Sequential Batch Reactor for Bio Degradation of Organic Wastewater: A Review

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Abstract: Wastewater treatment is challengeable in today’s scenario, as it contains many types and varying physical and chemical pollutants which enormously effect the environment and its living beings. The current review elaborates treatment of various organic effluents using sequential batch reactor (SBR). Reactor operating conditions like anaerobic, anoxic and aerobic in single or mixed forms have been covered in the review. Literatures say that SBR can be used to treat many organic, industrial and municipal wastewater (MWW) successfully. Strict effluent characteristics from government force the individuals to treat the effluent to such extent so that it can match the discharge norms of wastewater.

Keywords: Aerobic Process, Anaerobic Process, Biological Oxygen Demand, Chemical Oxygen Demand, Sequential Batch Reactor.

Introduction

To serve the life, water is one of the foremost essential thing. Without water there is no life on earth. Out of 71% water available in earth, 5% water is contemporary. It is primarily impure by phylogeny sources like industrial, agricultural and household activities. Owing to growing industries and urbanization, contaminants in water is increasing day by day. Discharging untreated wastewater to water bodies lead to several environmental problems like (i) depletion of dissolved oxygen (DO) of the water stream, which is required to aquatic life (ii) untreated wastewater contains large no of pathogens, or disease causing microorganisms, that causes various epidemic diseases, (iii) it can contain toxic compounds which have harmful effects on human health. Therefore, the treatment of wastewater is very important before leaving it in the natural water bodies.

Wastewater can be treated by using different physical, chemical and biological treatment methods including biological degradation, chemical precipitation, adsorption, ion exchange, reverse osmosis, coagulation, flocculation, etc. All these treatment methods have different performance characteristics and also different direct impacts on the environment.

Conventional activated sludge (CAS) is most commonly used method for treatment of wastewater. This process generally not give water discharge quality, therefore, further treatment is required. Moreover, excessive amount of sludge produced in this process is one of the major drawbacks. The sludge produced is highly tough to stabilize and dewater¹. Due to this, effective methods are needed that can produce low sludge to reduce the
prices related to sludge dewatering and sludge production. SBR and MBR is advance process to that of CAS, which give better water quality and low sludge generation. Regulation in operating conditions like DO and sludge retention time (SRT) and addition of chemicals to reduce biomass growth are some options to reduce biomass production. SBR is a biological treatment method and its application has increased significantly than other biological treatment methods is due to (i) inherent flexibility in cycle time can be regulated and different organic load can be treated, (ii) ease of operation and less area is required (iii) low treatment cost (iv) low sludge generation. SBR treatment system consists of five sequencing operation: filling of wastewater to the reactor (fill phase); degradation of organic matter (react phase); settling of biomass (settle phase); withdrawing of treated water from reactor (draw phase) and keeping the reactor to inoperative condition (idle phase) for about 15 – 30 minutes for next cycle. SBR in various forms have been originally used for reduction of COD and BOD from different types of wastewaters. The SBR has several benefits to the activated sludge. The aim of this paper is to highlight the operation and use of SBR for treatment of wastewater.

Sequential Batch Reactor

A SBR is sort of activated sludge method applied for the wastewater treatment. According to 1999 U.S. EPA report, SBR operates based on space and ASP based on time. The operation of SBR has been described by Irvine and Davis. SBR can treat wastewater that is biodegradable, which can be directly generated from process or it can be pretreated by anaerobic digestion. To reduce organic load i.e COD and BOD the air is bubbled through wastewater and activated sludge mixture. The treated effluent could also be appropriate for discharge to water receiving bodies like river, pond, surface waters or presumably to be used towards land. There are many configurations of SBRs, the fundamental method is analogous. SBR installation may consist of one or additional tanks which is operated mainly as fully mixed reactors. The raw waste (influent) enters the one end and treated water (effluent) goes out the opposite. In multiple tank system one tank is operated as settled and decant mode while opposite in aerating and filling mode. This helps to mix the incoming influent and the returned activated sludge. High amount of pollutants like BOD, COD, TS, Total kjeldahl Nitrogen (TKN), phosphorous, oil and grease removal have been observed in treatment of various effluents like Tannery, Paper mill, Coke oven, Distillery, Brewery, Dairy, Piggery, Petrochemical, Textile, Palm oil refinery, complex chemicals, etc.

