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SEQUENCING BATCH REACTOR: A PROMISING TECHNOLOGY IN WASTEWATER TREATMENT

Devender Kumar

Department of Environmental Science, Himalayan University,
Itanagar, Arunachal Pradesh, India

ABSTRACT

Wastewater contains elements toxic to humans and the ecosystem discharge of domestic and industrial wastewater of surface or groundwater very dangerous to the environment. Therefore, treatment of any kind of wastewater to produce discharge of good quality is necessary. As such, choosing an effective treatment process is very important. Sequencing Batch Reactor (SBR) is modification of activated sludge process, which has been successfully used to treat municipal and industrial wastewater. SBR process due to its operational flexibility and excellent process control possibilities is being extensively used for treatment of wastewater. The process is applied to remove nutrients high biochemical oxygen demand, chemical oxygen demands, toxic material such as cyanide, copper, chromium, lead, nickel, total dissolved solids etc. As the SBR process can be effectively automated, it is known to save significant operating expenses and is able to achieve high effluent quality in a very short aeration time. The process advantages are single tank configuration, small foot print, easily expandable, simple operation and low capital costs. SBR process is gaining immense popularity in the recent years and many researches and investigations have been conducted on this treatment technology.

Key words: **Sequencing Batch Reactor, Domestic Wastewater, Industrial Wastewater, Organic removal, Nutrients removal.**

INTRODUCTION

A supply of clean water is an essential requirement for the establishment and maintenance of diverse human activities. Water resources provide valuable food through aquatic life and irrigation for agriculture production. However, liquid and solid wastes produced by human settlements and industrial activities pollute most of the water sources throughout the world. As the environmental discharge standards are getting more and more stringent, the traditional continuous flow-based biological wastewater treatment process faces severe challenges. The sequencing batch reactor (SBR) technology is a modification of the much popular activated sludge process (ASP). Such a conversion of the continuous nature of the ASP-based treatment process to a batch process as in SBR helps introduce various process flexibilities and alternatives in process controls and design so as to better achieve the latest effluent discharge standards. The term SBR was originally coined by R.L. Irvine. Opposed to the common belief of SBR being a new technology, the SBR-like fill and draw processes were popular during 1914–1920. The revival of interest in SBR technology in its present form occurred during the late 1950s and early 1960s due to the improvement in technology related with aeration and process control. In its initial years, SBR technology was mainly used by small communities for sewage treatment and for the treatment of high strength industrial wastes. Due to the design flexibility and better process control that can be achieved by the modern technology, the use of the SBR process has not been limited to the field of sewage treatment only; it has also found wide acceptance in biological treatment of industrial wastewater containing difficult-to-treat organic chemicals. As the SBR process can be effectively automated, it is known to save more than 60% of the operating expenses required for a conventional ASP and is able to achieve high effluent quality in a very short aeration time. In densely populated countries such as India and regions such as Europe, SBR is being considered as a preferable technology due to its low requirement of area as well as manpower for operation. The SBR process is often preferred over Continuous Flow Process (CFP) due to reduction in energy consumption and enhancement in the selective pressures for BOD, nutrient removal, and control of filamentous bacteria. Due to these reasons, SBR process is gaining immense popularity in the recent years. The SBR technology has been undergoing several minor and major modifications over the past few years to be able to effectively treat the exponentially increasing number of new pollutants in wastewater. This article provides an insight into the technology as well as reviews the recent advances in the design and application of SBR technology.

The Process

In an SBR process, all these unit processes take place within a single tank for their specific duration and intervals, sequentially spaced over a span of time. Thus, SBR provides in time the same treatment what the CFP provides in space. The SBR technology basically incorporates a fill-and-draw type biological wastewater treatment process, functionally resembling to an activated sludge process. Depending on the scale of operation, the SBR system, along with its variants and hybrids, may involve single or multiple tanks, each of which features five basic operating modes, namely, Fill, React, Settle, Draw, and Idle. Being a batch process, the time duration of each mode within a tank can be adjusted to meet the different treatment needs, such as low COD in the effluent, biological nutrient removal, etc.

SBR Operating Principles

In its most basic form, the SBR system is a set of tanks that operate on a fill-and draw basis. Each tank in the SBR system is filled during a discrete period of time and then operated as a batch reactor. After desired treatment, the mixed liquor is allowed to settle and the clarified supernatant is then drawn from the tank. The cycle for each tank in a typical SBR is divided into five discrete periods: Fill, React, Settle, Draw and Idle. There are several types of Fill and React periods, which vary according to aeration and mixing procedures. Sludge wasting may take place near the end of React, or during Settle, Draw or Idle. Central to SBR design is the use of a single tank for multiple aspects of wastewater treatment. SBR operation for each tank for one cycle for the five discrete time periods of Fill, React, Settle, Draw, and Idle (Irvine and Ketchum, 2004).

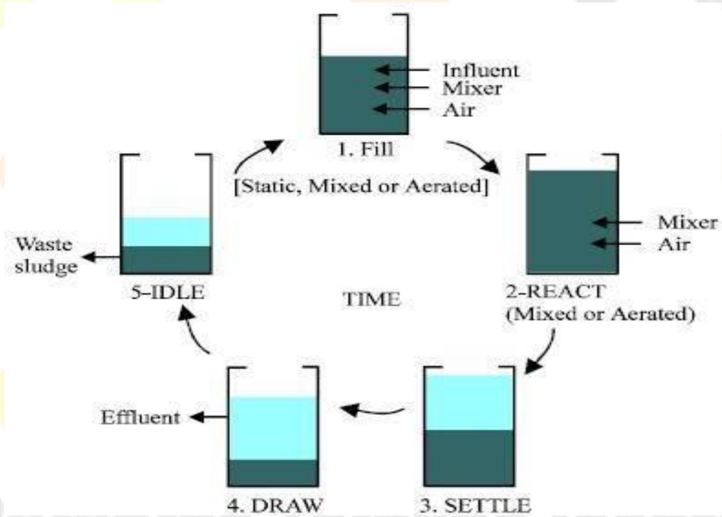

Fig. 1: A typical Cycles in SBR

Fill

The influent to the tank may be either raw wastewater (screened and degritted) or primary effluent. It may be either pumped in or allowed to flow in by gravity. The feed volume is determined based on a number of factors including desired loading and detention time and expected settling characteristics of the organisms. The time of Fill depends upon the volume of each tank, the number of parallel tanks in operation, and the extent of

diurnal variations in the wastewater flow rate. Virtually any aeration system (e.g., diffused, floating mechanical, or jet) can be used. The ideal aeration system, however, must be able to provide both a range of mixing intensities, from zero to complete agitation, and the flexibility of mixing without aeration. Level sensing devices, or timers, or in-tank probes (e.g., for the measurement of either dissolved oxygen or ammonia nitrogen) can be used to switch the aerators and/or mixers on and off as desired.

React

Biological reactions, which were initiated during Fill, are completed during React. As in Fill, alternating conditions of low dissolved oxygen concentrations (e.g., Mixed React) and high dissolved oxygen concentrations (e.g. Aerated React) may be required. The liquid level remains at the maximum throughout react, sludge wasting can take place during this period as a simple means for controlling the sludge age. By wasting during React, sludge is removed from the reactor as a means of maintaining or decreasing the volume of sludge in the reactor and decreases the solids volume. Time dedicated to react can be as high as 50% or more of total cycle time. The end of React may be dictated by a time specification (e.g. the time in React shall always be 1.5 h) or a level controller in an adjacent tank.

Settle

In the SBR, solids separation takes place under quiescent conditions (i.e., without inflow or outflow) in a tank, which may have a volume more than ten times that of the secondary clarifier used for conventional continuous-flow activated sludge plant. This major advantage in the clarification process results from the fact that the entire aeration tank serves as the clarifier during the period when no flow enters the tank. Because all of the biomass remains in the tank until some fraction must be wasted, there is no need for underflow hardware normally found in conventional clarifiers. By way of contrast, mixed liquor is continuously removed from continuous-flow activated-sludge aeration tank and passed through the clarifiers only to have major portion of the sludge returned to the aeration tank.

