International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 10, October - 2013

Aerobic Sequencing Batch Reactor for wastewater treatment: A review

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Abstract

Sequencing Batch Reactor (SBR) is a single vessel reactor with activated sludge system which operates in time rather than in space. SBR is fill and draw type system used for treating wastewater. SBR is used to treat the wastewater from chemical, dairy, industrial estate wastewater, landfill lechate, paper and pulp, petrochemical, petroleum, pharmaceutical, piggery, sewage, swine, synthetic wastewater, tannery, textile industries by using lab scale, pilot scale and industrial scales models. SBR is operated for different operating conditions. SBR is found to be low cost, efficient and flexible technology which can be atomized in treating different industrial wastewater.

Keywords:AerobicSequencing Batch Reactor (ASBR),Industrial wastewater treatment.

1. Introduction

Industrial wastewater is characterized by high BOD, high COD, high temperature, with colour and varying pH. Generally it is treated by conventional activated sludge process. Activated sludge process is costly, requires more land, requires more attention and difficult to maintain.

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. (USEPA, Wastewater Technology Factsheet SBR, 1999)

Sequencing batch reactor consists of single tank equipped with an inlet- for wastewater, air diffuser with compressor and piping- for aeration, sludge drawing mechanism- for draining sludge, decant mechanism- for drawing supernatant, stirrer- for inducing aeration and control mechanism- for operation control with respect to time and sequence. (USEPA, Summary Report SBR, 1986) SBR operation system has five basic operating modes - Fill, React, Settle, Draw and Idle.

1) Fill

In this step the wastewater is added to the reactor. The addition of wastewater is controlled to set the time period or to set the volume. The time and volume limits are determined by actual operational constraints and performance required. It covers 25 percent of the total cycle time and covers 25 to 100 percent of total volume. Air flow may be on or off according to the fill defined. Depending on the operating strategy the fill step may be of static fill, mixed fill, aerated fill type.

Static fill:-In this fill wastewater is added to the biomass already present in the sequencing batch reactor vessel. It is characterized by no mixing or aeration. At this stage high substrate concentration is available. It creates favorable environment to floc formation providing good settling characteristics for the sludge.

Mixed fill:- In this fill wastewater is mixed with the biomass. It initiates biological reactions, degrades the organics by using residual oxygen. De-nitrification may occur in this fill.

Aerated fill:- In this fill the contents of sequencing batch reactor vessel are aerated and made ready to reactfor next step- react. It reduces aeration time required in react step.

2) React (Aeration)

In this step the wastewater filled in the reactor is allowed to react by aerating, stirring continuously

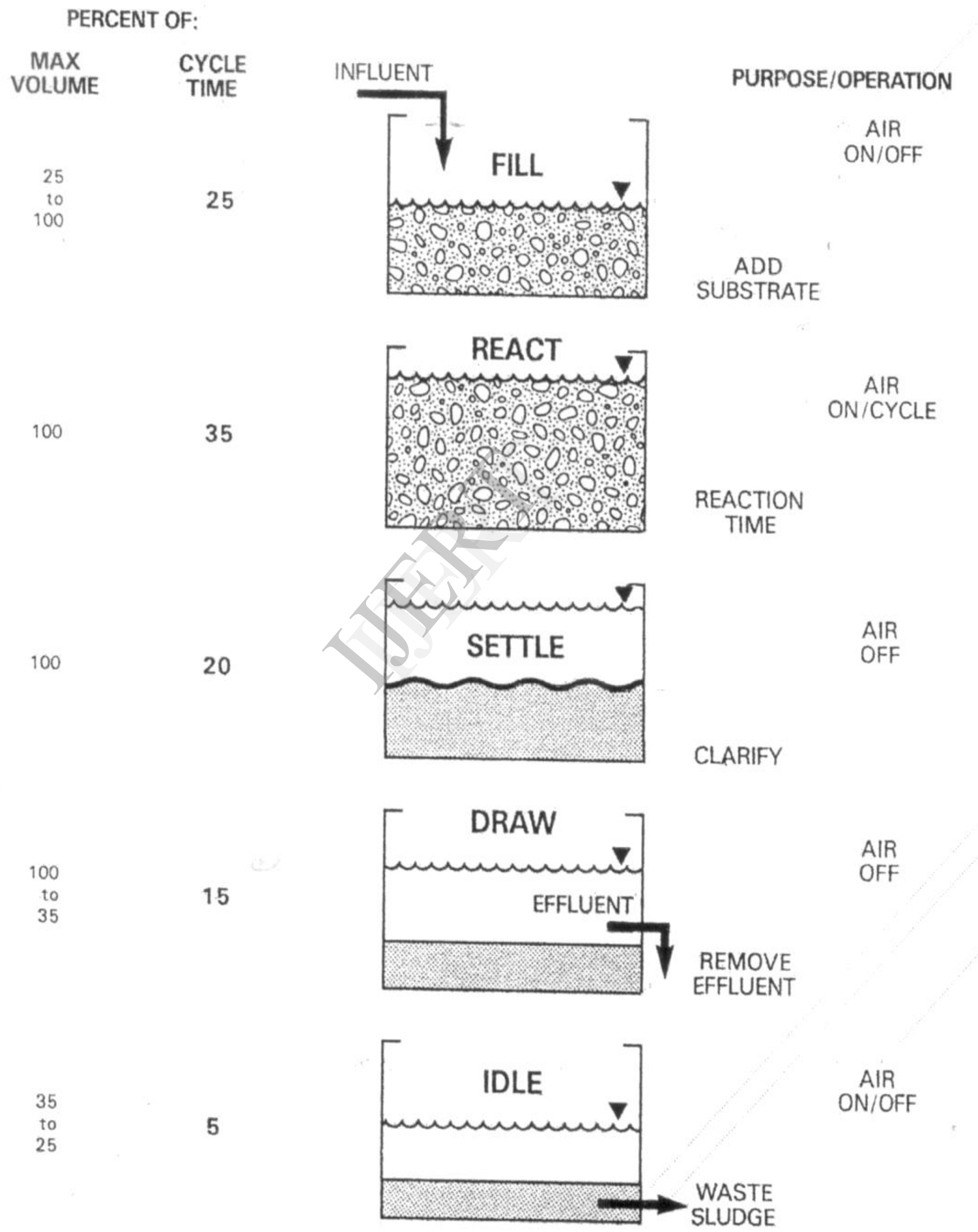

Fig.1: SBR operating modes with percentage of volume and cycle time.

throughout the length/period of react step. The duration required depends on preset time limit or multiple tank system. It covers 35 percent of the total cycle time and covers 100 percent of total volume. It may be mixed react or aerated react type. Mixed react allows anoxic condition to achieve de-nitrification and aerated react allows aerobic condition during aerated fill to achieve complete nitrification.

3) Settle (Sedimentation/Clarification)

In this step separation of solids as settled sludge is allowed to provide clarified supernatant under quiescent condition. No influent or effluent currents interfere with settling process. It covers 20 percent of the total cycle time and covers 100 percent of total volume. In some cases gentle mixing during initial stages of settling allows clearer effluent and more concentrated sludge.

4) Draw (Decant)

In this step clarified treated supernatant is allowed to remove within the predetermined cycle time. Decanters are used in this process which may be of floating type or fixed type. Floating type decanters are advantageous. It covers 15 percent of the total cycle time and covers 35 to 100 percent of total volume.

5) Idle (Sludge Wasting)

In this step equalization, sludge wasting condition, mixing to biomass condition can be achieved. The length of the idle step depends upon influent flow rate and operating conditions. It covers 5 percent of the total cycle time and covers 35 to 25 percent of total volume. It occurs between draw step of one cycle and fill step of successive cycle. (USEPA, Wastewater Technology Factsheet SBR, 1999)

2. Sequencing Batch Reactor (SBR): Review

The sequencing batch reactor is used for treating the wastewater from chemical, dairy, industrial estate wastewater, landfill lechate, paper and pulp, petrochemical, petroleum, pharmaceutical, piggery, sewage, swine, synthetic wastewater, tannery, textile, fish farming, food processing, fruit juice, hospital, palm oil mill, shrimp aquaculture, soybean curd, wood fiber etc. industries.