The SBRs are used for (i) Anaerobic (ii) Aerobic treatment of wastewater which is described below.

Anaerobic Process

Anaoxic SBR are often used for anaerobic treatment processes. During this case, the reactors are purged of oxygen by flushing with nitrogen. As the microorganisms multiply and die, the sludge at intervals in the tank increases with time which is removed using sludge pump. The mass or age of sludge in the tank is closely monitored at time intervals, because it has a vigorous impact on the treatment method. The sludge is allowed to settle till clear water is obtained at the top of the reactor as supernatant, mostly 20-30% of the tank contains sludge. The clear liquid can be further treated or it can be used as water source to vegetables.

Aerobic Process

When oxygen is added to the SBR, it enhances the multiplication of aerobic microorganism so that they can consume the nutrients and hydrocarbons. The method converses ammonia to chemical group and nitrate forms is referred to as nitrification. COD and BOD also reduced by oxidation bacteria. The sludge attached with microorganisms is allowed to settle in the tank. The aerobic microorganism still multiply till the dissolved oxygen is virtually spent. The schematic diagram of SBR process is presented in Figure 1. The utilization of SBR in wastewater treatment is presented in Table 1.
The hydraulic retention time (HRT) and fill time have been found to major effect on SBR operation which is discussed below.

**Effect of HRT**

HRT play an important role during wastewater treatment in SBR. HRT is defined as the time required by the wastewater to pass through the system. Effect of HRT on degradation of pollutants from coking wastewater (CWW) was studied in a pilot plant SBR. Average values of COD = 1100 – 1700 mg/dm$^3$, Phenol = 185 – 253 mg/dm$^3$, thiocyanide = 210 – 485 mg/dm$^3$, ammonia nitrogen = 532 – 567 mg/dm$^3$ contained in CWW. For HRT = 58 – 225 h, COD removal was in between 69 to 81 %, phenol removal was 97 to 99 %, SCN$^- \text{removal was 90 to 98 \%}, \text{NH}_3-N \text{removal was 41 to 85 \%. In the study, 58 h HRT was found to be optimum. A study done by Kushwaha et al.}\text{for the treatment of diary waste water showed 96.5 \% COD removal and 64.61 \% TKN removal at HRT = 24 h. Similar studies were performed by Thakur et al. to treat petroleum refinery wastewater (PRW) which had a COD = 350 ± 25 mg/dm$^3$ and TOC = 70 ± 10 mg/dm$^3$. HRT was varied in between 0.56 to 3.33 days. Among these studies, HRT = 0.83 d gave maximum 80 \% COD and 83 \% TOC removal. The reason for lower COD and TOC removal at HRT> 0.83 was due to lower growth rate of microorganisms and accumulation of older cell.}

