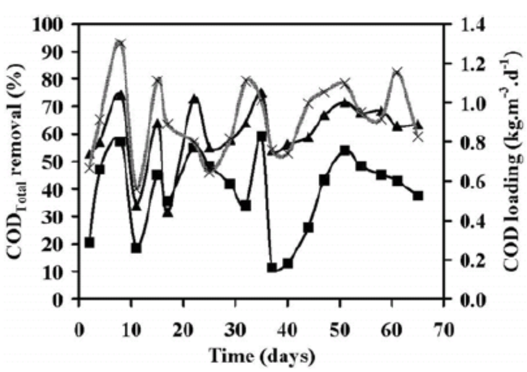


Fig. 5 the COD removal efficiency of two kinds of ASBR and organic loading rate. (Sarti et al., 2007)

Sequencing Batch Biofilm Reactor (SBBR) and Anaerobic Sequencing Batch Biofilm Reactor (ASBBR)

Sirianuntapiboon et al. (2005) reported that a SBBR system installed plastic media on the bottom of the SBR system could increase the removal efficiencies, improve sludge quality, reduce the amount of excess bio-sludge, and also reduce the acclimatization period of the system. The SBBR system was 2–3 d faster than the SBR system in reaching steady state and maintained almost stable removal efficiencies due to the low standard derivation values. Table 2 shows the comparison of the treatment result of SBR and SBBR.

Table 2. The effluent qualities and removal efficiencies of SBR and SBBR system (Sirianuntapiboon, et al., 2005)

SBR system

HRT (d)	Organic loading (g BOD/m^3 d)	COD		BOD		TKN		Oil & grease		Effluent SS (mg/l)
		Effluent (mg/l)	% Removal	Effluent (mg/l)	% Removal	Effluent (mg/l)	% Removal	Effluent (mg/l)	% Removal	
3	1340	912±16	87.0±0.2	805±12	79.9±0.3	51±2	48.7±1.7	41±3	79.3±1	100±12
4	1000	456±11	93.5±0.2	423±10	89.4±0.3	44±1	56.4±0.8	26±1	87.1±0.6	80±10
6	680	190±8	97.3±0.1	176±8	95.6±0.2	38±1	62.3±1.0	16±1	92.1±0.6	25±6
8	500	122±4	98.3±0.1	106±6	97.4±0.2	21±1	79.4±1.1	11±1	94.6±0.5	15±5

SBBR system

HRT (d)	Organic loading (g BOD/m^3 d)	COD		BOD		TKN		Oil & grease		Effluent SS (mg/l)
		Effluent (mg/l)	% Removal	Effluent (mg/l)	% Removal	Effluent (mg/l)	% Removal	Effluent (mg/l)	% Removal	
3	1340	750±7	89.3±0.1	681±10	83.0±0.2	41±1	59.4±0.8	35±1	82.4±0.4	75±11
4	1000	403±6	94.2±0.1	323±6	91.9±0.1	31±1	69.4±1.0	22±3	89.1±1.7	62±8
6	680	150±3	97.9±0.0	120±3	97.0±0.1	21±1	79.3±1.0	11±1	94.8±0.5	15±6
8	500	102±2	98.6±0.0	91±4	97.7±0.1	13±1	87.0±1.3	6±1	97.1±0.5	10±7

Venkata Mohan et al. (2007) reported that Biofilm configured sequencing batch reactor (SBR) showed comparatively higher efficiency to the corresponding suspended growth and granular activated carbon (GAC) configured systems studied with same wastewater and sulfate removal efficiency of 20% was observed due to the prevailing anoxic microenvironment during the sequence phase operation and the existing internal anoxic zones in the biofilm. Table 3 presents the comparison among Biofilm, Suspended GAC and Suspended.

Table 3. Comparative performance evaluation of SBBR with other reactor configurations studied (Venkata Mohan et al., 2007)

Configuration (reactor microenvironment)	OLR (kg COD/ cum-day)	HRT (h)	COD removal efficiency (%)	BOD removal efficiency (%)	SDR (kg COD/ cum-day)	Sulfate removal efficiency (%)
Biofilm (anoxic–aerobic–anoxic)	0.92	24	88.05	88.89	0.81	14.67
	1.50	24	78.68	84.21	1.18	20.10
	3.07	24	56.67	76.00	1.74	22.0
	4.76	24	55.00	75.45	2.62	17.80
	4.76	48	70.24	88.24	3.38	19.82
Suspended GAC (anoxic–aerobic–anoxic)	1.70	24	67.34	86.21	1.13	13.21
	3.50	24	55.19	81.12	1.92	10.62
	5.50	24	37.99	66.01	2.09	9.67
Suspended (anoxic–aerobic–anoxic)	0.80	24	66.36	92.22	0.53	7.79
	1.70	24	47.01	72.67	0.80	8.26
	3.50	24	25.34	57.00	0.88	8.31

Pinho et al. (2005) reported that the anaerobic sequencing batch biofilm reactor (ASBBR) containing biomass immobilized in inert support and homogenized by mechanical stirring offers a potential alternative for accelerating the hydrolysis process, and stirring can help hasten the reduction of the particle diameter of particulate organic matter. The bioparticle size exerted a decisive influence on the performance of the anaerobic process under the conditions tested. The dissolution rates were apparently influenced mainly by the foam packing, whereas the consumption of filtered COD was probably influenced by more complex factors. (Pinho et al., 2005)

Conclusion

Advantages of SBRs are that equalization, primary clarification, biological treatment, and secondary clarification can be achieved in a single reactor vessel. These advantages can reduce the treatment area and cost.

The pollutant removal efficiency of SBR system is shown high removal efficiency for nitrogen and phosphate. And the SBR system can remove heavy metal such as Zn^{2+}, Cu^{2+}, Pb^{2+} and Ni^{2+} with organic pollutant and nitrogen.

The efficiency of SBR system to treat specific nutrient (COD, NH_4-N and PO_4-P) is affected on salt concentration in wastewater due to adverse effects of salt on microorganisms. And the heavy metals such as Cu^{2+} and Zn^{2+} in competition with organic matters could reduce COD and BOD_5 removal abilities, because the heavy metals adsorption efficiency of the system increased with the increase of MLSS concentration of the system.

The comparison of removal efficiency between SBR and SBBR shows that the efficiency of SBBR system is higher than SBR system for COD, BOD. To complement some disadvantages of SBR system such as lots of sludge amount and high sludge volume index, SBBR or ASBBR system is used to treatment of wastewater.

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