2.1. Chemical industry wastewater

Wei et. al., (2007), studied process evaluation of an alternating aerobic-anoxic process applied in a sequencing batch reactor for nitrogen removal by using a lab-scale reactor of 38 litres operated at 30 - 32°C, MLSS concentration maintained at 3000 - 3100 mg/l fed by chemical industrial wastewater operated under Alternating Aerobic-Anoxic process (AAA process)and One Aerobic-Anoxic process (OAA process). It concluded that the AAA process was an optimal strategy as under deficient influent alkalinity, the AAA process improved treatment efficiency and effluent quality with NH_4^+ N in the effluent below the detection limit and in the nitrification, the average stoichiometric ratio between alkalinity consumption and ammonia oxidation is 7.07 mg CaCO3/mg NH_4^+ N while in the de-nitrification, the average stoichiometric ratio between alkalinity production and NO_3- N reduction is 3.57 mg $CaCO_3$/mg NO_3- N.

Qaderiet. al., (2007), studied role of moving bed bio-film reactor and sequencing batch reactor in biological degradation of formaldehyde wastewater. MBBR with two SBRs in series were utilized, each reactor made up of 4mm thick plexi glass with internal diameter 10 cm, height 70 cm and effective volume of 5 litres, operated in batch-flow mode for 8 hours retention time. For SBR system, retention time for each reactor was 24 hours as 60% of the treated wastewater in the first reactor entered into the second one after 24 hours operated manually. The removal efficiencies for MBBR and SBR which were 93% and 99.4%, respectively under influent formaldehyde COD of 200 mg/l and the systems were capable to treat higher formaldehyde concentrations up to 2500 mg/l.

Farooqiet. al., (2007), studied biodegradation of phenols and m-cresols by up-flow anaerobic sludge blanket and aerobic sequential batch reactor of column-type with 5 cm diameter, 100 cm height with working volume of 1.4 litres, seeded with 1-liter aerobic digested sludge having Volatile Suspended Solid (VSS) of 3.0 g/ l operated for a cycle of 6 hours and HRT of 12 hours at room temperature fed by different concentrations of phenols. The removal efficiency of 95% was obtained for phenol and m-cresol up to 1.1: 1, 800: 700 mg/ l.

Mohan et. al., (2006), treated low-biodegradable composite chemical wastewater treatment by bio-film configured sequencing batch reactor (SBBR) by utilizing bench scale reactor made in perplex glass with internal diameter of 7.5 cm, height 63 cm, 1.4 litres capacity, working volume of 1.3 litres, configured with bio-film operated in the up-flow mode fed by low-biodegradable composite chemical wastewater having low BOD/COD ratio = 0.3, high sulphate content 1.75 g/l operated under anoxic–aerobic–anoxic microenvironment conditions for total cycle period of 24 hours under organic loading rates of 0.92, 1.50, 3.07and 4.76 kg COD/cum-day. Sulfate removal efficiency of 20% was observed in induced anoxic conditions. Bio-film configured sequencing batch reactor showed comparatively higher efficiency to the corresponding suspended growth and Granular Activated Carbon (GAC) configured systems studied with same wastewater.

Khan et. al., (2010), studied degradation profile of phenol in sequential batch reactor of column type having 5 cm diameter 150 cm height made in transparent perfex glass with total volume of 1.5 litres operated at about 30±20°C fed with phenol as a sole carbon source at hydraulic retention time (HRT) of 8 hours. High concentration of phenol 400 mg /l, 650 mg/l took 240 minutes for complete removal and low phenol concentration of 50, 100, 200 mg/l can't be detected after for 170 minutes of the SBR cycle.

Luoet. al., (2011), studied effect of trace amounts of polyacrylamide (PAM) on long-term performance of activated sludge by using four lab-scale identical reactors of an internal diameter 10 cm, height 40 cm, working volume of 3 litres, operated at pH 7.3 -6.8, dissolved oxygen (DO) within range 2.0 - 4.0 mg/l, mechanically stirred at 100 r.p.m. for 12 hours cycle of operation, fed by organic synthetic wastewater with PAM concentrations of 0.0,0.01, 0.1, 1.0 mg/l. PAM addition dosage of PAM was 0.1 mg/L improved the best removal efficiencies of COD, ammonium and exhibited sludge performance in settling, flocculation and microbial activity. High level of PAM (1 mg/L) led to the formation of large amounts of loose-structure flocs, affecting dissolved oxygen transfer and caused the sludge disintegration, resulted in bad settleability, lower microbial activity.

2.2. Dairy industry wastewater

Torrijos et al., (2001), studied the SBR process: an efficient and economic solution for the treatment of wastewater at small cheese making dairies. 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. It was concluded that, the SBR treatment will costs around 2 centimes (0.33 US cent) per liter of milk processed. SBR process can easily be run in minimum time with it's simple design and operation.

Mohseni and Bazari., (2004), studied biological treatment of dairy wastewater by sequencing batch reactor. The reactor was supplied with fine air bubble diffuser to run DO concentrations of 3, 5, 6.5, and 7.5 mg/L. The dairy wastewater was applied to reactor at different COD concentrations of 1000, 1500, 2000, and 2500 mg/L and operated with total cycle time of 7 hours. The highest COD removal efficiency was more than (90%) for aerated period of 6 hours.

Mohamed and Saed, (1995), studied SBR efficiency in the treatment of wastewater from a dairy plant. The SBR is utilized for 30-minutes aeration feed, 12-hours reaction with O2, 1-hour settling period without O2, 30-minutes draw without O2, and 15-minutes idle phase. The removal of 96.7% of NH3-N, 94% of COD, and 96% of SS were achieved.

Li and Zhang, (2002), studied the aerobic treatment of dairy wastewater with sequencing batch reactor systems. A single-stage SBR system was tested with 10,000 mg/l COD influent at three HRTs of 1, 2, and 3 days and 20,000 mg/l COD influent at four HRTs of 1, 2, 3, and 4 days. 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.

Kaewsuk J. et. al., (2010), studied kinetic development and evaluation of membrane sequencing batch reactor with mixed cultures photosynthetic bacteria for dairy wastewater treatment. The kinetic coefficients half velocity coefficient (Ks), maximum rate of substrate degradation (k), bacteria decay rate (kd) , yield coefficient (Y) and biomass retention time (µm) are 174 mg-COD/L, 7.42 mg-COD/mg-VSS/d, 0.1383/d, 0.2281 mg-VSS/mg-COD and 1.69/d, and at controlled temperature of 25-400C, pH range 7.0-7.5 to get COD removal from concentration from 2500 mg/L to 149 mg/L.

Samkuttyet. al., (1996), studied biological treatment of dairy plant wastewater with SBR and concluded that SBR is a good system for the primary and secondary treatment of dairy wastewaters. The study was carried for 2 months of operation in pH range 7 to 8. The viable biomass of the samples was determined by Adenosine Tri Phosphate (ATP), measured in Relative Light Units (RLU) and Heterotrophic Plate Count (HPC). BOD is highly correlated with COD, TS, TSS, HPC, and ATP in the effluent. A significant correlation was also observed between ATP and HPC. Results shows significant reduction of 97% BOD, 93% COD, 97% TSS, 76% TS.

Tam et. al., (1986), treated milking centre waste using sequencing batch reactors with the help of three 5.0 litres, acrylic, plastic bench-scale sequencing batch reactors of 460 mm in height and 138 mm in diameter operated at 3.7, 10.5, 21.6 and 29.8°C for a 6-hours cycle. The removal efficiency for 5-days Biochemical Oxygen Demand (BOD_5) and chemical oxygen demand (COD) over 90% and 70% were observed even at low temperatures 10.5

and 3.7°C. NH_3-N and total suspended solids removal efficiency was over 92% at 21.6 and 29.8°C and in the range 86 to 95%.