**Table 1: Applications of SBR in wastewater treatment**

| S. No. | Wastewater | Experimental Setup/ Waste properties | Parameters observed | Result/ Conclusion | Reference |
|-------|------------|--------------------------------------|---------------------|--------------------|-----------|
| 1     | Wastewater from pulp and paper mill | The Laboratory scale reactor consists of four 4 dm$^3$ capacity with the use of aquarium type air pump for aeration. Minimum of 2 mg/dm$^3$ of DO level were maintained. The experiments were performed at 25–30 °C. Wastewater characterized as COD of 1200-1400 mg/dm$^3$, BOD of 550-790 mg/dm$^3$, TSS of 200-500 mg/dm$^3$ and pH varies form 6.2-6.6. | Effect of MLSS concentration, volume exchange rate, aeration time, temperature and cycles per day. | COD removal efficiency under the optimized condition was 93 \%, at MLSS = 4500 mg/dm$^3$, aeration time = 5 h per cycle, temperature = 30 °C | Tsang et al. (2007) |
| 2     | Landfill leachate. | The reactors, with a working volume of 6 dm$^3$ each were used. The stirrers was operated at 36 rpm. The leachate was supplied to the reactors for 4 h of the cycle at 0.125 dm$^3$/h (SBR 1), 0.2 dm$^3$/h (SBR 2), 0.5 dm$^3$/h (SBR 3) and 0.75 dm$^3$/h (SBR 4). All the four SBRs were operated at HRT of 12, 6, 3 and 2 d. | COD and BOD$\delta$ removal efficiency and bio mass yield co-efficient was observed. | The process had littleeffect to BOD$\delta$ removal efficiency, while better COD removal efficiency. | Kulikowska et al. (2007) |
| 3     | Treatment of municipal solid | The comparison of SBR with normal working procedure (Control reactor) to the SBR using zeolite powder to increase the activity of sludge was | Operational efficiency of both the SBRs in removing COD. | The addition of Zeolite powder enhanced the activity of the | He et al. (2007) |
|   | wastewater | performed. The reactors used were of 0.3 m diameter and 0.6 m height with an effective volume of 31.1 dm$^3$. The characteristics of the wastewater used in the study was SS = 94-212 mg/ dm$^3$; COD = 274-421 mg/ dm$^3$; NH$_4$$^+$N = 25.5-44.2 mg/ dm$^3$; TN = 33.5-68.7 mg/ dm$^3$; TP = 2.65-4.85 mg/ dm$^3$ and pH = 6.67-7.86. The Zeolite concentration was maintained at 1000 mg/ dm$^3$. |   | TN, NH$_4$$^+$N and TP. Variation of DO in operating cycle and comparison of sludge characteristics | sludge and specific O$_2$ utilization rate. The pollutants like COD, TN, NH$_4$$^+$N and TP was removed in shorter length of time. The zeolite contained reactor treated 1.22 times more wastewater than normal SBR. |
|---|-----------|-------------------------------------------------|---|-----------------|----------------------------------|
|   | Treatment of synthetic phenolic wastewater. | Two identical SBRs of working volume of 5 dm$^3$ were used. It was operated with fill, react, settle and draw periods in the ratio of 4:6:1:1 for a cycle time of 12 h. First reactor was aerated during fill and react phase, while the second was aerated only in the react phase. |   | The performance of SBR was evaluated for aerated and unaerated fill phase. | The fill mode was not effective for phenol and COD reduction; The kinetic studies found to high concentration of phenol has an inhibitory effect on the degradation rate of phenol. |
|   | Landfill leachate | The SBR bioreactor was made of plexiglas with operating volume of 50 dm$^3$. It was operated with the cycle time of 24 h with fill phase 2 h, anoxic phase 2 h, aeration 18 h, settling 1 h, decant and idle period 1 h. |   | Removal of COD BOD and N. Change of alkalinity and cycle time study | Removal efficiencies of COD = 93.28%, BOD = 98.76%, TN = 84.74% and NH$_4$$^+$-N = 9.21% |
|   | Synthetic wastewater | Three identical SBRs were used in the study with anaerobic/aerobic sequence to reduce COD and phosphorus. The working volume of the reactor was 4 dm$^3$ with the operating cycle of 14 h. |   | COD and phosphorus removal. | Complete removal of 20 mg/dm$^3$ PO$_4$$^{3-}$ P was achieved in 35 d of operation. The COD removal efficiency was 90% |
|   | Synthetic wastewater | Four cylindrical SBR of 127 cm height and 5 cm diameter with a working volume of 2.5 dm$^3$ was used with 5 mints for filling and 5 mints for decantation. Total operating cycle was 4 h. The air flow rate was maintained to 3 dm$^3$/min. |   | Granular characteristics and sludge settlability. | Granules were successfully cultivated and settled in 5 mints |
|   | Synthetic wastewater | The SBR was operated under different conditions. It consists of a 5 dm$^3$ working volume with microprocessor controlled for aeration, pH, agitation and DO. SBRs performance was done with three different operating schemes i.e. one with three step operation: anaerobic (An)/ anoxic (Ax)/oxic (Ox); four step operation: An/Ox/ Ax/Ox and five step operation: An/Ax/Ox/Ax/Ox |   | COD, phosphate and nitrogen removal. | The most of the COD and ammonium were removed during the first three steps. However, for removal of phosphate-P and nitrate-N five-step operation was required. |
|   | Petroleum refineries | SBR with working volume 15 dm$^2$ at 15°C was used. One third of the Amonical nitrogen and phenol Upto 95%, NH$^+$ and phenol removal |   | | Silvia et al. |