Draw (Decant)

The withdrawal mechanism may take one of several forms, including a pipe fixed at some predetermined level with the flow regulated by an automatic valve or a pump, or an adjustable or floating weir at or just beneath the liquid surface. In any case, the withdrawal mechanism should be designed and operated in a manner the prevents floating matter from being discharged. The time dedicated to draw can range from 5 to more than 30 % of the total cycle time. The time in Draw, however, should not be overly extended because of possible problems with rising sludge.

Idle

The period between Draw and Fill is termed Idle. Despite its name, this “idle” time can be used effectively to waste settled sludge. While sludge wasting can be as infrequent as once every 2 to 3 months, more frequent sludge wasting programs are recommended to maintain process efficiency and sludge settling SBR technology has the advantage of being much more flexible than Conventional Activated Sludge Processes (CASP) in terms of matching reaction times to the concentration and degree of treatment required for a particular wastewater. For example, the SBR process allows for the following adjustments to be made in addition to those (such as sludge age and operating mixed liquor solids concentration) that can be made in an equivalent conventional process: total cycle duration of each phase within the process cycle pattern of inflow dissolved oxygen profile during aeration operating top water level operating bottom water level.

Flow Diagram

Over one cycle

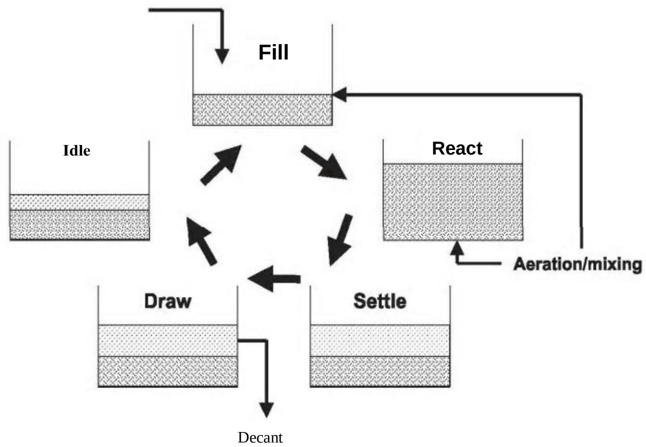

Fig. 2: A typical SBR over One Cycle

Advantages

The primary advantages of the SBR process are:

- Equalization, primary clarification (in most cases), biological treatment, and secondary clarification can be achieved in a single reactor vessel.
- Small space requirements.
- Common wall construction for rectangular tanks.
- Easy expansion into modules.
- Operating flexibility and control.
- Controllable react time and perfect quiescent settling.
- Elimination of return sludge pumping.
- Potential capital cost savings by eliminating clarifiers and other equipment.

Disadvantages

The primary disadvantages of the SBR process are:

- A higher level of sophistication is required (compared to conventional systems), especially for larger systems, of timing units and controls.
- Higher level of maintenance (compared to conventional systems) associated with more sophisticated controls, automated switches, and automated valves.
- Potential of discharging floating or settled sludge during the Draw or Decant phase with some SBR configurations.
- Potential plugging of aeration devices during selected operating cycles, depending on the aeration system used by the manufacturer.
- Potential requirement for equalization after the SBR, depending on the downstream processes.
- Installed aeration power based on percent toxic of the treatment time.
- Batch feeding from storage or bios electors required to control bulking.

SBR Process Configuration

The essential components of SBR are:

- Reactor basin Waste sludge draw-off mechanism.
- Aeration equipment.
- Effluent decanter.
- Process control system

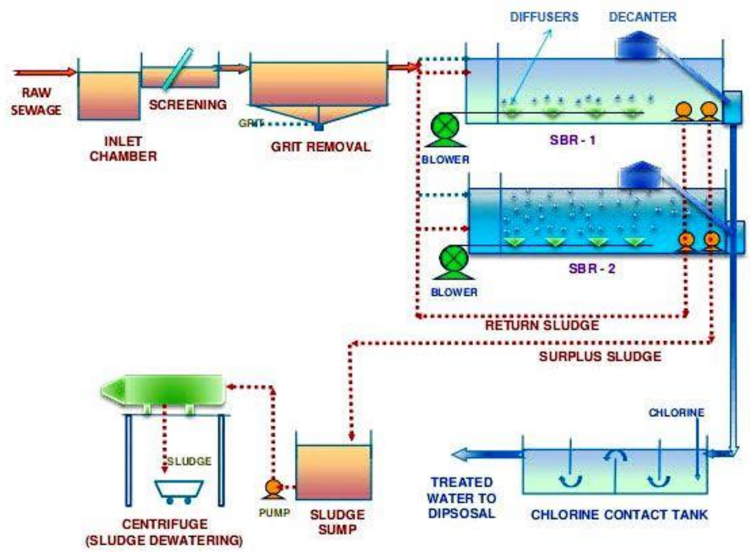

Fig. 3: SBR - Process Configuration Flow Diagram

To accommodate continuous inflow of wastewater, the SBR system generally comprises either a storage/equalization tank and a single SBR tank or a minimum of two tanks. As with conventional activated sludge treatment systems, conventional screening and grit removal are usually provided as preliminary treatment. A primary sedimentation stage is not usually required with SBR processes unless the influent suspended solids are excessive. Settled sewage may also be treated if the SBR is installed downstream of existing primary settlement tanks. Reactors are usually simple circular, square or rectangular tanks and may be constructed from concrete or steel. Lagoon structures can also be used and existing tanks, for example, primary sedimentation tanks, can be retrofitted. Since the tank serves as an aeration tank and a final clarifier, fewer structures are used for the treatment plant as a whole and a more compact layout for the site can be obtained. Extensions to the plant by the addition of modular basins using common wall construction can easily be designed for future loading conditions.

The wasting of microorganisms is done once per cycle during the react phase in high yielding multiple tank system while the frequency of wasting may be as low as once every 2 weeks for low yielding single tank operation. The simultaneous aeration, mixing, reaction, and settling occurring within the SBR tank obviate the requirement of a separate clarifier unit. The duration of Fill and React phases can be adjusted to impart the SBR system. The SBR system provides major operational flexibilities like internal equalization and control of biological reactions through regulation of aeration. The presence of microorganisms in high concentrations right from the Fill phase reduces the treatment duration significantly. The ability to control the substrate availability by varying the aeration duration during Fill provides a high degree of flexibility in controlling the filamentous organism population and concentration of nitrogen. Anoxic period during the React phase is useful in nitrogen removal from the system.