Sirianuntapiboonet. al., (2005), studied sequencing batch reactor bio-film system for treatment of milk industry wastewater by using conventional sequencing batch reactor system and sequencing batch bio-film reactor (SBBR) system each of 25 litres capacity made in acrylic, plastic 5 mm thick 0.29 m in diameter and 0.35 m in height with working volume of 20 litres. Plastic media of 2.7 m^2 surface area is used at the bottom of the reactor to increase the efficiency and operated at different organic loadings. The removal efficiencies of COD, BOD_5, total Kjeldahl nitrogen (TKN) and oil & grease for the MSBR system, and 89.3±0.1, 83.0±0.2, 59.4±0.8, and 82.4±0.4% respectively and for conventional SBR system 87.0±0.2, 79.9±0.3, 48.7±1.7 and 79.3±10%, respectively under organic loading 1340 g BOD_5/m^3d. The SBBR system gave the highest COD, BOD_5, TKN and oil & grease removal efficiencies of 97.9±0.0, 97.9±0.1, 79.3±1.0 and 94.8±0.5%, respectively, under an organic loading of 680 g BOD_5/m^3 d without wasting any excess bio-sludge. The SVI of suspended bio-sludge in the SBBR system was 44±3.4 ml/g and lower than 100 ml/g for an organic loading of 680 g BOD_5/m^3 d and 1340 g BOD_5/m^3 d. The amount of excess bio-sludge generated in the SBBR system was about 3 times lower than that in the conventional SBR system.

Zinatizadehet. al., (2005), studied influence of process and operational factors on a sequencing batch reactor performance treating stimulated dairy wastewater by using a lab-scale SBR, constructed from plexi glass with dimensions, 10 cm length, 10 cm width, 30 cm height with a working volume of 2 litres operated and controlled by pre-programmed timers under organic loadings 1000, 3000, 5000 mg/l in terms of COD, MLVSS 3000, 5000 and 7000 mg/l and aeration time 2, 10 and 18 hours. 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.

Rio et. al., (2012), studied aerobic granular sequencing batch reactor systems applied to the treatment of industrial effluents by using four lab scale sequencing batch reactors each with height of 465 mm and inner diameter of 85 mm, height to the diameter ratio (H/D) being 5.5, total volume of 2.5 litres and a working volume of 1.5 litres, controlled by a Programmable Logic Controller (PLC). The reactors were operated at room temperature 15-20 °C and at oxygen concentrations 4 and 8 mg/l for 3-hours cycle fed by four different types wastewater characterized by dairy products having a high concentration of suspended solids (R_1), fish canning industry with 30 g NaCl/l (R_2), marine products industry with previous physical-chemical treatment (R_3) and a pig farm with high organic matter and nitrogen (R_4) at organic loadings ranged between 0.7 - 5.0 g/l/d of COD and 0.15 - 0.65 g/l/d of nitrogen(NH_4^+-N) loading rates gave the removal efficiencies of 60-95% and 15% -76%.

2.3. Industrial Estate Wastewater

Asadiet. al., (2013), studied comparatively performance of two aerobic sequencing batch reactors with flocculated and granulated sludge treating an industrial estate wastewater process analysis and modelling, by utilizing reactors of internal diameter 8.5 cm, total height 36 cm, working volume 2 litres, operated at dissolved oxygen (DO) concentration 7 mg/l, MLVSS / MLSS ratio at about 0.7 in average, one system operated with granulated sludge system (GSS) and another with flocculated sludge system (FSS) under varied aeration time of 6-24 hours.The experimentation based on a Central Composite Design (CCD) and analyzed by response surface methodology (RSM) gave the removal efficiency 70 % in COD removal in both systems and granulated sludge system was more efficient in removing the non-biodegradable COD (nbCOD), total nitrogen (TN), total phosphorus (TP) than the flocculated sludge system.

Asadi and Ziantizadeh., (2011), studied statistical analysis and optimization of an aerobic SBR treating an industrial estate wastewater using Response Surface Methodology (RSM), by using reactors of internal diameter 8.5 cm, total height 36 cm, working volume 2 litres, operated at dissolved oxygen (DO) concentration 7 mg/l, MLVSS concentration 2000-7000 mg/l. The maximum removal efficiency of 73.89% was obtained in total COD (TCOD) removal under 24 hours aeration at 7000 mg/l of MLVSS and total nitrogen (TN) removal efficiency was 36.39.

2.4. Landfill lechate

Neczajet. al., (2008), studied sequencing batch reactor system for the co-treatment of landfill leachate and dairy wastewater. Two laboratory scale-reactors of 5 litres were supplied with fine bubble air diffuser, magnetic stirrers and set of two peristaltic pumps. The reactors were operated at Dissolved Oxygen (DO) concentration above 3 mg/l and at the room temperature (18–20°C). The cycle time of the reactors was 24 hours, with leachate dilution of 25% by volume with a dairy wastewater, 4 g/l sludge concentration. COD was varied between 6000 and 7500 mg/l and BOD concentration in the range of 4000–5000 mg/L of dairy wastewater. The COD strength of the leachate was varied between 3800 and 4250 mg/l and BOD concentration less than 430 mg/l. Both systems were inoculated with sludge collected from the municipal wastewater treatment. The most suitable mode for co-treatment of landfill leachate and dairy wastewater was with aeration time of 19 hours and anoxic phase of 2 hours. The removal efficiencies of the SBR systems were decreased with increase in organic loading or decrease in Hydraulic Retention Time (HRT). During co-treatment process of landfill leachate the best effluent quality was observed under organic loading of 0.8 kg BOD_5 /m^3 d and HRT of 10 days.

Spagniet. al., (2009), studied nitrogen removal via nitrite in a sequencing batch reactor treating sanitary landfill leachate by using laboratory scale SBR reactor with a maximum working volume of about 24 litres, was operated at 20 ± 1^0C, controlled by a PC-based control system, at SRT of 20-25 days under anoxic–anaerobic phase followed by an oxic phase, fed by leachate flow of 1.2 l/h was added to the tank to a loading rate of approximately 0.1 gTKN/(l.d) and 0.15 gCOD/(l.d). COD removal was approximately 20–30%, nitrification and nitrogen removal efficiencies were usually higher than 98% and 95%, respectively.

Spagniet. al., (2008), studied optimization of sanitary landfill leachate treatment in a sequencing batch reactor by using bench-scale reactor of working volume 24 litres, operated at 20 ±0.5^0C, for full cycle of 24 hours divided in 4 sub-cycles of 5.75 hours in series fed by municipal landfill leachate. The removal efficiencies of nitrification and N removal were usually higher than 98%, 90%, respectively, whereas COD (of the leachate) removal was approximately 30–40%.

2.5. Paper and pulp industry wastewater

Khan N. A. et. al., (2011), studied treatment of paper and pulp mill wastewater by column type sequencing batch reactor. Lab scale SBR of 3.46 litres capacity supplied with air diffuser, fully automatically controlled was used. The seeded aerobic sludge from aeration tank initially fed by phenol 200mg/l for two weeks is applied to reactor. The paper industry wastewater was fed to reactor and operated for 24 hours cycle. The COD removal of 87% and turbidity removal of 95% was observed. The pH and alkalinity of treated wastewater were within permissible limits. Sludge settling characteristics were improved and significant increase in volatile suspended solids was observed.

Sirianuntapiboon S., (2002), studied application of Granular Activated Carbon- Sequencing Batch Reactor (GAC-SBR) system for treating pulp and paper industry wastewater by utilizing six reactors of 10 litres capacity made up of 5 mm thick acrylic plastic with l8 cm in diameter and 40 cm in height, working volume was 7.5 litres, operated at 60 r.p.m. fed by paper and pulp industry wastewater. GAC showed the COD and colour adsorption under jar test conditions as 127.00 mg/g of GAC and 248'00 Pt-Co/g of GAC, respectively. For full aeration SBR conditions the COD and colour removal efficiencies of GAC were increased by 3.l6% and 1.05%, after 30 days of operation of GAC-SBR, the COD adsorption ability of GAC was increased to 107.85 mg/g. 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.