Chan and Lim (2007) | Zhou et al. (2006) | Sarioglu (2005) | Qin (2004) | Kargi and Uygur (2003) | Silva et al. |
| No. | Process Details | Description                                                                 | Results                                                                                     |
|-----|----------------|------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| 10  | Phenolic       | Application of granulated activated carbon (GAC) in SBR to treat wastewater with phenolic shock loading was studied. Two reactors of 12 dm³ and operating volume of 10 dm³ was used. The adsorbent used was lignite based granular activated carbon with 0.75 mm diameter. Adsorption characteristics of GAC, step-up shock loading, short term fluctuation and stepwise augmentation for phenol removal. | SBR with GAC was found to high stability to phenol shock loading and worked as a buffer by adsorbing the high strength of influent phenol and as a supporting media for microorganisms. |
| 11  | Petrochemical wastewater | The three phase experiments were performed for study of different parameters in four reactors of glass cylinder have capacity of 3.5 dm³. The working volume of SBRs was 2 dm³. The flow rate of wastewater was 2 dm³/d and 0.4dm³/d. The HRT was maintained to 2 d and SRT to 10 d. Phenol removal at different operating parameters. Degradation of phenol reached to less than 0.1 mg/dm³ from 950 mg/dm³. | The work done by various researchers are presented below: Hsu (1986). |

**Effect of Fill Time**

The reactor needs to give feed which has to be treated. Amount of total feed given in particular time is known as fill time. Thakur et al. studied the fill time variation for COD and TOC removal of PRW. In fill time of 0.5, 1 and 2 h, respectively, COD removal efficiencies were 58%, 68% and 74%, and TOC removal were 28%, 51% and 59%. Pollutants removal rate was low initially for higher fill time, which was increased when time proceeded. Effect of fill time was also performed by Kushwaha et al. For fill time = 0 to 2 h, they have also found increase in COD reduction with increase in fill time. DO was found to increase with increase in fill time. Yu and Gu, did fill time studies for treatment of synthetic phenolic wastewater in the two SBRs which was operated at aerated fill and un-aerated fill conditions. When phenol concentration was low (< 400 mg/dm³), the SBR was operated at un-aerated fill condition performed better to that SBR operated with aerated fill condition. It was noted that at higher phenol concentration (> 800 mg/dm³), accumulation of phenol during fill period had become inhibitory to microorganisms causes low phenol removal efficiency and low growth of dispersed biomass. The studies show, fill strategies should be selected according to wastewater composition, biodegradability and concentration of toxic substances in wastewater.

As we know that SBR has been utilized for treatment of various effluents. The work done by various researchers are presented below:

Sarfaraz et al. conducted anoxic treatment for degradation of phenol in SBR using granular denitrifying sludge. The different cycle lengths and influent phenol concentration was main variable parameters. In the process upto 80% phenol was degraded from its initial value of 1050 mg/dm³ at cycle length of 6 h, which was corresponded to 6.4 g COD/dm³.d. When phenol concentration was increased, the phenol and COD removal efficiencies was decreased. Tomei et al. performed the biodegradation of 4-nitrophenol (4NP) in a SBR. In the experiments, both long feed phase and high biomass concentration showed much effective to reduce the 4 NP. Sahinkaya and Dilek investigated the biodegradation kinetics of 4-chlorophenol (4-CP) and 2,4-dichlorophenol (2,4-DCP) separately in batch reactors and in mixed SBR. Fang et al. investigated removal efficiency of phenol from synthetic wastewater using anaerobic thermophilic condition (55°C). Maximum phenol removal 99% was achieved at HRT of 40 h.
Shariati et al.\(^4\) have treated synthetic petroleum wastewater in a SBR at different HRT, similarly, Kutty et al.\(^4\) also used six different SBR to treat PRW having COD concentration in the range of 500-750 mg/dm\(^3\). Experiments were performed at anaerobic and aerobic modes with a 24 h cycle in 2 dm\(^3\) reactor. The process gave COD removal of 91\%, 91\%, and 88\% respectively, for aerobic reactor, combined anaerobic-aerobic reactors and aerobic mixed.