Review of Related Literature

The SBR technology is being applied in a large number of treatment processes owing to the operational flexibility it offers. The ability of SBR to perform flow equalization, biological treatment, and secondary clarification within a single tank by varying the duration of each phase and aeration period makes it a versatile treatment technology. In the recent years, the combination of different treatment technologies has been tested at lab scale to extend the application of SBR technology further. A variation of SBR is a sequencing batch bio film reactor (SBBR), which is a Combination of Suspended and Attached Growth (CSAG) system. Bio film grows at a solid–fluid interface by attachment to a support material. It provides a chance to slow growing microorganisms to proliferate, irrespective of the HRT, and sedimentation characteristics of the bio-aggregates. The selection of support material and its size depends on the characteristics of the wastewater and the treatment objectives. The reactor may be packed with the support material or it may be suspended in the reactor fluid. A typical SBBR cycle has Fill, React, and Draw phases only. Plug flow conditions exist within an SBBR. The time required for washing of the support media may be considered analogous to the settling time in an SBR. Due to the excessive head loss and sloughing off risk, the SBBR systems are unsuitable for influent with high TSS and when excessive microbial growth is expected. There have been numbers of installations after the first pilot scale SBBR was used to treat leach ate from the Georgswerder landfill, Germany. The immobilization of microorganisms on a carrier media reduces the microbial washout, protects them from toxic constituents, pH, and temperature extremes. As the media is retained, a shorter HRT is possible that results in smaller reactor size or higher treatment capacity with the same size reactor compared to conventional SBR. Bio film configured systems are more resilient and are well suited for treating wastewater with highly variable quality with low sludge production. When chosen judiciously, the media may help absorb shock loads, for example, activated carbon for high organic load or zeolite for high ammonia in influent. These buffers temporarily absorb the shock load-causing constituent and later gradually desorb the pollutants along with their simultaneous or subsequent biodegradation. The powdered activated carbon (PAC) for treatment of raw landfill leach ate demonstrated better NH3-N, color, and COD removal than conventional SBR. The use of intelligent dynamic control systems over the conventional time control system has shown to improve the COD, TP, and TN removal efficiencies with considerable energy savings. A modified SBR system with bio-floc technology (BFT) has found interesting application in aquaculture where protein feed for fish as well as treatment of wastewater are considered to be cost-inhibiting. Bio-floc refers to a special kind of macro aggregate of microorganisms which are able to take up nitrogenous compounds present in wastewater and to convert it to microbial protein. Bio-floc organisms can be used as food to the fishes. It has been shown at the lab-scale that SBR envisaged as external growth reactor for bio-floc was able to attain nitrogen removal efficiency of up to 98 % when an optimal C/N ratio between 10 and 15 was maintained. It has also been demonstrated that the BFT in SBR reactor also enabled conversion of nitrogen in aquaculture suspended solids into bacterial biomass, which could potentially be used to feed fish, thereby increasing the efficiency of nitrogen—nearly reaching 100 % nitrate removal within 6 h. SBR and SBBR were used to treat industrial wastewater containing phenolic compounds, such as p-nitrophenol (PNP) which is a hazardous chemical widely used in agricultural, pharmaceutical, and dye industries as a synthetic intermediate in the manufacturing process. Complete removal was demonstrated for PNP removal up to 350 mg/L influent concentration (loading rate of 0.368 kg/m3day−1) by SBR and SBBR (with polyethylene rings). However, the average NH3-N removal efficiency for the SBR and SBBR was only slightly compromised; it reduced to 86 and 96 %, respectively. SBR has been successfully applied for wastewater with high nitrogen content and low COD such as anaerobic SBR (ASBR)-based simultaneous partial nitrification, anaerobic ammonium oxidation, and denitrification (SNAD) system that was applied to treat the opto-electronic industrial wastewater with C/N ratio of nearly 0.2. A similar study was performed by for the treatment of wastewater from production of thin-film transistor liquid crystal display (TFT-LCD) which contained chemicals like dimethyl sulfoxide (DMSO), monoethanolamine (MEA), and tetra-methyl ammonium hydroxide (TMAH). Two different SBR systems, aerobic and anoxic/oxic (A/O), were used. Effective MEA degradation could be easily achieved under all three conditions examined, while efficient DMSO and TMAH degradation could be attained only under anaerobic and aerobic conditions, respectively. These days, hybrid systems like the Porous biomass carrier SBR (PBCSBR) are being investigated to achieve improved nutrient removal efficiency using time-sequenced anoxic/oxic phases and high biomass [18]. In another study, a new biomass retention strategy using natural fibers as biofilm carriers was utilized to treat dairy manure. The concept, evaluated for treating flushed dairy manure in a psychrophilic ASBR, showed higher methane yield despite short HRT (6 days) and low temperature. ASBRs are known to be capable of uncoupling HRT with SRT for biomass retention. Additionally, a particular sequence of operation of ASBR was used to exert selection pressures on microbes for immobilization. Aerobic SBR process, coupled the photo-fenton process and reverse osmosis (RO), was used to reclaim wastewater from textile industry enabling complete internal reuse of water. SBR operating conditions such as cyclic feast and famine regimes, high shear stress, and short settling time promote formation of floc granules which are nothing but dense microbial consortia consisting of different bacterial species that perform different roles in degrading the complex wastes. Alternating anoxic/oxic condition combined with step-feeding mode (AASF) was proved to be an efficient method for nitrogen removal in Granular SBR (GSBR). Aerobic granular sludge presents several advantages over activated sludge, such as excellent settling properties, high biomass retention and biosorption, and ability to deal with high organic loading rates and to perform diverse biological processes simultaneously, such as COD, N, and P removal. The utility of aerobic granular sludge in SBR for degradation of toxic organ fluorine compounds such as 2-fluorophenol (2-FP) has been demonstrated. The fluoroaromatic compounds are usually biodegraded via halo-catechols. The maintenance of a good population of halo-aromatics degraders in bioreactors is highly desirable due to the low concentration discontinuous nature of these compounds. The GSBR provides high biomass retention and thus is extremely promising for the treatment of effluents containing toxic compounds. Conventional SBRs treating wastewaters with flocculating sludge can be converted to granular SBRs by reducing the settle time. A study with wastewater containing azo dyes attempting for simultaneous bio-decolorization and COD removal in SBR having a combination of anoxic-aerobic React phase revealed the following: (a) longer anoxic React phase promotes decolorization, while (b) COD removal was better with shorter anoxic phase. The granular-activated carbon-SBR (GAC-SBR) has shown promising results for the treatment of textile wastewater containing dyes where the dye was removed by GAC via physical adsorption mechanism. Addition of extraneous organic carbon increased the removal efficiency of direct dye. In recent years, the presence of endocrine disruptor compounds (EDCs) in surface water, public water supplies as well as in wastewater has generated much public concern. EDCs are a group of different chemical substances that even in low concentrations such as sub-μg/L level in water may interfere with the normal functioning of human endocrine system and animals. SBR process presents an attractive avenue for the removal of EDCs from wastewater due to its ability to provide anoxic/anaerobic/aerobic conditions within the same basin. Maintenance of such dynamic environmental conditions inside the SBR process tank provides ample scope for the microorganisms capable of degrading EDCs to utilize them. Longer SRT and HRT have been observed to cause greater degree of removal of EDCs primarily because such conditions allow for the proper growth of the slow growing microorganisms capable of utilizing the EDCs. Table 2 summarizes brief details of some of the recent studies performed on the efficiencies of different SBR configurations for the removal of EDCs commonly occurring in wastewater. Ozonation and other polishing steps are suggested after proper study of final products in critical cases where significant dilution of STP effluent does not occur.

OBJECTIVE OF THE STUDY

1. Designing of treatment process using Sequential Batch Reactor (SBR) for Waste Water Treatment.
2. Physio-Chemical characterization of pre and post treatment of Sewage and Waste Water.
3. Performance assessment and hydrodynamic analysis by developing a dynamic model of Sequential Batch Reactor (SBR) and investigate the properties and behavior of Sequential Batch Reactor (SBR) under different inputs and operating conditions.
4. Removal and recovery of nutrient by fill and draw activated Sludge System to remove undesirable components of waste water.
5. Energy conversation potential and economic evaluation of Sewage and Waste Water.

RESEARCH METHODOLOGY

Site of Sewage Treatment Plant, Haryana Shehari Vikas Pradhikaran, Sector-25, Rohtak has been chosen for sample collection. A pilot scale study using Sequential Batch Reactor (which works on Fill and Draw operation) with Sewage Waste Water has been conducted. The raw feed of sewage collected in tank which has aeration system (e.g. Diffused Floating Mechanical or Jet) is used. Biological reaction takes place and the sludge is removed from reactor. Again the tank is filled with some Sewage Waste Water sample and the same process will be repeated based on the sizing calculation of treatment plant. The waste water is passed through a pipe and the waste sludge remains in the tank.