Khan N. A., (2012), studied treatment and GC/MS analysis on paper pulp mill wastewater from Naini Paper mill, India by using lab scale column-type SBR, 7 cm in diameter, 90 cm in height and working volume of 3.46 litres operated at room temperature, under constant HRT of 22 hours, 24-hours cycle, seeded by sludge with Volatile Suspended Solid (VSS) content of 3.0 g/l, fed by paper pulp mill wastewater. Chlorine-dioxide present in concentration 2, 3, 7, 8 of TetraChloroDibenzo-P-Dioxin (TCDD) in mill effluent found below detectable limit to 0.12 mg/l. The relative standard deviation of reproducibility and percent recovery of 2, 3, 7, and 8 of TCDD were 2.07, 82.4% in pulp and 2.8, 92% in effluent, respectively. Dichlorobenzene, trichlorophenyl, hexachlorobiphenyl were found in the treated, untreated effluent and sludge samples.

2.6. Petrochemical Industry wastewater

Malakahmad A. et. al., (2011), studied SBR for the removal of Hg^{2+} and Cd^{2+} from synthetic petrochemical factory wastewater. The reactor of 24 litres capacity was fed by synthetic wastewater prepared to match the characteristics of real wastewater with addition of sugar, powdered milk and urea added as organic sources. Mercury and cadmium salts were then added at selected concentrations and pH was increased to 7.5 from 6.9. The reactor was connected to feed tank (120 litres), treated wastewater tank (120 litres) and sludge tank (60 litres). Returned sludge brought from an activated sludge process was seeded and SBR was operated for 8 hours cycle consisting five distinct modes- fill, react, settle, draw and idle. At maximum concentrations of the heavy metals, the SBR removes 76-90% of Hg^{2+} and 96-98% of Cd^{2+}. The removal efficiencies of COD and mixed liquor volatile suspended solids (MLVSS) show declination with addition of heavy metals. Average Hg^{2+} and Cd^{2+} removal efficiencies is found to be 88.3% and 97.4% for the concentrations of 9.03$\pm$0.02 mg/l Hg^{2+} and 15.52$\pm$0.02 mg/l Cd^{2+} respectively.

Shakerkhatibiet. al., (2013), studied feasibility study on ethylene oxide/ethylene glycol (EO/EG) wastewater treatment using pilot scale SBR by using four identical reactors of plexi glass with internal diameter 0.2 m, height 0.3 m, total volume 9 litres, effective volume 7 litres operated respectively in parallel, at pH 7.1±0.2, over dissolved oxygen concentration 2 mg/l, biomass concentration 3500-5000 mgVSS/l, at the room temperature 20°C, under organic loadings of 500, 1000, 1500 and 3000 g COD/m3.day, for sludge ages of 10, 20 and 30 days, fed by petrochemical wastewater. The removal efficiencies of 79.5 and 83.5 % were obtained at SRT 20 days and 86% at SRT 30 days was observed for SBR 1 and 2 respectively in COD removal at the OLRs of 0.5 and 1 kg COD/ m3.day. COD removal efficiency of 86% at the SRT 20 days and 92% at the SRT 30 days was achieved at aeration time of 34.5 hours at the OLR of 1 kg-COD/m3.day for SBR 3. The aeration times required for SBR 4 were 34.5 and 22.5 hours to achieve the COD removal of 89.7 and 91.1% at the sludge ages of 20 and 30 days respectively.

2.7. Petroleum Industry wastewater

Ahmed et. al., (2011), studied petroleum refinery effluent biodegradation in Sequencing Batch Reactor by using four 3litres reactors, operated in parallel at a 24 hours cycle fed as R_1 fed by petroleum refinery raw wastewater operated under aerobic mode, R_2 fed by petroleum refinery raw wastewater operated under anaerobic and aerobic mode, R_3 fed by R_2 effluent operated under aerobic mode, R_4 fed by petroleum refinery raw wastewater and domestic wastewater operated under aerobic mode. The effluent parameters sCOD, ammonia-nitrogen, nitrate-nitrogen, TSS, and VSS for aerobic SBR were 54 mg/l, 5.9 mg/l, 1.47 mg/l, 66 mg/l, and 19 mg/l respectively. R_2 operated anaerobic-aerobic mode showed outlet effluent parameters 49 mg/l, 0.8 mg/l, 3.1 mg/l, 60 mg/l, and 17 mg/l of sCOD, ammonia-nitrogen, nitrate-nitrogen, TSS, and VSS respectively and proved better performance with maximum biodegradation.

Ishaket. al., (2011), reviewed shortly in refinery wastewater biological treatment and stated that Nakla (1993) operated SBR for HRT of 1day, SRT of 14 days under toxic loading of phenol 0.1-0.8 kg/m3.d, O-cresol 0.1-0.8 kg/m3.d showed 99% and 94% removal efficiencies with BOD5 <5 mg/l, TSS<12 mg/l and SVI<80 ml/g.

2.8. Pharmaceutical Industry wastewater

Elmolla E.S., (2012), studied optimization of SBR operating conditions for treatment of high strength pharmaceutical wastewater. Two reactors of 1.5 litres supplied with air pump, air diffuser are utilized. The reactors are fed by non-penicillin pharmaceutical wastewater mixed with domestic wastewater in ratios 25:75, 50:50, 75:25. The HRT was varied for 12, 24, 48 hours, mixed liquor suspended solids concentration was varied 6000 mg/l, 4000 mg/l at DO concentration 3 mg/l. SBR achieved 94% BOD_5 removal and 83% COD removal at 24 hours HRT and 4000 mg/l of MLSS.

Adishkumar.et. al., (2012), 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_3/COD ratio from 0.015 to 0.54. Solar photo-fenton process enhances biodegradability at the optimum condition of pH 3, H_2O_2 concentration of 5 g /l, Fe^{2+} concentration of 1 g/l and irradiation time of 60 minutes. The COD removal of 98% was obtained with the effluent COD concentration was found to be 100 mg/l.

Altaf and Ali., (2010), studied wastewater treatment using sequential batch reactor and development of microbiological method for the analysis of relative toxicity operated at dissolved oxygen 2.0 mg/l, at different pH 6.62, 6.69, 6.79, 6.9, for 7, 14, 21 days treatment, fed by pharmaceutical wastewater . The changes in pH, BOD, COD, TDS, TSS, ammonia levels, oil and grease levels were significant and meet the National Environmental Quality Standards (NEQS).

2.9. Piggery Industry Wastewater

Obajaet. al., (2004), studied biological nutrient removal by a SBR using an internal organic carbon source in digested piggery wastewater. Lab-scale SBR is utilized with an internal carbon source (non-digested pig manure) for biological nitrogen and phosphorus removal in digested piggery wastewater with initial content feed of 900 mg/l ammonia and 90 mg/l phosphate. The removal of 99.8% of nitrogen and 97.8% of phosphate was observed.

Sombatsompopet. al., (2011), comparatively studied sequencing batch reactor and moving bed sequencing batch reactor for piggery wastewater treatment by using acrylic reactors of 0.5 cm thick, 16 cm diameter, 40 cm height, working volume of 6 litters, operated at pH 7.5$\pm$0.5, ambient temperature 27$\pm$2°C, volatile suspended solids

/suspended solids ratio of the activated sludge was 0.89, mixed liquor suspended solids concentration of 3000 mg/l, sludge retention time (SRT) 10 days, hydraulic retention time (HRT) 0.75 day and dissolved oxygen concentration in maintained by an air flow rate of 1.0 l/min. Polyvinyl chloride sponge, cut in 1.5 cm cubes, was used as the floating medium in the moving-bed reactor circulated in the reactor by air, the moving medium of density of 0.0145 g/cm3, specific surface area 400 m^2/m^3, was used at 20% fill fraction fed by varying the organic load from 0.59 to 2.36 kg COD/m^3.d. 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. The suspended solids for SBR systems exceeded the piggery wastewater limit of 200 mg/l at the organic load of 2.36 kg COD/m^3.d. For increased organic load of 2.36 kg COD/m^3.d the moving-bed SBR system yielded better treatment efficiency than that of the SBR system.

Zhu et. al., (2006), studied a laboratory scale sequencing batch reactor with the addition of acetate to remove nutrient and organic matter in pig slurry by using laboratory-scale column type reactor of transparent polyvinyl chloride (PVC), 190mm in diameter, total volume 11 litters, working volume 8 litters, operated at $21\pm2\,^{\circ}C$, hydraulic retention time (HRT) of 3.3 days, for 8 hours cycle, under anaerobic-anoxic-anaerobic-anoxic $(An/Ax)_2$ mode. The removal efficiencies of ammonium nitrogen, total Kjeldahl nitrogen, chemical oxygen demand, biochemical oxygen demand and total phosphorus are 100.0%, 98.7%, 97.4%, 100.0%, and 98.7%, respectively with acetate addition, without acetate addition the reductions are 100.0%, 100.0%, 97.7%, 100.0%, and 97.8%.The phosphorus removal efficiency was 87.2% with acetate addition and 67.9% without acetate addition. The removal efficiencies for total solids 77.5% and 78.8%, total volatile solids 97.0% and 95.6%, total suspended solids 99.9% and 99.3%, and total volatile suspended solids 99.1% and 98.4% were obtained for acetate addition and without acetate addition.

Daumeret. al., (2007), studied the effect of nitrification on phosphorus dissolving in a piggery effluent treated by a sequencing batch reactor by using modified 100 litters pilot reactor, fed by homogenized and separated with a 100 mm screen centrifuge of piggery wastewater, operated in feeding, anoxic phase, anaerobic, aerobic phase and withdrawal phase. The dissolved phosphorus was increased with the increase in nitrified nitrogen, at regulated pH, dissolving of phosphorus was observed. The modified sequencing batch reactor process management hydraulic retention time and anaerobic/aerobic step duration controlled the amount of nitrogen nitrified in and in turn the amount of the phosphorus dissolved.

Vetter et. al., (2006), studied IFAS media in a sequencing batch reactor for nitrification and de-nitrification of high strength wastewater by using reactor tank of 7.62 m. diameter, 4.3 m. height, operating volume 177 $m^3$and glass-lined cylindrical tank with conical bottom, with three banks of manufactured fixed-film synthetic media. Average biochemical oxygen demand of approximately 1,600 mg/l was reduced to 50 mg/l, consistently less than 100 mg/l. Total Kjeldahl nitrogen concentrations are reduced from 60-90 % depending upon the loading rate and the operating schedule.

Bernetet. al., (2000), studied combined anaerobic-aerobic SBR for the treatment of piggery wastewater by utilizing an anaerobic reactor of liquid volume of 1.5 litres, seeded with 0.75 litre anaerobic sludge, operated at 35^0C temperature, magnetically stirred at a constant speed of 400 r.p.m. Two aerobic reactors N_1 had an active volume of 1.5 litres used when wastewater flow rate was 0.1 l /d, N_2 of 4 litres reactor containing 3 litres of mixed liquor used when the organic carbon load of the system was doubled, operated at temperature 20 ± 2.2^0C, magnetically stirred at 700 r.p.m. For the 24 hours cycle TOC removal of 81-91% and TKN removal of 85 to 91% obtained.

2.10. Sewage Wastewater

Coats et. al., (2011), studied toward polyhydroxyalkanoate (PHAs) production concurrent with municipal wastewater treatment in a Sequencing Batch Reactor System by using bench-scale reactor of 15 litres, operated at 22-23°C, solids retention time (SRT) 3.75 days. SBR supplied with moderate strength wastewater can enrich the target microorganisms, with PHA yields of 0.23-0.31 mg PHA per mg chemical oxygen demand, and produce high quality effluent and 1 million gallon per day SBR WWT-PHA production system could generate 12–40 tons of PHA annually.

Qing et. al., (2007), studied advanced nitrogen removal using pilot-scale SBR with intelligent control system built on three layer network by utilizing pilot-scale aerobic-anoxic sequencing batch reactor (SBR) with a treatment capacity of 60 m^3/d. Characteristics profiles of dissolved oxygen (DO), pH, and oxidation reduction potential

(ORP), nitrification and de-nitrification controlled by the intelligent control system. The outlet effluent chemical oxygen demand (COD) and total nitrogen (TN) were under 50 and 5 mg/l respectively even for low temperature 13°C.

Iaconiet. al., (2008), studied technological transfer to demonstrative scale of sequencing batch bio-filter granular reactor (SBBGR) technology for municipal and industrial wastewater treatment by utilizing cylindrical steel reactor of volume of $2m^3$, completely automatic by using a programmable logic controller (PLC). For municipal wastewater the removal efficiency of 80-90% was obtained for COD, total suspended solids and ammonia were independent of the hydraulic residence time (12 to 4 hours). For municipal wastewater SBBGR technology removed 80-90% of the COD, suspended solids and ammonia content up to organic loading values of 3.5 kg $COD/m^3 \cdot d$. In both cycles very high sludge age value < 150 days which led to a biomass concentration as high as 35 g TSS/l bed and a sludge production 5-6 times lower than conventional treatment plants.

Maiti., (2007), studied sequencing batch reactor for simultaneous removal of BOD_5, nitrogen and phosphorus from wastewater. One case study of treatment expansion by using SBR and another conversion of ASP to SBR illustrated that reactor operated at MLSS of 2300 mg/l, F/M = 0.12, SVI= 100-200 ml/g, for 6 hours cycle as fill: 2.9-3.1 hours, react: 0.7-0.4 hours, settle: 0.7 hours, draw: 0.7 hours, idle: 1.0-1.1 hours, fed by domestic wastewater containing nitrogen and phosphorus concentration 5-6 mg/l were reduced to less than 0.5 mg/l. SBR gives very promising results for treatments of intermittent, lower flows in BOD_5 in N and P removal.

Mahvi., (2004), studied feasibility of continuous flow sequencing batch reactor in domestic wastewater treatment by using pilot scale reactor with an operating volume 36 litres, operated at 10-30^{o}C for Run 1: 6 - hour cycle (Q = 1.5 l/hr., HRT = 16.7 hr), Run 2: 6 - hour cycle (Q = 2 l/hr., HRT = 14 hr.), and Run 3: 6 - hour cycle (Q = 2.5 l/hr., HRT = 12.4 hr.).The removal efficiencies of 97.7%, 94.9%, 85.4%, 71.4 %, 55.9% and 99%were obtained in BOD, COD, TKN, TN, TP and TSS removal respectively.

Main and Ingavale., (2012), studied the sequencing batch reactor for grey-water treatment by using reactor made up of acrylic sheets with square cross sectional area 30.5 cm X 30.5 cm X 19.3 cm, total volume 23 litres, working volume 18 litres, outlet fixed at 13.5 cm height, volume of grey water to be treated was 5.4 litres, fed by 7 litres capacity feeding tank, operated at MLSS concentrations 2000-4000 mg/l, HRT 4 to 8 hours, SRT of 10 days for one cycle per day. The SBR unit was operated for cycle time 5, 6, 7 and 8 hours and optimum BOD removal efficiency 94.69% was observed for 7 hour cycle. Then SBR unit was operated for four different fill : react ratios as per 7 hour cycle (105 minutes) and the react time is varied with ratios 1:1, 1:1.2, 1:1.4, 1:1.6 and 1:1.8. The optimum BOD removal efficiency 94.57% was observed for ratio 1: 1.2. The optimum cycle time was 399 minutes comprising - Fill time: 105 minutes, React time: 126 minutes, Settle time: 84 minutes, Draw time: 63 minutes and Idle time: 21 minutes. The average characteristics of treated effluent for ratio 1:1.2 were as pH -7.9, Total Suspended Solids - 30 mg/l, Total Solids - 178 mg/l, COD - 58.36 mg/l, BOD - 9.48 mg/l.

2.11. Swine Wastewater

Deng et. al., (2007), studied improvement in post-treatment of digested swine wastewater by using sequencing batch reactor with cylindrical reactor of acrylic plastic, 200 mm in diameter, 400 mm height, total volume of 12.5 litres, working volume of 10.0 litres, operated at dissolved oxygen (DO) 3 mg/l, for 8-hours cycle. SBR operation to treat the digested effluent directly, gives the performance was very poor in COD removal rate about 10%, and NH_4^+-N removal 50%, with a scarce removal of total phosphorus. The performance was improved after adding raw swine wastewater or alkali to digested effluent proved superior in removing total nitrogen and total phosphorus. The combined anaerobic-SBR process with addition of raw swine wastewater was effective.

Figueroa et. al., (2012), studied the CANON reactor an alternative for nitrogen removal from pre-treated swine slurry by using a laboratory scale air pulsing sequencing batch reactor with a working volume of 1.5 litres, at pH 7.7±0.2, hydraulic retention time 0.5 days, feeding flow rate of 2.18 ml/min, at room temperature 18-24^{0}C, operational cycles of 360 minutes were distributed as: 345 minutes of feeding and aeration, 10 minutes of settling and 5 minutes of effluent withdrawal. The ammonium removal, under oxygen-limited conditions, in a system with anammox bacteria mainly in the form of granules and aerobic ammonium oxidizing bacteria mainly as dispersed biomass was researched in an air pulsing sequencing batch reactor operated at room temperature. The achieved nitrogen removal rate was of 0.46 kg N/m^3d treating 300 mg NH_4^+-N/l with value of nitrogen removal efficiency around 75%.

2.12. Synthetic Wastewater

Jin et. al., (2012), studied performance of sequencing batch bio-film reactors with different control systems in treating synthetic municipal wastewater by using two acrylic reactors with 400 mm length, 250 mm width, 300 mm height and total working volume 20 litres. Multiple cylinders of 40 mm diameter, 260 mm height with many holes of 0.5 mm diameter evenly distributed on their surfaces used as water collectors, fibre threads attached to the cylinder acts as bio-film carriers. At 25 ± 1^0C the performances of sequencing batch bio-film reactors (SBBRs) in removing nitrogen and phosphorus under intelligent control system (ICS-SBBR) 87.7%, 92.3% and 97.6% in COD removal, 95.0%, 97.0% and 97.2% in total phosphorous (TP) removals at C/N ratios were 10.0, 5.0 and 3.3. At C/N ratio 5.0, the TN removal efficiency was 81.0% under ICS and 65.4% under TCS.

Debsarkaret. al., (2004), studied sequencing batch reactor treatment for simultaneous organic carbon and nitrogen removal in a laboratory study, by using a reactor made in 5 mm thick Perspex sheet, having effective volume 20.0 litres, operated at combination 1 - 4 hour aerobic react period and 4 hours anoxic react period, combination 2 - 5 hours aerobic react period and 3 hours anoxic react period, combination 3 - 3 hours aerobic react period and 5 hours anoxic react period in aerobic-anoxic sequence, fed by synthetic wastewater having soluble chemical oxygen demand 1000±100 mg/l, ammonia nitrogen of 40-90 mg/l. The removal efficiency of 85-92% of sCOD removal was obtained for 8.0 hours cycle period, irrespective of aerobic react period. At combination 4+4 hours 88-100%, 73-75%, 91-94% removal efficiencies were obtained for nitrification, de-nitrification and organic carbon.

Chookietwattana and Khonsarn., (2011), studied biotechnological conversion of wastewater to Polyhydroxyalkanoate (PHA) by Bacillus in a sequencing batch reactor by using a glass reactor of working volume 5 litres fed by synthetic wastewater having COD 1000±50 mg/l operated for 24 hours. At two anoxic/aerobic modes of 4/18 hours operational condition conversion of wastewater to PHA was suitable and yields 1.4054 g/l and 74 % as dry sludge weight. The removal efficiencies of 87.5%, 80.0% and 57.2% were obtained in COD, TKN and orthophosphate removal.

Bindhu and Madhu., (2013), studied influence of organic loading rates on aerobic granulation process for the treatment of wastewater by using column type SBR with internal diameter 6.5 cm, height 60.3 cm, an effective volume of 2 litres operated in successive cycles of 4 hours fed by synthetic wastewater under organic loading rates 3, 6, and 9 kg COD/m^3.d. At organic loading 6 kg COD/m^3.d the COD removal efficiency of 97.9% and sludge with sludge volume index (SVI) of 25.1 ml/g was achieved, the maximum COD removal efficiency observed. The COD removal efficiency of 96%, 95% and SVI of 31 and 30.6 ml/g was observed for organic loading 3, 9 kg COD/m^3.d respectively.

Sirianuntapiboonet. al., (2005), studied application of a new type of moving bio-film in aerobic Sequencing Batch Reactor (aerobic-SBR) by using six 10 litres reactors of 5 mm thick acrylic plastic 18 cm in diameter, 40 cm in height, working volume 7.5 litres, applied with a moving bio-film (MB), made up of inner tube of used tyres for increasing the system efficiency and quality of bio-sludge due to good sedimentation, non-biodegradability and reusability. The reactor was operated at dissolved oxygen 2-3 mg/l and MLSS 2500 mg/l. The amount of suspended bio-sludge waste, SVI and SRT of the MB-aerobic SBR under a low organic loading of 80±9.3 g BOD_5/m^3.d were 1485±146 mg/d, 51±3.7 ml/g and 10.1±5.1 days, respectively and 1800±152 mg/d, 69±4.0 ml/g and 8.3±5.3 days, respectively in the conventional aerobic SBR. The BOD_5, TKN and TP removal efficiencies of the MB-aerobic-SBR were about 1-2, 2-3 and 10-12% higher, respectively, than that of the conventional-aerobic-SBR. The BOD_5 and COD removal efficiencies of the MB-aerobic-SBR were higher than 95% under organic loading 528±50.8 g BOD_5/m^3.d with synthetic wastewater containing 800 mg/l BOD_5 for HRT of 1.5 days. The effluent BOD_5, COD, total Kjeldahl nitrogen, total phosphorus and suspended solids of the MB-aerobic SBR under a high organic loading of 528±50.8 g BOD_5/m^3.d were 45±5.1, 37±3.6, 4.1±1.0, 1.5±0.80 and 41±2 mg/l, respectively.

Hu et. al., (2010), studied effect of aeration rate on the emission of N_2O in anoxic-aerobic SBR (A/O SBR) by using three bench scale reactors of effective volume 24 litres operated at 23 ± 2^0C, 3000 mg/l of MLSS, under anoxic-aerobic mode supplied by N_2 and air for the cycle of 10 minutes feed, 2 hours anoxic, 4 hours aerobic, 40 minutes settling, 10 minutes decanting. The higher aeration rate causes smaller N_2O emission, mild aeration rate led to best nitrogen removal efficiency. As most N_2O is produced during aerobic phase, incomplete de-nitrification is responsible for higher N_2O emission at low aeration rate and complete nitrification is reason of N_2O emission at higher aeration rate. Nitrogen removal efficiency is induced by reducing N_2O emission and lowering energy consumption.

Kusmierczaket. al., (2012), studied long-term cultivation of an aerobic granular activated sludge by using SBR of working volume of 3 litres operated at room temperature sequentially in a 6-hours cycle of 5 minutes of feeding, 345 minutes of aeration, 5 minutes of settling and 5 minutes of effluent withdrawal, supplied with up-flow air, at sludge retention time of 8 days, hydraulic retention time of 12 hours and at pH 7.2. At superficial up-flow air velocity of 1.9 cm/s and an organic loading rate (OLR) of 2 g COD/l.d cultivated granules during 1 year were stable and had capability in simultaneous removal of carbon, nitrogen and phosphorus from wastewater. For 6 hours SBR cycle removal efficiency of chemical oxygen demand (COD), N-NH_4^+, P-PO_4^{3-} were 93%, 66% and 83%, respectively. The sludge volume index (SVI) was 90-110 ml/g and biomass concentration 8.0 g/l. Aerobic granules mean diameter was 4.9 mm with increased specific gravity and surface hydrophobicity of sludge.

Wang et. al., (2012), studied aerobic granulation for 2, 4-dichlorophenol biodegradation in a sequencing batch reactor by using 4 litres column-type reactor of 8 cm diameter, 100 cm height, operated at temperature 25 ± 2^0C sequentially in a 4-hours cycle of 4 minutes of influent filling, 30 minutes of anoxic (no stirring), 200-210 minutes aeration, 1-11 minutes settling, and 5 minutes effluent withdrawal, hydraulic retention time (HRT) of 8 hours. After operation of 39 days stable granules of 1-2 mm diameter with definite shape and appearance were formed. Aerobic granules biologically degrades of 2, 4-dichlorophenol (2, 4-DCP) in a sequencing batch reactor 2, 4-DCP and chemical oxygen demand concentrations were 4.8 mg/ l and 41 mg /l, with high removal efficiencies of 94% and 95%, respectively.

2.13. Tannery Wastewater

Durai and Rajasimman, (2011), reviewed biological treatment of tannery wastewater. The tannery wastewater containing chromium is treated by lab scale SBR under aerobic and anaerobic batch processes and concluded that nitrification and de-nitrification rates at same chromium concentration were higher in SBR with un-acclimated biomass. SBRs were able to produce more resistant biomass which acclimates quickly. The tannery wastewater produced after oxidation of sulphide compounds with average COD and ammonia concentration 550 and 90 mg/l fed by membrane sequencing batch reactor (MSBR). The removal efficiencies of 100%, 90% and 60-90% in ammonium, COD and total nitrogen were achieved.

Faouziet. al., (2013), 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.

Duraiet. al., (2011), studied kinetic studies on biodegradation of tannery wastewater in a sequential batch bioreactor by using two bench scale reactors of Plexi glass having total volume of 10 litres, operated at 30^oC temperature and pH 7, mechanical stirred at the speed of 150 r.p.m., for cycle of 24 hours as 1 hour filling, 20 hours reaction, 2 hours settling, 0.75 hour withdrawal and 0.25 hour idle. The reactors were operated for 50 days for 6240 mg COD/l, 4680 mg COD/l, 3220 mg COD/l and 1560 mg COD/l at different OLR, initially 2 kg COD/m^3day for 15 days, 2.5 kg COD/m^3 from the day of 16-31, 3.3 kg COD/m^3 from the day of 32-40 and 5 kg COD/m^3 until the end, at hydraulic retention times 5, 4, 3, and 2 days. The maximum reduction in COD and colour were found to be 79% and 51% respectively.

Goltaraet. al., (2003), studied carbon and nitrogen removal from tannery wastewater with a membrane bioreactor by using a reactor of 3.5 litres equipped with a submerged hollow fibre membrane of 0.10 m^2. surface area of 0.04 and 0.1 micrometers average and maximum pore sizes were operated for cycle time of 8 hours, with 20 minutes for feeding, 4 hours 45 minutes of aeration, 1 hour 15 minute anoxic stage, 30 minutes of re-aeration and 1 hour 10 minutes of permeation, at HRT of 24 hours and controlled with PLC. The maximum biomass concentration in the reactor 10 g/l. Low biomass yield was achieved due to the low feed/microorganisms (F/M) ratio. Removal efficiency of 100% approximately in ammonium, 90% in COD and 60 to 90% in TN removal was achieved.

Ganesh et. al., (2003), studied biodegradation of tannery wastewater using sequencing batch reactor - respirometric assessment by utilizing bench-scale reactor made up of Plexi glass, 8 litres working volume with respirometry combined. At a 12-hour SBR cycle with a loading rate of 1.9-2.1kg/m^3.d, removal of 80-82% COD, 78–80% TKN and 83-99% NH_3-N were achieved. About 66-70% of the influent COD was readily biodegradable, 10-14% was slowly degradable and 17-21% was non-biodegradable. The oxygen mass transfer coefficient was KLa 19±1.7 /h.

Srinivasanet. al., (2011), studied combined advanced oxidation and biological treatment of tannery effluent by using SBR of 5 litres capacity, operated with 24 hours hydraulic retention time (HRT) and 6000 mg/l mixed liquor suspended solids (MLSS) concentration for the cycle 0.25 hour filling, 23 hours aeration, 0.5 hour settling, and 0.25 hour decanting. The removal efficiencies of 98% and 64% in colour and COD reduction were achieved.

Lefebvre et. al., (2004), studied halophilic biological treatment of tannery soak liquor in a sequencing batch reactor by using lab-scale with peristaltic pumps, air compressor at 30^0C temperature operated for cycle 24 hours divided as 22 hours for reacting, 1 hour 30 minutes settling, 30 minutes withdrawal and filling . The reactor was fed at 2, 3 and 4 l/d, for hydraulic retention time (HRT) 5, 3.3 and 2.5 days. The removal efficiencies of 95%, 93%, 96% and 92% for COD, PO_4^{3-}, TKN and SS respectively, were achieved for 5 days hydraulic retention time (HRT) and 0.6 kg COD/m^3.d and 34 g NaCl /l organic loading.

2.14. Textile Wastewater

Vaiganet. al., (2010), studied aerobic sequencing batch reactor system with granular activated carbon for the treatment of wastewater containing a reactive dye by using four cylindrical Plexi glass reactors operated at initial reactive dye Brill Blue KN-R concentrations of 20, 25, 30 and 40 mg/l in the reactors R_1, R_2, R_3 and R_4, respectively at constant concentration of granular activated carbon (GAC) 1000 mg/l. The dye removal efficiencies of R_1, R_2, R_3 and R_4 were increased by 23%, 23.65%, 18.7% and 18% percent, respectively, after adding GAC to SBR reactors. The average SVI of all reactors was in the range of 37- 49 ml/g and 27- 43 ml/g, respectively before and after adding GAC.

Buitronet. al., (2004), studied aerobic degradation of the azo dye acid red 151 in a sequencing batch bio-filter by utilizing aerated acrylic reactor with working volume 6 litres, total volume of 9.8 litres, applied with 3.8 litres porous volcanic rock (puzolane) of 2.0 to 2.5 cm diameter. The reactor was operated at 25 0C, pH 7, 2500 mg/l volatile suspended solids (VSS), for cycle times of 24, 12, 8 and 4 hours, at 25 and 50 mg AR 151/l initial concentrations of azo dye acid red 151 (AR151) were used. The maximum substrate degradation rate of 247 mg AR151/($l_{reactor}$ d) was obtained with colour removal 99% using an initial concentration of 50 mg AR151/l.

Mudaet. al., (2010), studied the development of granular sludge for textile wastewater treatment by using column type reactor of 8 cm internal diameter, 100 cm total height, working volume of 4 litres operated at pH 7.0±0.5, temperature 30±2 ^{0}C and substrate loading of 2.4 kg COD/ m^3.d, dissolved oxygen (DO) concentration 2 mg/l, under 6 hours successive cycle comprised of 5 minutes filling, 340 minutes reaction, 5 minutes settling, 5 minutes decanting and 5 minutes idle, under intermittent anaerobic and aerobic conditions. The development in average size of the granules from 0.02 - 0.01 mm to 2.3- 1.0 mm and in the average settling velocity increased from 9.9±0.7 m/h to 80±8 m/h in turn increased biomass concentration 2.9±0.8 g /l to 7.3±0.9 g /l. The removal efficiencies of 94%, 95% and 62% for COD, ammonia and colour was observed.

Khouniet. al., (2012), studied treatment of reconstituted textile wastewater containing a reactive dye in an aerobic sequencing batch reactor using a novel bacterial consortium by utilizing a laboratory scale bioreactor (8 litres) under aerobic conditions at room temperature 27±3 ^{0}C, pH 7.0, mixed liquor volatile suspended solids (MLVSS) concentration 3 g/l, under the cycle consisted 15 minutes of fill, 23 hours reaction , 30 minutes settle and 15 minutes draw periods, supplied with air diffuser fed by synthetic wastewater of different volumetric dye loading rates 3-20 g dye/m^3.d with organic nutrients addition C/N/P in100/5/1 proportion. De-colourization efficiency of 88-97%, COD removal efficiency of 95–98% was achieved for volumetric dye loading rates under 15 g dye/m^3.d.

2.15. Fish farming industry

Chang and Cajucom, (2008), studied feasibility of fish farm effluent treatment by sequencing batch membrane bioreactor of working volume of 6.0 litres, attached with membrane of pore size 0.4 um and surface area 0.108 m^2, operated at initial biomass concentration of 2900 mg VSS/l, sludge retention time (SRT) of 20 days, dissolved oxygen concentration above 4 mg /l, at 25^{o}C temperature, for 4 hours cycle duration fed by fish farm effluent. Two aerobic/anoxic durations aeration/stirring-settling, 100/45-45 minutes (as run 1) and 60/60-70 minutes (as run 2), were operated at MLSS concentration 1560 mg/l and 1890 mg/l for run 1 and run 2 respectively. The removal efficiencies of COD and BOD_5 were 81%, 90%, respectively of run 2. The average removal of nitrification and de-nitrification were significant during the same run and nitrite drawn to range 0.5-1.0 mg/l.

2.16. Food Processing Industry

Ariset. al., (2000), studied treatment of food processing industrial effluent using coagulation and sequential batch reactor of 0.4 m. in diameter, 1 m. in height, total fill volume of 85 litres, operated at mixed liquor suspended solids (MLSS) 3000 mg/l, dissolved oxygen (DO) 3 mg/l, within pH range 5-

8.5 with coagulant and polymer dose varied from 20 - 220 mg/l, fed by food processing wastewater. At SBR HRTs of 15, 30, 60, 120, 240, 360, 480 minutes COD and BOD_5 removal efficiencies were 73.85%, 92.4%, 80.7%, 88.9%, 97.9%, 98.4%, 99.2% and 63.7%, 96.6%, 75.0%, 99.1%, 97.0%, 98.3%.The optimum dose of coagulant ranges 20 - 80 mg/l and polymer dose 60-220 mg/l in optimum pH ranges from 5.5-7.0.

2.17.Fruit Juice Industry

Ozbaset. al., (2006), studied aerobic and anaerobic treatment of fruit juice industry effluent operated at HRT of 24 hours, F/M ratio of 0.5, 12 hours of cycle time. The removal efficiency of 90-95 % was obtained for soluble COD. Aerobic SBR treatment gives no problem in sludge settling.

2.18. Hospital Industry Effluent

Ahsan and Jafrudeen, (2006), reviewed the technologies for treatment of hospital wastewater and comparison of emerging and conventional technologies. The removal efficiency of SBR was 95-97% which produced effluent of quality having BOD_5< 5 mg/l, COD < 50 mg/l, TSS < 10 mg/l, Total nitrogen as N < 10 mg/l, Total phosphorus < 10 mg/l, E-coli removal 99-99% MPN/100ml. SBR was found to be more effective in treatment of hospital wastewater.

2.19. Palm Oil Mill Effluent (POME)

Abdullah et. al., (2000), studied aerobic granular sludge formation for high strength agro-based wastewater treatment in an open, cylindrical column type SBR having total volume of 3 litres, working volume of 1 litre, fed at loading rate of 2.5 kg COD/m^3/day, operated for successive cycles of 3 hours in pH range 6.5- 7.0, at initial MLSS concentration 3000 mg /l in the reactor. The removal efficiencies of 91.1%, 97.6% and 38% were obtained in COD, ammonia and colour removal. Stable granules were obtained with 2.0-4.0 mm diameter at COD loading rate of 2.5 kg COD/m^3/day and good biomass accumulation with good settling properties of granular sludge was obtained at sludge volume index (SVI) was 31.3 ml g/ss and biomass concentration of was 7600 mg /l.

2.20. Shrimp Aquaculture Wastewater

Kern and Boopathy, (2012), studied use of sequencing batch reactor in the treatment of shrimp aquaculture wastewater by using two pilot scales SBR with 5000 litres capacity, working volume 3000 litres, operated aerobically and an-aerobically alternated at regular intervals. 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 de-nitrification the C:N ratio should be maintained at 10:1.

Lyles et. al., (2008), studied biological treatment of shrimp aquaculture wastewater using a sequencing batch reactor by using four identical SBRs of 19 litres capacity, mixed with stirring motor at 100 r.p.m. during aerobic operation, operated sequentially in aerobic and anoxic modes. 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 de-nitrification of nitrate was achieved in the anaerobic process with 99% nitrate removal.

2.21. Soybean Curd Industry Wastewater

Gao et. al., (2010), studied kinetic model for biological nitrogen removal using shortcut nitrification-denitrification process in sequencing batch reactor by using reactor with cylindrical upper part, bottom in a cone shape, 70 cm height, 30 cm diameter, effective volume of 38 litres operated at 26 °C temperature, at DO 0.5-3.5 mg/l, at ammonium nitrogen concentration (NH_4^+-N) 50-65 mg/l, pH at 6.5, mixed liquor suspended solids (MLSS) in the reactor was maintained at 3.5-4.0 gSS/l, fed by soybean curd production wastewater having chemical oxygen demand (COD) 400-800 mg/l operated in aerobic and anoxic modes. During de-nitrification process nitrite removal was close to a zero-order reaction if the concentration COD > 100mg/l, and concentrations of nitrite and organic matter (as COD) had limited effect on de-nitrification rate.

2.22. Wood Fiber Industry Wastewater

Ganjidoust and Ayati, (2010), studied use of Sequencing Batch Reactors (SBRs) in treatment of wood fibre wastewater by utilizing four similar reactors in series with volume of 4 litres, operated under controlled SVI, in pH range 6.5-7.2. The removal efficiencies of 92%, 84%, and 52% for COD, turbidity and total solids, for 1000-2500 mg/L COD loading, 100:5.1:1 C/N/P ratio for 10 hours detention time was obtained.

3. Conclusions

Sequencing batch reactors are extremely flexible to adopt changes for varying effluent parameters. Wastewater treatment with sequencing batch reactors is very cost effective with minimal footprints and minimal sludge bulking. SBR performs equalization, primary clarification, biological treatment and secondary clarification in a single vessel reactor. It eliminates need of internal mixed liquor suspended solids and recirculation of return activated sludge for biological nutrient removal. (USEPA, Wastewater Technology Fact Sheet SBR,1999) SBR avoids the use of clarification equipment which saves more space, labour requirement and higher maintenance cost. Mixed liquor suspended solids cannot be washed out during decanting, they can be held in the tank as long as necessary. Sequencing batch reactors can be operated for COD removal, BOD removal, nitrification, de-nitrification, suspended solids removal. (USEPA, Summary Report SBR, 1986) Powdered activated carbon can be added to the sequencing batch reactor during operation cycle. (S. Mace, 2002)

Sequencing batch reactors have excellent performance and vast application in treating domestic as well as wastewater from chemical, dairy, industrial estate wastewater, landfill lechate, paper and pulp, petrochemical, petroleum, pharmaceutical, piggery, sewage, swine, synthetic wastewater, tannery, textile, fish farming, food processing, fruit juice, hospital, palm oil mill, shrimp aquaculture, soybean curd, wood fibre industries.etc. SBR manufacturer provides a process guarantee to produce an effluent of less than 10 mg/L BOD, 10 mg/L TSS, 5 - 8 mg/L TN, 1 - 2 mg/L TP (U.S. EPA Fact Sheet, 1983) Automation of SBR by programmed logic controllers (PLC), supervisory control and data acquisition (SCADA) can be done for effective treatment as per the different objectives such as turbidity removal.

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