Derlon et al.\(^4\) studied the formation of aerobic granular sludge in SBR for MWW treatment. Granular sludge formation was possible at low upflow velocities during anaerobic feeding phase. In a study by Alvarez et al.\(^4\) for treatment of DS in a two stage anaerobic pilot plant technique, total COD removal of 49\% - 65\% obtained with a 35.1\% methane conversion from influent COD.

Gutiérrez\(^3\) et al.\(^3\) did the lab scale removal of carbon and nitrogen from dairy wastewater using SBR. They used a 15 dm\(^3\) reactor for treatment and found the aeration time 4.5 h to optimum. During operation, the HRT was 4 days and 20 days. In the process, COD reduction reached to 97\% and total nitrogen to 90\%. Similarly, studied by Kushwaha et al.\(^4\) for treatment of dairy wastewater, the optimization of parameters like fill time, HRT, sludge disposal was done. Up to 97.05 % COD removal and 63.08 % TKN removal was observed. Rajabet et al.\(^3\) investigated the performance of a lab scale anaerobic/aerobic SBR for poultry slaughterhouse wastewater. The anaerobic reactor of volume 12 dm\(^3\) was used but the aerobic reactor volume varied according to the flow rate. Experiments were performed at room temperature of 26-28°C. The results obtained were overall COD removal of 97\% ± 2\%, NH\(_2\)-N removal 98\% ± 1.3\%, oil and grease removal 90\% ± 11\% and total suspended solids (TSS) removal 96\% ± 3\%.

González et al.\(^5\) worked on the photo fenton oxidation and sequential batch biofilm reactor. For 200 mg/dm\(^3\) of antibiotic sulfamethoxazole containing water, the 75.7\% TOC removal obtained. Biodegradation of organic compounds Dichlorodiethyl ether (DCDE) was performed in SBR. For this, removal of organic was 92\% in term of COD and 95\% in term of TOC. Miquelot et al.\(^5\) analysed the performance of anaerobic SBR for COD removal of synthetic glucose solution. At optimum condition, 93-97\% COD removal was seen for 500 mg/dm\(^3\) glucose solution. Evaluation and characterization of granular formation was performed by Jang et al.\(^5\) in aerobic and anoxic conditions. After 50 days of operation, the size of granules was found to be 1 ± 0.35 to 1.39 ± 0.45 mm. COD removal and nitrification efficiency was 95\% and 97\% respectively.

Frigon et al.\(^5\) treated the cheese whey wastewater sequentially in anaerobic and aerobic SBR. They found, in first 48 cycles (each cycle of 2, 3 and 4 days) with organic loading rates of 0.56, 1.04 and 0.78 gCOD/dm\(^3\)/d, for 2, 3 and 4 days, respectively; COD removal was 89 ± 4\%, 97 ± 3\% and 98 ± 2\%. Whereas, in the second 16 cycles (each cycle of 2 days) with organic loading rate 1.55 gCOD/dm\(^3\)/d, COD removal was 88 ± 3\%. High strength semiconductor wastewater using fenton oxidation was performed in SBR by Lin et al.\(^5\). In the process, 95\% COD and 99\% color removal was seen after fenton oxidation with a 5 g/dm\(^3\) FeSO\(_4\) dosage and 45 g/dm\(^3\) H\(_2\)O\(_2\) concentration and 180 min of digestion.

Some of the literatures are listed in Table 2.

| S. No. | Authors | Type of wastewater and initial values (mg/dm\(^3\)) | Aerobic/Aerobic Process | Reactor configuration and operating conditions | Results at optimum condition % Removal, values (mg/dm\(^3\)) |
|--------|---------|-----------------------------------------------|------------------------|-----------------------------------------------|------------------------------------------------|
| 1      | Maranço \`n et al.\(^3\) (2008) | Coke wastewater COD = 1303 Phenol = 207 SCN\(^-\) = 244 NH\(_4\) - N = 489 | Aerobic condition | Height = 6 m Volume = 1500 dm\(^3\) HRT = 58 h System composed biological SBR, stripping unit and homogenization tank | COD = 85\% SCN\(^-\) = 98\% phenol = 99\% |
| 2      | Jiang et al.\(^6\) | Synthetic wastewater (aniline) | Anaerobic/aerobic/anoxic | Diameter/Height = 6.67 Volume = 9 dm\(^3\) HRT = 12 h | COD = 95.80\% NH\(_4\)-N = 83.03\% TN = 87.13\% |

Table 2: Wastewater treatment through sequential batch reactor (SBR)
| (2016) | COD = 900 | (A/O/A) | DO = 5.5 ± 0.5 | TP = 90.95% |
|--------|-----------|---------|---------------|-------------|
| 3 Kushwa ha et al. (2013) | Dairy wastewater COD = 3900 TKN = 113.18 | Aerobic condition | Working Volume = 5 dm³ HRT = 24 h | COD = 96.7% TKN = 76.7% |
| 4 Sarti et al. 67 (2007) | Domestic sewage COD = 600-1200 | Anaerobic condition | Total Volume = 1.2 dm³ | COD = 65% Suspended solid = 79% |
| 5 Sarti et al. 68 (2007) | Domestic sewage COD = 119-701 | Anaerobic condition | Total Volume = 1.2 dm³ Diameter = 1m Height = 1.5m Anaerobic sequencing batch biofilm reactor (ASBBR) immobilized in inert support (polyurethane foam cubes). | COD = 40%–83% |
| 6 Pereira et al. 69 (2009) | Synthetic wastewater. Formaldehyde COD = 31.6 ± 8.7 to 1104.4 ± 130.8 | AnSBR | Total Volume = 5 dm³ Diameter = 0.23 m Biomass immobilized in polyurethane foam cubes. HRT = 212 d Temperature = 35°C cycles = 8 h each | formaldehyde = 99.3% COD = 70.8% |
| 7 Stadler et al. 70 (2015) | Pharmaceutical wastewater | Aerobic, anoxic/aerobic, and microaerobic conditions | Working Volume = 1.8 dm³ DO = 0.3 | COD = 93 ± 2% |
| 8 Jiang et al. 71 (2016) | Phenolic wastewater. Phenol concentration = 200 to 1400 | - | Working Volume = 1 dm³ | Phenol = 100% |
| 9 Akin et al. 72 (2004) | Synthetic wastewater COD = 400 Phosphate = 21 Ammonia = 53 | Anaerobic/anoxic condition | Total Volume = 10 dm³ SRT = 25 d | Phosphate = 80% Ammonia nitrogen = 98% COD = 97% |
| 10 Gimeno et al. 73 (2016) | Synthetic MWW | Aerobic SBR followed by solar Photocatalytic oxidation | Total Volume = 1.8 dm³ Nine pharmaceuticals model compounds (acetaminophen ACM, antipyrine ANT, caffeine CAF, ketorolac KET, metoprolol MET, sulfamethoxazole SFX, carbamazepine CARB, hydrochlorothiazide HCT and diclofenac DIC) were analyzed | Single ozonation = 34% Photocatalytic ozonation = 41.3% |
| 11 Liang et al. 74 (2013) | Synthetic wastewater TOC = 550-600 NH₄⁺-N = 50 | Anaerobic condition | Diameter = 0.1016 m Height = 0.7 m Working Volume = 1.7 dm³ High pressure system (HP) = 3 bars | Granulation was high at high pressure condition |
| 12 Sharma et al. 75 (2010) | Resorcinol = 50 | Aerobic | Diameter = 0.13 m Working Volume = 2 dm³ | Resorcinol = 85.81% |
| No. | Authors et al. (Year) | Description/Condition | Details | Results/Findings |
|-----|----------------------|------------------------|---------|-----------------|
| 13  | Leong et al. (2011)  | Synthetic wastewater  | Phenol = 100-400 | Aerobic condition |
|     |                      |                        | Working Volume = 28 dm³ | Height = 0.30 m |
|     |                      |                        |                      | Width = 0.15 m  |
|     |                      |                        |                      | Length = 0.35 m |
|     |                      |                        |                      | Flow rate = 58 ml/min |
| 14  | Durai et al. (2011)  | Tannery wastewater.   | COD = 6240, 4680, 3220, 1560 | Aerobic condition |
|     |                      |                        | Total Volume = 10 dm³ | HRT = 2-3 d |
|     |                      |                        |                      | COD = 90.4% |
|     |                      |                        |                      | Color = 78.6% |
| 15  | Rasheed et al. (2010)| Petrochemical wastewater. | COD = 40,000, Total Solids = 1700, Dissolved Solids = 700, SS = 1000 | Aerobic, anoxic, and anaerobic modes |