The Sequential Batch Reactor which is established according to the précised particulars, so the outcomes are very accurate and the outcome was more than expectations. The sludge took a little more time for settling.

ANALYSIS AND INTERPRETATION OF DATA

PH	BOD	COD	TSS	NITROGEN TOTAL	PHOSPHOROUS TOTAL	FECAL COLIFORM
5.5-9.0	≤10	≤250	≤100	≤20	≤5	≤100

1. RAW WASTE WATER

Sr. No.	Test Parameters	UNIT	Results	Testing Methods
1.	pH Value	-	7.21	IS 3025(P-44)-1983
2.	Total Suspended Solids	Mg/l	148.0	IS 3025(P-17)-1984
3.	Biochemical Oxygen Demand (BOD- 3 DAYS at 27□ C	Mg/l	125.0	IS 3025(P-11)-1993
4.	Chemical Oxygen Demand	Mg/l	462.0	IS 3025(P-58)-2006

2. TREATED WASTE WATER

Sr. No.	Test Parameters	Unit	Results	Testing method
1.	pH Value	-	7.88	IS 3025(P-11)-1983
2.	Total Suspended Solids	mg/l	26.3	IS 3025(P-17)-1984
3.	Biochemical Oxygen Demand (BOD- 3 DAYS at 27□ C	mg/l	2.5	IS 3025(P-44)-1993
4.	Chemical Oxygen Demand	mg/l	117.0	IS 3025(P-58)-2006
5.	Total Phosphorus (as P)	mg/l	0.76	IS 3025(P-31)-1988
6.	Total Nitrogen (as N)	mg/l	12.4	IS 3025(P-34)-1988
7.	Faecal Coliform	MPN/100ml	70	IS:1622-1981

3. STP SLUDGE RESULT

Sr. No.	Test Parameters	Unit	Results
1.	Color	-	Light Gray
2.	Odor		Slight Odor
3.	Bulk Density	g/cm3	1.06
4.	Moisture	%	18.68
5.	pH	-	6.72
6.	Organic Carbon	%	9.78
7.	Total Nitrogen (as N)	%	1.32
8.	Total Phosphorous (as P)	%	0.16
9.	Total Potassium (as K)	%	<0.1
10.	Conductivity	dSm-1	2.77
11.	C/N Ratio	-	0.13
12.	Arsenic (as As)	mg/kg	ND
13.	Cadmium (as Cd)	mg/kg	ND
14.	Chromium (as Cr)	mg/kg	ND
15.	Copper (as Cu)	mg/kg	ND
16.	Lead (as Pb)	mg/kg	ND
17.	Mercury (as Hg)	mg/kg	ND
18.	Nickel (as Ni)	mg/kg	ND
19.	Zinc (as Zn)	mg/kg	ND

EXPECTED OUTCOMES OF STUDY

Wastewater treatment involves breakdown of complex organic compounds in the wastewater into simpler compounds that are stable and nuisance-free, either physico-chemically and/or by using micro-organisms (biological treatment). The adverse environmental impact of allowing untreated wastewater to be discharged in groundwater or surface water bodies and or lands are as follows:

1. The decomposition of the organic materials contained in wastewater can lead to the production of large quantities of malodorous gases.
2. Untreated wastewater (sewage) containing a large amount of organic matter, if discharged into a river/stream, will consume the dissolved oxygen for satisfying the Biochemical Oxygen Demand (BOD) of wastewater and thus deplete the dissolved oxygen of the stream, thereby causing aquatic species kills and other undesirable effects.
3. Wastewater may also contain nutrients, which can stimulate the growth of aquatic plants and algal blooms, thus leading to eutrophication of the lakes and streams.
4. Untreated wastewater usually contains numerous pathogenic, or disease causing microorganisms and toxic compounds, that dwell in the human intestinal tract or may be present in certain industrial waste. These may contaminate the land or the water body, where such sewage is disposed.

CONCLUSION

For the above-mentioned reasons the treatment and disposal of wastewater, is not only desirable but also necessary. Need for recycling of treated wastewater in many parts of the world has necessitated the introduction of newer stringent standards for treated wastewater. Unlike the conventional wastewater treatment plants, SBR-based wastewater treatment plants can achieve better treated water quality with no or minor modification in the installed infrastructure, only by simple alteration of the process control parameters in one or more of the phases of the treatment cycle. The SBR process offers smaller foot-print area, lower investment cost, lower operation complexity, and significant control performance as compared to conventional treatment process. If properly designed, the process may achieve significant degree of biological nutrient removal too. Although the SBR process is well developed, and different variants are continuously evolving, there are issues that need to be addressed further.

Ensuring process reliability for simultaneous N and P removal in SBR requires further work towards clear understanding of the microbial diversity of the system with an emphasis on its dynamics under different changing process situations. The study and improved design may follow the principles of ecologically engineered processes that derive stability from the presence of multiple species that accumulate phosphorus (functional richness). This may make the system more resilient with each species showing differential sensitivity to variations in the environmental conditions such as temperature and pH swings, toxic pollutants, presence of nitrite and nitrate, prevalence of VFAs, etc.

Appropriate process control is the heart of the SBR process as it important in ensuring removal of the target contaminants from the wastewater. PLC-based pre-programmed control strategies are popular. Introduction of real-time control strategies can enable SBR process to achieve better robustness, reliability, and optimized operation. This will enhance energy efficiency and also shall help widen the areas of application of the SBR process. Future studies on SBR control strategies would include the development of intelligent control system, which is a real-time control strategy working on feedback-based control. This shall make the SBR process adaptive to changing environmental conditions and to varying wastewater quality so that optimum effluent quality is maintained with high degree of reliability.

REFERENCES

1. Irvine RL, Davis WB. Use of sequencing batch reactor for wastewater treatment. CPC international, Corpus Christi, TX. Presented at the 26th annual industrial waste conference. West Lafayette, IN: Purdue University; 1971.

2. Irvine RL, Busch AW. Sequencing batch biological reactor: an overview. J Water Pollut Con Fed. 1979;51:235.

3. Chiu YC, Lee LL, Chang CN, Chao AC. Control of carbon and ammonium ratio for simultaneous

nitrification and denitrification in a sequencing batch bioreactor. Int Biodeterior Biodegrade. 2007;59(1):1–7.

4. Wastewater Technology Fact Sheet Sequencing Batch Reactors. USEPA. Office of Water. Washington DC. EPA 832-F-99-073. 1999.

5. Smith RG, Wilderer PA. Treatability of hazardous landfill leachate using sequencing batch reactors with silicone membrane oxygenation. 41st Purdue Indust. Chelsea, Michigan: Waste Conf., Purdue University, Lewis Publ; 1987. p. 272.

6. Lessel TH. Upgrading and nitrification by submerged bio-film reactors-experiences from a large scale plant. Water Sci Tech. 1994;29:167–74.

7. Mohan SV, Rao NC, Sarma PN. Low-biodegradable composite chemical wastewater treatment by biofilm configured sequencing batch reactor (SBBR). J Hazard Mater. 2007;144(1-2):108–17.

8. Di Iaconi C, Lopez A, Ramadori R, Di Pinto AC, Passino R. Combined chemical and biological degradation of tannery wastewater by a periodic submerged filter (SBBR). Water Res. 2002;36(9):2205–14.

9. Wilderer PA, Arnz P, Arnold E. Application of biofilms and biofilm support materials as a temporary sink and source. Water Air Soil Pollut. 2000;123(1-4):147–58.

10. Aziz SQ, Aziz HA, Yusoff MS. Optimum process parameters for the treatment of landfill leachate using powdered activated carbon augmented sequencing batch reactor (SBR) technology. Sep Sci Technol. 2011;46(15):2348–59.

11. Jin Y, Ding D, Feng C, Tong S, Suemura T, Zhang F. Performance of sequencing batch biofilm reactors with different control systems in treating synthetic municipal wastewater. Bioresour Technol. 2012;104:12–8.

12. Emerenciano M, Gaxiola G and Cuzon G. Biofloc Technology (BFT): A Review for Aquaculture Application and Animal Food Industry. In: Matovic DM, editor. Biomass Now – Cultivation and Utilization. InTech; 2013. 301-328.

13. Schryver PD, Verstraete W. Nitrogen removal from aquaculture pond water by heterotrophic nitrogen assimilation in lab-scale sequencing batch reactors. Bioresour Technol. 2009;100:1162–7.

14. Luo G, Avnimelech Y, Pan Y, Tan H. Inorganic nitrogen dynamics in sequencing batch reactors using biofloc technology to treat aquaculture sludge. Aquac Eng. 2013;52:73–9.

15. Schryver PD, Verstraete W. Nitrogen removal from aquaculture pond water by heterotrophic nitrogen assimilation in lab-scale sequencing batch reactors. Bioresour Technol. 2009;100:1162–7.

16. Goh CP, Seng CE, Sujari AN, Lim PE. Performance of sequencing batch biofilm and sequencing batch reactors in simultaneous p-nitrophenol and nitrogen removal. Environ Technol. 2009;30(7):725–36.

17. Daverey A, Su SH, Huang YT, Lin JG. Nitrogen removal from opto-electronic wastewater using the simultaneous partial nitrification, anaerobic ammonium oxidation and denitrification (SNAD) process in sequencing batch reactor. Bioresour Technol. 2012;113:225–31.

18. Lei CN, Whang LM, Chen PC. Biological treatment of thin-film transistor liquid crystal display (TFT-LCD) wastewater using aerobic and anoxic/oxic sequencing batch reactors. Chemosphere. 2010;81(1):57–64.

19. Shin HS, Park HS. Enhanced nutrient removal in porous biomass carrier sequencing batch reactor (PBCSBR). Water Sci Tech. 1991;23:719–28.

20. Ma J, Yu L, Frear C, Zhao Q, Li X, Chen S. Kinetics of psychrophilic anaerobic sequencing batch reactor treating flushed dairy manure. Bioresour Technol. 2013;131:6– 12.

21. Liu Y, Wang ZW, Qin L, Liu YQ, Tay JH. Selection pressure-driven aerobic granulation in a sequencing batch reactor. Appl Microbiol Biotechnol. 2005;67(1):26–32.

22. Wang ZW, Ma J, Chen S. Bipolar effects of settling time on active biomass retention in anaerobic sequencing batch reactors digesting flushed dairy manure. Bioresour Technol. 2011;102(2):697–702.

23. Blanco J, Torrades F, Morón M, Brouta-Agnésa M, García-Montaño J. Photo-Fenton and sequencing batch reactor coupled to photo-Fenton processes for textile wastewater reclamation: feasibility of reuse in dyeing processes. Chem Eng J. 2014;240:469–75.

24. Chen FY, Liu YQ, Tay JH, Ning P. Alternating anoxic/oxic condition combined with step- feeding mode for nitrogen removal in granular sequencing batch reactors (GSBRs). Sep Purif Technol. 2013;105:63–8.

25. Wei Y, Ji M, Li R, Qin F. Organic and nitrogen removal from landfill leachate in aerobic granular sludge sequencing batch reactors. Waste Manag. 2012;32(3):448–55.

26. De Bruin LMM, de Kreuk MK, van der Roest HFR, Uijterlinde C, van Loosdrecht MCM. Aerobic granular sludge technology: an alternative to activated sludge? Water Sci Technol. 2004;49(11–12):1–7.

27. Kreuk D, Heijnen JJ, van Loosdrecht MCM. Simultaneous COD, nitrogen, and phosphate removal by aerobic granular sludge. Biotechnol Bioeng. 2005;90(6):761–9.

28. Xu H, Tay JH, Foo SK, Yang SF, Liu Y. Removal of dissolved copper (II) and zinc(II) by aerobic granular sludge. Water Sci Technol. 2004;50:155–60.

29. Duquea AF, Bessa VS, Carvalhoa MF, de Kreuk MK, van Loosdrecht MCM, Castro PML. 2-Fluorophenol degradation by aerobic granular sludge in a sequencing batch reactor. Water Res. 2011;45(20):6745–52.

30. Haggblom MM. Microbial breakdown of halogenated aromatic pesticides and related compounds. FEMS Microbiol Rev. 1992;103:29–72.

31. Murphy CD, Clark BR, Amadio J. Metabolism of fluoroorganic compounds in microorganisms: impacts for the environment and the production of fine chemicals. Appl Microbiol Biotechnol. 2009;84:617–29.

32. Cassidy DP, Belia E. Nitrogen and phosphorus removal from an abattoir wastewater in a SBR with aerobic granular sludge. Water Res. 2005;39:4817–23.

33. Al-Amrani WA, Lim PE, Seng CE, Ngah WSW. Factors affecting bio-decolorization of azo dyes and COD removal in anoxic–aerobic REACT operated sequencing batch reactor. J Taiwan Inst Chem Eng. 2014;45:609–16.

34. Sirianuntapiboon S, Sansak J. Treatability studies with granular activated carbon (GAC) and sequencing batch reactor (SBR) system for textile wastewater containing direct dyes. J Hazard Mater. 2008;159(2-3):404–11.

35. Liu ZH, Kanjo Y, Mizutani S. Removal mechanisms for endocrine disrupting compounds (EDCs) in wastewater treatment—physical means, biodegradation, and chemical advanced oxidation: a review. Sci Total Environ. 2009;407(2):731–48.

36. Zhou Y, Huang X, Zhou H, Chen J, Xue W. Removal of typical endocrine disrupting chemicals by membrane bioreactor: in comparison with sequencing batch reactor. Water Sci Technol. 2011;64(10):2096–102.

37. Irvine RL, Davis WB. Use of sequencing batch reactor for waste- water treatment. CPC international, corpus Christi, TX. Presented at the 26th annual industrial waste conference. West Lafayette, IN: Purdue University; 1971.

38. Irvine RL, Busch AW. Sequencing batch biological reactor: an overview. J Water Pollut Con Fed. 1979;51:235.

39. Chiu YC, Lee LL, Chang CN, Chao AC. Control of carbon and ammonium ratio for simultaneous nitrification and denitrification in a sequencing batch bioreactor. Int Biodeterior Biodegrad. 2007;59(1):1–7.
40. Fatone F, Dante M, Nota E, Di Fabio S, Frison N, Pavan P. Biological short-cut Nitrogen removal from anaerobic digestate in a demonstration sequencing batch reactor. Chem Eng Trans. 2011;24:1135–40.
41. Cervantes FJ, Editor. Environmental technologies to treat nitrogen pollution, IWA Publishing, London. 2009.
42. Spagni A, Lavagnolo MC, Scarpa C, Vendrame P, Rizzo A, Luccarini L. J Environ Sci Health. 2007;42(6):757–65.
43. Gujer W. Nitrification and me—a subjective review. Water Res. 2010;44:1–19.
44. Mulder A, van de Graaf AA, Robertson LA, Kuenen JG. Anaerobic ammonium oxidation discovered in a denitrifying fluidized bed reactor. FEMS Microbiol Ecol. 1995;16:177–84.
45. Gong Z, Yang FL, Liu S, Bao H, Hu S, Furukawa K. Feasibility of a membrane-aerated biofilm reactor to achieve single-stage auto- trophic nitrogen removal based on Anammox. Chemosphere. 2007;69(5):776–84.
46. Wyffels S, Boeckx P, Zhang D, Van Cleemput O, Chen G, Verstraete W. Nitrogen removal from sludge reject water by a two-stage oxygen-limited autotrophic nitrification denitri- fication process. Water Sci Technol. 2004;49(5−6):57–64.
47. Liu S, Yang F, Xue Y, Gong Z, Chen H, Wang T, et al. Evaluation of oxygen adaptation and identification of functional bacteria com- position for anammox consortium in non-woven biological rotat- ing contactor Bioresour. Bioresour Technol. 2008;99:8273–9.
48. Lackner S, Horn H. Evaluating operation strategies and process stability of a single stage nitritation-anammox SBR by use of oxidation-reduction potential (ORP). Bioresour Technol. 2012;107:70–7. The paper presents a comprehensive study on different combinations of feeding and aeration strategies. The interval feeding and interval aeration are found to be the most suitable case in terms of process performance (ammoni- um removal, nitrate production and pH stability) and the use of ORP value as indicator parameter is endorsed.
49. Tang CJ, Zheng P, Wang CH, Mahmood Q, Zhang JQ, Chen XG, et al. Performance of high-loaded ANAMMOX UASB reactors containing granular sludge. Water Res. 2011;45:135–44.
50. Chamchoi N, Nitisoravut S, Schmidt JE. Inactivation of ANAMMOX communities under concurrent operation of anaer- obic ammonium-N oxidation (ANAMMOX) and denitrification. Bioresour Technol. 2008;99:3331–6.
51. Ni SQ, Ni JY, Hu DL, Sung S. Effect of organic matter on the performance of granular anammox process. Bioresour Technol. 2012;110:701–5.
52. Du R, Peng Y, Cao S, Wu C, Wneg D, Wang S, et al. Advanced nitrogen removal with simultaneous anammox and denitrification in sequencing batch reactor. Bioresour Technol. 2014;162:316–22.
53. Joss A, Salzgeber D, Eugster J, Konig R, Rottermann K, Burger S, et al. Full-scale nitrogen removal from digester liquid with partial nitritation and anammox in One SBR. Environ Sci Technol. 2009;43(14):5301–6.
54. Cassidy DP, Belia E. Nitrogen and phosphorus removal from an abattoir wastewater in a SBR with aerobic granular sludge. Water Res. 2005;39(19):4817–23.
55. Lin CK, Katayama Y, Hosomi M, Murakami A, Okada M. The characteristics of the bacterial community structure and population dynamics for phosphorus removal in SBR. Water Res. 2003;37(12):2944–52.
56. Bitton G. Wastewater microbiology. John Willey: New York; 1999. p. 225–57.
57. Lopez-Vazquez CM, Oehmen A, Hooijmans CM, Brdjanovic D, Gijzen HJ, Yuan Z, et al. Modeling the PAO-GAO competition: effects of carbon source, pH and temperature. Water Res. 2009;43(2):450–62.
58. Schuler AJ, Jenkins D. Effects of pH on enhanced biological phosphorus removal metabolisms. Water Sci Technol. 2002;46: 171–8.
59. Harper WF, Jenkins D. The effect of an initial anaerobic zone on the nutrient requirements of activated sludge. Water Environ Res. 2003;75:216–24.
60. Randall AA, Benefield LD, Hill WE. The effect of fermentation products on enhanced biological phosphorus removal, polyphosphate storage, and microbial population dynamics. Water Sci Technol. 1994;30:213–9.
61. Barnard JL, Abraham K. Key features of successful BNR opera- tion. Water Sci Technol. 2006;53(12):1–9.
62. Ge H, Batstone DJ, Keller J. Biological phosphorus removal from abattoir wastewater at very short sludge ages mediated by novel PAO clade Comamonadaceae. Water Res. 2015;69:173–82. A novel, high-rate phosphorus removal process that can be ef- fectively integrated with short SRT (<4 days), energy-efficient carbon removal and recovery processes has been demonstrat- ed in this paper.

63. Gao D, Yin H, Liu L, Li X, Liang H. Effects of idle time on biological phosphorus removal by sequencing batch reactors. J Environ Sci. 2013;25(12):2396–402. This paper investigates the impact of idle time on BPR and shows that although prolonged idle time can increase intracellular polymer pro- duction in influent with low phosphorus concentration, the system tends to become unstable on raising the influent phos- phorus concentration.
64. Wang DB, Xu Q, Yang W, Chen H, Li X, Liao D, et al. A new configuration of sequencing batch reactor operated as a modified aerobic/extended-idle regime for simultaneously saving reactor volume and enhancing biological phosphorus removal. Biochem Eng J. 2014;87:15–24. A new sludge tank halved configuration (STH-SBR) is designed in this paper which resolves the issue of very long idle phase as compared to anaerobic phase per- formed in the Aerobic/oxic (A/O regime) in Aerobic/extended idle (AEI-SBR).
65. Saito T, Brdjanovic D, van Loosdrecht MCM. Effect of nitrite on phosphate uptake by phosphate accumulating organisms. Water Res. 2004;38:3760–8.
66. Barnard JL. A review of biological phosphorus removal in the activated sludge process. Water SA. 1976;2:136–44.
67. Barker PS, Dold PC. Denitrification behavior in biological excess phosphorus removal activated sludge systems. Water Res. 1996;30:769–80.
68. Hu JY, Ong SL, Ng WJ, Lu F, Fan XJ. A New method for charac- terizing denitrifying phosphorus removal bacteria by using three different types of electron acceptors. Water Res. 2003;37:3463–71.
69. Jiang Y, Wang B, Wang L, Chen J, He S. Dynamic response of denitrifying poly-P accumulating organisms batch culture to in- creased nitrite concentration as electron acceptor. J Environ Sci Health. 2006;41A:2557–70.
70. Zhou Y, Pijuan M, Yuan Z. Free nitrous acid inhibition on anoxic phosphorus uptake and denitrification by poly-phosphate accumu- lating organisms. Biotechnol Bioeng. 2007;98(4):903–12.
71. He S, Bishop FI, McMahon KD. Bacterial community and candidatus accumulibacter population dynamics in laboratory- scale enhanced biological phosphorus removal reactors. Appl Environ Microbiol. 2010;76:5479–87.
72. Guerrero J, Guisasola A, Baeza JA. The nature of the carbon source rules the competition between PAO and denitrifiers in sys- tems for simultaneous biological nitrogen and phosphorus remov- al. Water Res. 2011;45:4793–802.
73. Freitas F, Temudo M, Reis MAM. Microbial population response to changes of the operating conditions in a dynamic nutrient- removal sequencing batch reactor. Bioprocess Biosyst Eng. 2005;28:199–209.
74. Kerrn-Jespersen JP, Henze M. Biological phosphorus uptake un- der anoxic and aerobic conditions. Water Res. 1993;27(4):617–24.
75. Kuba T, Wachtmeister A, van Loosdrecht MCM, Heijnen JJ. Effect of nitrate on phosphorus release in biological phosphorus removal systems. Water Sci Technol. 1994;30(6):263–9.
76. Gebremariam SY, Beutel MW, Christian D, Hess TF. Research advances and challenges in the microbiology of enhanced biolog- ical phosphorus removal—a critical review. Water Environ Res. 2011;83(3):195–219.
77. Kuba T, van Loosdrecht MCM, Heijnen JJ. Phosphorus and nitro- gen removal with minimal COD requirement by integration of denitrifying dephosphatation and nitrification in a two-sludge sys- tem. Water Res. 1996;30(7):1702–10.
78. Rim YT, Yang HT, Yoon CH, Kim YS, Seo JB.A full-scale test ofa biological nutrients removal system using the sequencing batch re- actor activated sludge process. Water Sci Technol. 1997;35:241–7.
79. Lee DS, Jeon CO, Park JM. Biological nitrogen removal with enhanced phosphate uptake in a sequencing batch reactor using single sludge system. Water Res. 2001;35(16):3968–76.
80. Soejima K, Matsumoto S, Ohgushi S, Naraki K, Terada A, Tsuneda S, et al. Modeling and experimental study on the anaer- obic/aerobic/anoxic process for simultaneous nitrogen and phos- phorus removal: the effect of acetate addition. Process Biochem. 2008;43(6):605–14.
81. Frison N, Katsou E, Malamis E, Fatone F. A novel scheme for denitrifying biological phosphorus removal via nitrite from nutrient-rich anaerobic effluents in a short-cut sequencing batch reactor. J Chem Technol Biotechnol. 2014.
82. Kargi F, Uygur A. Biological nutrient removal in sequencing batch reactor with different number of steps. Clean Technol Environ. 2003;6(1):61–5.

83. Uygur A, Kargı F. Nutrient removal in a three-step sequencing batch reactor with different carbon sources. Water Air Soil Pollut. 2004;156:71–82.

84. Lee DS, Jeon CO, Park JM. Biological nitrogen removal with enhanced phosphate uptake in a sequencing batch reactor using single sludge system. Water Res. 2001;35(16):3968–76.

85. Chang CH, Hao OJ. Sequencing batch reactor system for nutrient removal: ORP and pH Profiles. J Chem Technol Biotechnol. 1996;67(1):27–38.

86. Debik E, Manav N. Sequence optimization in a sequencing batch reactor for biological nutrient removal from domestic wastewater. Bioprocess Biosyst Eng. 2010;33(5):533–40.

87. Keller J, Watts S, Battye-Smith W, Chong R. Full-scale demon- stration of biological nutrient removal single tank SBR process. Water Sci Technol. 2001;43(3):355–62.

88. Lemaire R, Yuan ZG, Bernet N, Marcos M, Yilmaz G, Keller J. A sequencing batch reactor system for high-level biological nitrogen and phosphorus removal from abattoir wastewater. Biodegradation. 2009;20:339–50.

89. Obaja D, Mace S, Costa J, Sans C, Mata-Alvarez J. Nitrification, denitrification and biological phosphorus removal in piggery wastewater using a sequencing batch reactor. Bioresour Technol. 2003;87(1):103–11.

90. Tilche A, Bacilieri E, Bortone G, Malaspina F, Piccinini S, Stante L. Biological Phosphorus and nitrogen removal in a full scale sequencing batch reactor treating piggery wastewater. Water Sci Technol. 1999;40(1):199–206.

91. Demoulin G, Goronszy MC, Wutscher K, Forsthuber E. Co- current nitrification/ denitrification and biological p-removal in cyclic activated sludge plants by redox controlled cycle operation. Water Sci Technol. 1997;35(1):215–24.

92. Mittal A. Biological Wastewater Treatment. http://www. watertoday.org/Article%20Archieve/Aquatech%2012.pdf. Accessed on 18th August 2015.

93. Bao DJ, Liu ZM, Li J. Research on UNITANK technology and its application in municipal wastewater treatment plant. Appl Mech Mater. 2013;361–363:640–3.

94. UNITANK® - Aerobic & Anaerobic Treatment brochure by Keppel Seghers.

95. Sanitaire ICEAS™ Advanced SBR. http://www.xylem.com/ Assets/Resources/1710-Sanitatire-ICEAS-BiologicalTreatmentProcess.pdf. Accessed on 19th August 2015.

96. Sanitaire ICEAS SBR. http://www.xylemwatersolutions.com/scs/ usa/en-us/Resource%20Library/Brochures/Documents/Sanitaire/ Sanitiare%20ICEAS%20SBR%20Brochure.pdf. Accessed on 19th August 2015.

97. Koch FA, Oldham WK. Oxidation-reduction potential—a tool for monitoring, control and optimization of biological nutrient remov- al system. Water Sci Technol. 1985;17(11-12):259–81.

98. Chang CH, Hao OJ. Sequencing batch reactor system for nutrient removal: ORP and pH profiles. J Chem Technol Biotechnol. 1996;67:27–38.

99. Peng YZ, Shao-Po W, Shu-Ying W, Jian-Ge H, Hai-Bing Q. Effect of denitrification type on pH profiles in the sequencing batch reactor process. Water Sci Technol. 2006;53(9):87–93.

100. Yang Q, Peng YZ, Liu XH, Zeng W, Mino T, Satoh H. Nitrogen removal via nitrite from municipal wastewater at low temperatures using real-time control to optimize nitrifying communities. Environ Sci Technol. 2007;41(23):8159–64.

101. Buitron G, Schoeb ME, Moreno-Andrade L, Moreno JA. Evaluation of two control strategies for a sequencing batch reactor degrading high concentration peaks of 4-chlorophenol. Water Res. 2005;39(6):1015–24.

102. Klapwijk A, Brouwer H, Vrolijk E, Kujawa K. Control of inter- mittently aerated nitrogen removal plants by detection endpoints of nitrification and denitrification using respirometry only. Water Res. 1998;32(5):1700–3.

103. Blackburne R, Yuan ZQ, Keller J. Demonstration of nitrogen re- moval via nitrite in a sequencing batch reactor treating domestic wastewater. Water Res. 2008;42(8–9):2166–76.

104. Pambrun V, Paul E, Sperandio M. Control and modelling of partial nitrification of effluents with high ammonia concentrations in se- quencing batch reactor. Chem Eng Proc. 2008;47(3):323–9.

105. Guisasola A, Pijuan M, Baeza JA, Carrera J, Lafuente J. Improving the start-up of an EBPR system using OUR to control the aerobic phase length: a simulation study. Water Sci Technol. 2006;53(4–5):253–62.

106. Casellas M, Dagot C, Baudu M. Set up and assessment of a control strategy in a SBR in order to enhance

nitrogen and phosphorus removal. Proc Biochem. 2006;41(9):1994–2001.

107. Puig S, Corominas L, Traore A, Colomer J, Balaguer MD, Colprim J. An on-line optimisation of a SBR cycle for carbon and nitrogen removal based on on-line pH and OUR: the role of dissolved oxygen control. Water Sci Technol. 2006;53(4–5): 171–8.

108. Poo KM, Im JH, Ko JH, Kim YJ, Woo HJ, Kim CW. Control and nitrogen load estimation of aerobic stage in full-scale sequencing batch reactor to treat strong nitrogen swine wastewater. Korean J Chem Eng. 2005;22(5):666–70.

109. Lemaire R, Marcelino M, Yuan ZG. Achieving the nitrite pathway using aeration phase length control and step-feed in an SBR re- moving nutrients from abattoir wastewater. Biotechnol Bioeng. 2008;100(6):1228–36.

110. Yang Q, Gu S, Peng Y, Wang S, Liu X. Progress in development of control strategies for the SBR process. Clean-Soil Air Water. 2010;38(8):732–49.

111. Pavselj N, Hvala N, Kocijan J, Ros M, Subelj M, Music G, et al. Experimental design of an optimal phase duration control strategy used in batch biological wastewater treatment. ISA Trans. 2001;40(1):41–56.

112. Yoo CK, Lee DS, Vanrolleghem PA. Application of multiway ICA for on-line process monitoring of a sequencing batch reactor. Water Res. 2004;38(7):1715–32.

113. Aguado D, Ferrer A, Ferrer J, Seco A. Multivariate SPC of a sequencing batch reactor for wastewater treatment. Chemom Intell Lab. 2007;85(1):82–93.

114. Marsili-Libelli S. Control of SBR switching by fuzzy pattern rec- ognition. Water Res. 2006;40(5):1095–107.

115. Ng WJ, Ong SL, Hossain F. An algorithmic approach for system- specific modelling of activated sludge bulking in an SBR. Environ Model Softw. 2000;15(2):199–210.

116. Cohen A, Hegg D, de Michele M, Song Q, Kasabov N. An intel- ligent controller for automated operation of sequencing batch re- actors. Water Sci Technol. 2003;47(12):57–63.

117. Furumai H, Kazmi AA, Fujita M, Furuya Y, Sasaki K. Modeling long term nutrient removal in a sequencing batch reactor. Water Res. 1999;33(11):2708–14.

118. Wastewater Technology Fact Sheet Sequencing Batch Reactors. USEPA. Office of Water. Washington DC. EPA 832-F-99-073. 1999.

119. Smith RG, Wilderer PA. Treatability of hazardous landfill leachate using sequencing batch reactors with silicone membrane oxygen- ation. 41st Purdue Indust. Chelsea, Michigan: Waste Conf., Purdue University, Lewis Publ; 1987. p. 272.

120. Lessel TH. Upgrading and nitrification by submerged bio-film reactors-experiences from a large scale plant. Water Sci Tech. 1994;29:167–74.

121. Mohan SV, Rao NC, Sarma PN. Low-biodegradable composite chemical wastewater treatment by biofilm configured sequencing batch reactor (SBBR). J Hazard Mater. 2007;144(1-2):108–17.

122. Di Iaconi C, Lopez A, Ramadori R, Di Pinto AC, Passino R. Combined chemical and biological degradation of tannery waste- water by a periodic submerged filter (SBBR). Water Res. 2002;36(9):2205–14.

123. Wilderer PA, Arnz P, Arnold E. Application of biofilms and bio- film support materials as a temporary sink and source. Water Air Soil Pollut. 2000;123(1-4):147–58.

124. Aziz SQ, Aziz HA, Yusoff MS. Optimum process parameters for the treatment of landfill leachate using powdered activated carbon augmented sequencing batch reactor (SBR) technology. Sep Sci Technol. 2011;46(15):2348–59.

125. Jin Y, Ding D, Feng C, Tong S, Suemura T, Zhang F. Performance of sequencing batch biofilm reactors with different control sys- tems in treating synthetic municipal wastewater. Bioresour Technol. 2012;104:12–8.

126. Emerenciano M, Gaxiola G and Cuzon G. Biofloc Technology (BFT): A Review for Aquaculture Application and Animal Food Industry. In: Matovic DM, editor. Biomass Now – Cultivation and Utilization. InTech; 2013. 301-328. This chapter gives a com- prehensive idea about the emerging BFT and its application and scope

127. Schryver PD, Verstraete W. Nitrogen removal from aquaculture pond water by heterotrophic nitrogen assimilation in lab-scale sequencing batch reactors. Bioresour Technol. 2009;100:1162–7.

128. Luo G, Avnimelech Y, Pan Y, Tan H. Inorganic nitrogen dynamics in sequencing batch reactors using biofloc technology to treat aquaculture sludge. Aquac Eng. 2013;52:73–9. This work repre- sents an initial research concerning the pretreatment of aqua- cultural SS and the quantification of NO3−-N pathways in SBR to treat

aquacultural sludge using BFT.

129. Schryver PD, Verstraete W. Nitrogen removal from aquaculture pond water by heterotrophic nitrogen assimilation in lab-scale sequencing batch reactors. Bioresour Technol. 2009;100:1162–7.

130. Goh CP, Seng CE, Sujari AN, Lim PE. Performance of sequencing batch biofilm and sequencing batch reactors in simultaneous p- nitrophenol and nitrogen removal. Environ Technol. 2009;30(7): 725–36.

131. Daverey A, Su SH, Huang YT, Lin JG. Nitrogen removal from opto-electronic wastewater using the simultaneous partial nitrifi- cation, anaerobic ammonium oxidation and denitrification (SNAD) process in sequencing batch reactor. Bioresour Technol. 2012;113:225–31.

132. Lei CN, Whang LM, Chen PC. Biological treatment of thin-film transistor liquid crystal display (TFT-LCD) wastewater using aer- obic and anoxic/oxic sequencing batch reactors. Chemosphere. 2010;81(1):57–64.

133. Shin HS, Park HS. Enhanced nutrient removal in porous biomass carrier sequencing batch reactor (PBCSBR). Water Sci Tech. 1991;23:719–28.

134. Ma J, Yu L, Frear C, Zhao Q, Li X, Chen S. Kinetics of psychro- philic anaerobic sequencing batch reactor treating flushed dairy manure. Bioresour Technol. 2013;131:6–12.

135. Liu Y, Wang ZW, Qin L, Liu YQ, Tay JH. Selection pressure- driven aerobic granulation in a sequencing batch reactor. Appl Microbiol Biotechnol. 2005;67(1):26–32.

136. Wang ZW, Ma J, Chen S. Bipolar effects of settling time on active biomass retention in anaerobic sequencing batch reactors digesting flushed dairy manure. Bioresour Technol. 2011;102(2):697–702.

137. Blanco J, Torrades F, Morón M, Brouta-Agnésa M, García- Montaño J. Photo-Fenton and sequencing batch reactor coupled to photo-Fenton processes for textile wastewater reclamation: fea- sibility of reuse in dyeing processes. Chem Eng J. 2014;240:469–

138. Chen FY, Liu YQ, Tay JH, Ning P. Alternating anoxic/oxic con- dition combined with step-feeding mode for nitrogen removal in granular sequencing batch reactors (GSBRs). Sep Purif Technol. 2013;105:63–8.

139. Wei Y, Ji M, Li R, Qin F. Organic and nitrogen removal from landfill leachate in aerobic granular sludge sequencing batch reac- tors. Waste Manag. 2012;32(3):448–55. The application of Granule sequencing batch reactors (GSBR) for landfill leach- ate treatment, and the COD removal is analyzed kinetically using a modified model in this paper. DO has been shown to be a useful process controlling parameter for the organics and nitrogen removal at low ammonium input.

140. De Bruin LMM, de Kreuk MK, van der Roest HFR, Uijterlinde C, van Loosdrecht MCM. Aerobic granular sludge technology: an alternative to activated sludge? Water Sci Technol. 2004;49(11– 12):1–7.

141. Kreuk D, Heijnen JJ, van Loosdrecht MCM. Simultaneous COD, nitrogen, and phosphate removal by aerobic granular sludge. Biotechnol Bioeng. 2005;90(6):761–9.

142. Xu H, Tay JH, Foo SK, Yang SF, Liu Y. Removal of dissolved copper (II) and zinc(II) by aerobic granular sludge. Water Sci Technol. 2004;50:155–60.

143. Duquea AF, Bessa VS, Carvalhoa MF, de Kreuk MK, van Loosdrecht MCM, Castro PML. 2-Fluorophenol degradation by aerobic granular sludge in a sequencing batch reactor. Water Res. 2011;45(20):6745–52.

144. Haggblom MM. Microbial breakdown of halogenated aromatic pesticides and related compounds. FEMS Microbiol Rev. 1992;103:29–72.

145. Murphy CD, Clark BR, Amadio J. Metabolism of fluoroorganic compounds in microorganisms: impacts for the environment and the production of fine chemicals. Appl Microbiol Biotechnol. 2009;84:617–29.

146. Cassidy DP, Belia E. Nitrogen and phosphorus removal from an abattoir wastewater in a SBR with aerobic granular sludge. Water Res. 2005;39:4817–23.

147. Al-Amrani WA, Lim PE, Seng CE, Ngah WSW. Factors affecting bio-decolorization of azo dyes and COD removal in anoxic–aero- bic REACT operated sequencing batch reactor. J Taiwan Inst Chem Eng. 2014;45:609–16. This study investigates the effects of duration of operating periods, azo dye molecular structure and presence/absence of co-substrate on the performances of the anoxic–aerobic REACT operated sequencing batch reac- tors (SBRs).

148. Sirianuntapiboon S, Sansak J. Treatability studies with granular activated carbon (GAC) and sequencing batch reactor (SBR) sys- tem for textile wastewater containing direct dyes. J Hazard Mater. 2008;159(2-3):404–11.

149. Liu ZH, Kanjo Y, Mizutani S. Removal mechanisms for endocrine disrupting compounds (EDCs) in wastewater treatment—physical means, biodegradation, and chemical advanced oxidation: a re- view. Sci Total Environ. 2009;407(2):731–48.

150. Zhou Y, