Sequencing Batch Reactor in Indusrial Wastewater Treatment: A Review

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Abstract

Sequencing batch reactor (SBR) is a viable alternative in the treatment of industrial wastewater such as dairy, textile, paper, piggery, brewery, tannery, petrochemical, pharmaceutical, shrimp aquaculture and other industrial wastewaters. SBR is found to be low cost, efficient and flexible technology in treating different industrial wastewater, mainly because of its single-tank design and ease of automation. This review includes relevant experiments carried out for industrial wastewater treatment by using the laboratory, pilot-plant and industrial scales-SBR.

Key words: Sequencing batch reactor, industrial wastewater treatment, laboratory scale-SBR.

1. Introduction

SBRs are used all over the world and have been around since the 1920s. With their growing popularity in Europe and China as well as the United States, they are being used successfully to treat both municipal and industrial wastewater, particularly in areas characterized by low or varying flow patterns. Improvements in equipment and technology, especially in aeration devices and computer control systems, have made SBRs a viable choice over the conventional activated-sludge system [1].

Sequencing batch reactor is a fill and draw type sludge system which operates in time rather than in space. SBR performs equalization, neutralization, biological treatments and secondary clarification in a single tank using timed control sequence and in some cases primary clarification [2]. The SBR process is characterized by a series of process phases including, fill, react, settle, draw and idle, each lasting for a defined period.

The treatment of industrial, high-strength organic wastewater is often complex, since many industries experience wide fluctuations in both the quantity and quality of their waste streams [3]. High strength wastewaters are currently produced from various industrial plants including dairy, textiles, paper mill, and tanneries, etc. Generally, untreated wastewater contains high levels of organic material, numerous pathogenic microorganisms, as well as nutrients and toxic compounds. Wastewaters generated from these processes contain a large number of pollutants at high concentrations and have adverse environmental impacts. Sequencing batch reactor (SBR) is one of the best available techniques for the biological treatment of industrial wastewaters. This review examines the use of the laboratory, pilot-plant and industrial scales-SBR for the treatment of the various industrial wastewaters.

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2. Use of SBR for Treatment of Various Industrial Wastewater

2.1. Dairy wastewater

Dairy industry wastewaters are characterized by their high content in nutrients, especially nitrogen (400 mg/l TKN and 20-50 mg/l TP). The SBR system would be more suitable to treat daily industry wastewater because of its ability to reduce nitrogen compounds by nitrification and denitrification [4].

Mohamed and Saed [5] demonstrated SBR efficiency in the treatment of wastewater from a dairy plant. The sequence followed by the SBR consisted of a 30-min aeration feed, 12-h reaction with O_2, 1-h settling period without O_2, 30-min draw without O_2, and 15-min idle phase. With this cycle, removals of 96.7% of NH_3-N, 94% of COD, and 96% of SS were achieved.

Samkutty et al. [6] studied biological treatment of dairy plant wastewater with SBR. After 2 months of operation, very significant reductions of some parameters were reached (97% BOD, 93% COD, 97% TSS, 76% TS). The conclusion was that an SBR is a good system for the primary and secondary treatment of dairy wastewaters.

Dugba and Zhang [7] evaluated the temperature-phased anaerobic sequential batch reactor (AnSBR) for dairy wastewater treatment. Thermophilic (55^{o}C)-mesophilic (35^{o}C) system was tested at two different hydraulic retention times (HRTs) (3 and 6 days) and five loading rates (2, 3, 4, 6, and 8 g/l day). Both thermophilic and mesophilic system was found to be more effective in solids removal, biogas production and coliform bacteria destruction.

Torrijos et al. [8] studied SBR technology for treating wastewater from small cheese-making plants. The SBR technology is extremely flexible and effective with removal of 97.7% total COD and 99.8% BOD_5 for treating wastewater from cheese-making industry.

Li and Zhang [9] studied the aerobic treatment of dairy wastewater using single-stage and two-stage SBR systems with various organic load and HRTs. A 1-day HRT was found sufficient for treating 10,000-mg/l COD wastewater, with the removal efficiency of 80.2% COD, 63.4% total solids, 66.2% volatile solids, 75% total Kjeldahl nitrogen, and 38.3% total nitrogen from the liquid effluent For complete ammonia oxidation in the single-stage SBR system, 4 d HRT was required. However, 1/3 HRT was required in a two-stage system (SBR and a complete-mix biofilm reactor) for complete ammonia oxidation as compared to the single SBR system.

Mohseni and Bazari [10] investigated the treatability of a wastewater from a milk factory in a bench-scale sequencing batch reactor. More than 90% COD removal efficiency was achieved in the reactor with minimum influent COD.