|     |                      |                        | Total Volume = 1 dm³ | DO = 2.2 mg/dm³ |
| 16  | Thakur et al. (2014) | PRW COD               | 350 ± 25, TOC = 70 ± 10 | Aerobic condition |
|     |                      |                        | Working Volume = 5 dm³ | Fill time = 2h |
|     |                      |                        |                      | HRT = 0.83 d |
|     |                      |                        |                      | COD = 80% |
|     |                      |                        |                      | TOC = 83% |
| 17  | Jang et al. (2003)   | Synthetic wastewater  | COD = 300            | Anaerobic/anoxic |
|     |                      |                        | Working volume = 8 dm³, Total height = 150 cm, Internal diameter = 10 cm SVI value = 70-90 ml/g | COD = 95% |
| 18  | Yang et al. (2003)   | Synthetic wastewater  | COD = 500 NH₄-N = 400, NO₃-N = 20 | Aerobic, Anaerobic/anoxic |
|     |                      |                        | 4 columns having working volume = 2.4 dm³, Total height = 80 cm Diameter = 6 cm was operated for 1 year | COD = 95% |
| 19  | Prokopov et al. (2014)| Municipal wastewater  | COD = 274, BOD₅ = 119, Total nitrogen = 25.7, Total phosphorus = 3.8 Suspended solids = 79 | Aerobic condition |
|     |                      |                        | 3 aereration basins of SBR with aerobic sludge stabilization, dewatering and lime conditioning was done | COD = 95.7% |
|     |                      |                        |                      | BOD₅ = 96.6% |
|     |                      |                        |                      | TKN = 81.3% |
|     |                      |                        |                      | TP = 53.7% |
|     |                      |                        |                      | Suspended solids = 95.7% |
| 20  | Xiangwen et al. (2008)| Brewery wastewater  | COD = 22500–32500  | AnSBR |
|     |                      |                        | HRT = 1 d (60 days operation) | A pilot scale ASBR was used for COD removal of wastewater and gas production |
|     |                      |                        |                      | COD > 90% |
|     |                      |                        |                      | Gas production = 2.4 L/d |
| 21  | Bao et al. (2009)    | Synthetic COD = 1120  | Sequencing Biological airlift reactor | Volume = 5 dm³ |
|     |                      |                        |                                           | COD = 90.6 -95.4% |
| 22  | Yang et al. (2008)   | Glucose-synthetic wastewater | COD = 1000 | SBR |
|     |                      |                        | Volume = 2.4 dm³ | COD = 90 % |
| 23  | Wang et al. (2008)   | Municipal wastewater COD = 400 | SBR | Volume = 12 dm³ |
|     |                      |                        |                      | HRT = 0.6 d |
|     |                      |                        |                      | COD = 83.3 % |
| 24  | Sharma               | Resorcinol SBR         | Volume = 2 dm³ | Resorcinol = 85.81 |
| Reference | Process | COD | Medium | Vol | HRT | COD | Percentage |
|-----------|---------|-----|--------|-----|-----|-----|------------|
| Chin and Ng (1987) | Palm oil refinery | 1500 | | | | SBR | 2 dm³ | 2 dm³ | 50 % |
| Fakhru'l-Razi et al. (2010) | Oil field produced water | 1300 | | | | Membrane-coupled sequencing batch reactor | 5 dm³ | 20 d | 90.9 % |
| Jern (1987) | Piggery | 2028 | | | | SBR | 8 dm³ | 24 d | 81 % |
| Kim et al. (2008) | Synthetic wastewater | 1760 | | | | SBR | 8 dm³ | 24 d | 93 % |
| Nava et al. (2008) | Stainless steel rinse wastewater | 335.4 | | | | SBR | 3 dm³ | 2 dm³ | 78 % |
| Wang et al. (2007) | 2,4-di chloro phenol = 50 -100 | | | | | SBR | 4 dm³ | 8 h | 99 % |
| Chan and Lim (2007) | Phenol = 10-100 | | | | | SBR | 5 dm³ | 12 h | Phenol = 99 % |
| Tomei et al. (2003) | 4-Nitrophenol = 320 - 400 | | | | | SBR | 5 dm³ | 8 h | 4-Nitrophenol = 98 % |
| Chiavola et al. (2010) | Polycyclic aromatic hydrocarbons = 70 | | | | | SBR | 5 dm³ | 168 h | Polycyclic aromatic hydrocarbons = 80 % |
| Monsalvo et al. (2009) | Phenol = 525 | | | | | SBR | 2.5 dm³ | 12 h | Phenol = 41 % |
| Papadimitriou et al. (2009) | Phenol = 1400, Cyanide = 100 | | | | | SBR and CSTR | 5 dm³ | 12 h | Phenol and Cyanide = 93 % |
| Moussavi (2010) | Saline Phenol = 100 - 2000 | | | | | Granular SBR (GSBR) | 4 dm³ | 17 h | COD = 92% – 99% Phenol = 93% – 99% |
| Tomei and Annesini (2008) | Phenolic, 4-Nitrophenol = 40 – 60 | | | | | SBR | 5 dm³ | 8 h | Phenol = 90 – 95 % |
| Farooqi et al. (2008) | Phenol = 200-1000 and m-Cresol | | | | | SBR | 1.4 dm³ | 6 h | Phenol and m-Cresol = 90 – 95 % |
|   | Author(s)                                      | Process | Conditions | COD (%)  |
|---|-----------------------------------------------|---------|------------|----------|
| 39 | Yoong et al. (2000)                           | Phenolic, Phenol = 312 | SBR | Volume = 5 dm³, Cycle time = 4 h, HRT = 10 h, SRT = 4 d | COD = 97 % |
| 40 | Chiavola et al. (2010)                        | River Sediments COD = 200 – 4000 | Bench-scale, SS (sediment slurry) SBR | Volume = 5 dm³, Cycle time = 7 h, HRT = 70 d | Total PAH (polycyclic aromatic hydrocarbons) = 70 mg/kg (dry weight) |
| 42 | El-Gohary and Tawfik (2009)                   | Textile COD = 595 ± 131 | Aerobic | Volume = 4 dm³, HRT = 5 d | COD = 68.2 % |
| 43 | Xiangwen et al. (2009)                        | Brewery | AnSBR, Volume = 45 dm³, HRT = 1 d | COD > 90 % |
| 44 | Oliveira et al. (2008)                        | Automobile COD = 1400 | AnSBBR | Volume = 5 dm³, Cycle time = 8 h | COD = 88 % |
| 45 | Neczaj et al. (2008)                          | Dairy and Leachate | Aerobic | Volume = 3.5 dm³, Cycle time = 24 h, HRT = 12 d | COD = 98.4 % |
| 46 | Wang et al. (2007)                            | Brewery COD = 239 | Aerobic | Cycle time = 6 h | COD = 88.7 % |
| 47 | Tsang et al. (2007)                           | Paper Mill COD = 1200 - 1400 | Aerobic | Volume = 4 dm³, HRT = 1.6 – 3 d | COD = 93.1 ± 0.3 % |
| 48 | Mohan et al. (2007)                           | Dairy COD = 10400 | AnSBR | Volume = 2.3 dm³, Cycle time = 12 h, HRT = 1 d | COD = 65 % |
| 49 | Ganesh et al. (2006)                          | Tannery COD = 1908 | Aerobic | Volume = 8 dm³, Cycle time = 12 h, HRT = 2 d | COD = 80 - 82 % |

**Conclusions**

Following conclusions are drawn from the review

1. SBR can be applied for the treatment of almost all the industrial and MWW with wide variety of organic (COD) contents.
2. It is better to conventional activated sludge process in terms of space requirement and extent of pollutant removal.
3. SBR can bear shock load of organics, thus it can be used at low and high organic contents in wastewater.
4. It can be used at anaerobic, anoxic and aerobic conditions.
5. Sludge generation is less so management of sludge is easy.

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