Sirianuntapiboon et al. [11] examined treatment efficiencies for treatment of dairy wastewater by using conventional sequencing batch reactor system and sequencing batch bio-film reactor (SBBR) system. The COD, BOD_5, total TKN and oil & grease removal efficiencies of the MSBR system, under a high organic loading of 1.34 kg BOD_5/m^3-d were 89.3±0.1, 83.0±0.2, 59.4±0.8, and 82.4±0.4%, respectively. The respective removal efficiencies in the conventional SBR system were only 87.0 ± 0.2, 79.9 ± 0.3, 48.7 ± 1.7, and 79.3 ± 10%, respectively. The bio-sludge generated in MSBR was also three times lower as compared to conventional SBR.

Zinatizadeh et al. [12], studied influence of process and operational factors on a sequencing batch reactor performance treating stimulated dairy wastewater by using a lab-scale SBR, The experiments were carried out based on a Central Composite Design (CCD) and analyzed using Response Surface Methodology (RSM) giving COD removal efficiency of 96.5% for COD 3000 mg/l, MLVSS 5000 mg/l, and aeration time of 18 hours.

2.2. Textile wastewater

The kind of industrial activity associated with textiles can lead to major negative impact on the environment, both in terms of pollutant discharge as well as of water and energy consumption. The major pollutant types identified in textile wastewater are organic load, colour, nutrients (N and P), sulfur, toxicants, and refractory organics [13].

Lorenço et al. [14] investigated the effect of sludge age on decolorization in SBR system . An improvement in COD and decolorization of Brilliant Violet 5R by increasing sludge age from 10 to 15 days was obtained while there were no differences in the performance of the system for Remazol Black B for sludge retention times of 15 days and 20 days.

Fongsatitkul et al. [15] investigated textile wastewater by single process as well as in association with chemical oxidation at different conditions. With single biological(SBR) process, the reduction of 83.3% COD, 94.1% TKN, 77.4% TP and 35.5% colour was found. They found to be independent of variation in the anoxic time period of process, however, an increase in solids retention time (SRT) improved COD and colour removal, although it reduced the nutrient (TKN and TP) removal efficiency.

Çınar et al. [16] investigated the effects of cycle time on the biodegradation of the azo dye remazol brilliant violet 5R (RBV-5R) in an anaerobic–aerobic sequencing batch reactor (SBR). Aerobic phases of SBR with total cycle times of 48 h, 24h and 12h were able to remove benzene-based aromatic amines with removal efficiency of 64%, 92% and 89%, respectively.

Vaigan et al. [17] investigated the treatability of a reactive dye (Brill Blue KN-R) by sequencing batch reactor and the influence of the dye concentration on system performance. The dye concentrations were adjusted to be 20, 25, 30 and 40 mg/L in the reactors R1, R2, R3 and R4, respectively. According to the obtained data, average dye removal efficiencies of R1, R2, R3 and R4 were 57% ± 2, 50.18% ± 3, 44.97% ± 3 and 30.98% ± 3, respectively. The average COD removal efficiencies of all reactors were 97% ± 1, 97.12% ± 1, 96.93% ± 1 and 97.22% ± 1, respectively.
Farabegoli et al. [18] investigated biological decolorization of RR 195 under alternate anaerobic–aerobic conditions in a laboratory scale Sequencing Batch Reactor (SBR) containing a mixed culture and fed with a biodegradable carbon source. The optimal operating conditions were found

to be: 800 mg/l influent COD, 50 d SRT and a 24 h-cycle. Under these conditions, the maximum color efficiency of 97% was achieved for a 40 mg/l RR 195 in the feed.

Talouizte et.al. [19] studied the efficiency of aerobic SBR in treating real textile wastewater when operated at optimized conditions. Optimum removal efficiencies were attained under a low OLR of 0.3 kg COD/m^3- d, 30 days sludge age and biomass concentration of 2450 mg/l. COD, color and SS removal efficiencies attained 93.28, 99.41 and 99.9% respectively.

2.3. Paper wastewater

Pulp and paper making industry is know to generate large quantities of highly polluted wastewater, especially the lignin derived dissolved organic compounds used and/ or formed during the paper production processes [20].

Tripathi and Allen [21] investigated the effect of temperature in laboratory scale-SBR over 40 weeks for bleached kraft pulp mill effluent. They found that 63-75% COD and 20-70% AOX removal efficiency at the different temperature (35 ^oC and 60 ^oC).

Sirianuntapiboon [22] studied application of Granular Activated Carbon-Sequencing Batch Reactor (GAC-SBR) system for treating pulp and paper industry wastewater. The COD, BOD_5 and colour removal efficiencies of SBR system were 73.26%, 95.10 % and 56.96% respectively under HRT 1 day and were up to 90.60%, 91.84% and 52.94% respectively under HRT of 10 days.

Tsang et al. [20] studied the effects of operating parameters, including mixed liquor suspended solid (MLSS) concentration, volumetric exchange rate (VER), aeration time, temperature and daily operation cycle on biological treatment of the pulp and paper mill effluent using sequencing batch reactors. Under the optimal condition of MLSS concentration at 4500 mg/l, VER at 50%, aeration time for 5 h per cycle, temperature at 30 ^oC and 2 operation cycles per day, chemical oxygen demand (COD) removal efficiency was up to 93.1±0.3% and the volumetric loading reached 1.9 kgBOD/m^3-day.

Khan et. al. [23] studied treatment of paper and pulp mill wastewater by column type sequencing batch reactor. The COD removal of 87% and turbidity removal of 95% was observed.

2.4. Piggery wastewater

Su et al. [24] investigated an SBR for insitu studies of piggery wastewater. The pilot scale-SBR which was about 37.5 m^3 and HRT was 3 days. Removal efficiency of 94.5% COD, 36.3-52.9% total nitrogen, 88.7% BOD, 61.1% phosphorus and 93.4% SS were reached. However, in this case, nitrogen and phosphorus removal was poor, reaching between 36.3 and 52.9% for N and 61.1% for P.

Bernet et al. [25] investigated piggery wastewater treatment in a combined anaerobic-aerobic system using two laboratory scale sequencing batch reactors. For the 24 hours cycle TOC removal of 81-91% and TKN removal of 85 to 91% obtained.

Obaja et al. [26] studied biological nutrient removal by a SBR using an internal organic carbon source in digested piggery wastewater. The removal of 99.8% of nitrogen and 97.8% of phosphate was observed.

Sombatsompop et. al. [27] comparatively studied sequencing batch reactor and moving bed sequencing batch reactor for piggery wastewater treatment. The COD removal efficiency of the SBR and moving-bed SBR was higher than 60% for organic load 0.59 kg COD/m^3-d and higher than 80% at the organic loads 1.18-2.36 kg COD/m^3-d. The BOD removal efficiency was greater than 90% at high organic loads 1.18-2.36 kg COD/m^3-d. The TKN removal efficiency of 75-87% and 86-93% was obtained by SBR system and moving-bed SBR system.

2.5. Brewery wastewater

Ling and Lo [28] carried out some experiments with laboratory-scale aerobic sequencing batch reactors to study the treatment of brewery wastewaters. The suspended and attached growth-SBR with HRT 0.56-6.06 days was tested. They demonstrated that brewery wastewater can be successfully treated with removals of over 90% of TOC (total organic carbon), BOD_5, COD, and SS (suspended solids).

Rodrigues et al. [29] used the SBR for the post treatment process of brewery wastewater. They found that maximum rate of 0.175 kg NH_4^+-N/kg of VSS day. The removal of 97% nitrification efficiency was achieved in the SBR technology.

Wang et al. [30] have studied treatment of brewery wastewater in the laboratory scale-SBR with 239 mg/l influent COD. They found that removals of 88.7% COD and 88.9% NH_4^+-N efficiency.

2.6. Tannery wastewater

Tannery wastewater represents a powerful pollutant, mainly because of their high CODs and elevated chrome contents and deep colour content.

Carucci et al. [31] studied the laboratory scale-SBR was fed in the tannery wastewater with anoxic-aerobic conditions. Good nitrification was obtained and denitrification was effective when COD/TKN ratio in the influent was higher than 8. They found 84% COD removal from tannery wastewater in SBR using 8-hrs cycle.

Farabegoli et al. [32] studied the feasibility of treating tannery wastewater containing chromium, an inhibiting compound, with sequencing batch reactors (SBR). They obtained that chromium addition had less influence on the denitrification bacteria than on the nitrification bacteria. They demonstrated that SBR reactors can provide high nitrogen removal with high load feed containing chromium as an inhibiting substance.
Ganesh et al. [33] investigated tannery wastewater in a laboratory scale-SBR with the influent 1908 mg/l COD. The removals of 80-82% COD, 80% TKN with SVI of 110-50 mg/l. They concluded that cycle of period and HRT are 12 h and 2 days was optimum with maximum removal efficiency.

Durai et al. [34] studied kinetic studies on biodegradation of tannery wastewater in a sequential batch bioreactor. The maximum reduction in COD and colour were found to be 79% and 51% respectively.

Mekonnen and Leta [35] evaluated the feasibility of sequencing batch reactors (SBRs) for the treatment of tannery wastewater The study showed that sequencing batch reactor is an efficient tool for COD, sulfide, chromium and phosphorus removal from composite tannery wastewater but was not efficient for the removal of nitrogenous compounds from tannery strong wastewater.

Faouzi et al. [36] studied contribution to optimize the biological treatment of synthetic tannery effluent by the sequencing batch reactor fed by 500 and 1000 mg/l of total chromium to laboratory scale reactor. Both systems proved to be quite effective and the best one corresponds to total chromium concentration of 500 mg/l with one cycle per day, and an aeration time of 23 hours. The removal efficiencies of 100%, 100%, 95.6% and 100% for total chromium, COD, total nitrogen and suspended solids were obtained.

2.7. Petrochemical wastewater

Petrochemical wastewaters are considered to be the complex and hard to treat among the complex industrial wastes. The COD value of high level petrochemical wastewater is 17500 mg/l.

Misbahuddin and Farooq [37] conducted the characterization and biological treatability studies for the petrochemical wastewater using sequencing batch reactors (SBRs). Removals of 94% and 87%, respectively, were achieved for BOD and COD in the SBR biotreatment.

Hudson et al. [38] studied in the laboratory scale-SBR for the treatment petrochemical wastewater in the HRT of 53 h. 93% COD was achieved in this treatment method.

Malakahmad et al. [39] evaluated the performance of a lab-scale Sequencing Batch Reactor (SBR) to treat a synthetic petrochemical wastewater containing mercury and cadmium. Average Hg^{2+} and Cd^{2+} removal efficiencies is found to be 88.3% and 97.4% for the concentrations of 9.03±0.02 mg/L Hg and 15.52±0.02 mg/L Cd, respectively.

2.8. Pharmaceutical wastewater

Pharmaceutical industry generates wastewater containing toxic organic chemicals and the composition of the wastewater is very variable and presents high loads.

Zabczynski et al. [40] investigated the possibility of the removal PPCPs (pharmaceuticals and personal care products) in the SBRs at the sludge ages of 20 and 10 days and at the different temperatures 10^{o}C and 20^{o}C. At the sludge age 20 d ibuprofen was degraded in above 90%, but at the sludge age 10 d, it was removed at the same level only at the temperature of 20^{o}C.

Elmolla et al. [41] studied optimization of SBR operating conditions for treatment of high strength pharmaceutical wastewater. SBR achieved 94% BOD_5 removal and 83% COD removal at 24 hours HRT and 4000 mg/l of MLSS.

Adishkumar et al. [42] studied coupled solar photo-fenton process with aerobic sequential batch reactor for treatment of pharmaceutical wastewater by varying pH, ferrous ion concentration, H_2O_2 dosage, treatment time and BOD_5/COD ratio from 0.015 to 0.54. The COD removal of 98% was obtained with the effluent COD concentration was found to be 100 mg/l.

2.9. Shrimp Aquaculture Wastewater

Common water quality concerns for shrimp aquaculture include inorganic suspended solids (ISS), total suspended solids (TSS), biochemical oxygen demand (BOD), dissolved oxygen (DO) and nitrogen.

Boopathy et al. [43] investigated aquaculture wastewater which was influent 1201 mg/l COD in the laboratory scale-SBR. The removal efficiency was 97.3% COD and 99.99% total nitrogen.

Lyles et al. [44] studied biological treatment of shrimp aquaculture wastewater using a sequencing batch reactor. The initial chemical oxygen demand (COD) concentration of 1,593 mg/l was reduced to 44 mg/l within 10 days of reactor operation. Ammonia in the sludge was nitrified within 3 days and denitrification of nitrate was achieved in the anaerobic process with 99% nitrate removal.

Kern and Boopathy [45] studied use of sequencing batch reactor in the treatment of shrimp aquaculture wastewater by using two pilot scales SBR with The removal efficiencies of all nitrogen species were more than 95% and the treated wastewater was successfully recycled to the shrimp and for complete the denitrification the C:N ratio should be maintained at 10:1.

2.10. Other wastewaters

SBR technology has also been used for the treatment of other types of wastewater, such as petroleum [46], complex chemical [47]; hypersaline [48]; automobile [49]; work camp wastewater [50].

3. Conclusion

The SBR is a cost effective and reliable technique for the biological treatment of wastewater, even though with high concentrations of toxic compounds produced by various industrial processes. It provides provision for flexibility in variation of operating conditions to achieve desired results for it is time oriented rather than space oriented. Since the SBR system is typically operated with steps fill, react, settle, draw, and idle in a sequence, the fill/reaction ratio, aeration period, and mixing cycle may be altered to accommodate specific operating conditions required for the treatment of a particular type of wastewater. This study provided beneficial references of SBR for the effective treatment of different industrial wastewater. Literature review showed that SBR appears to be promising option for the effective treatment of industrial wastewater.

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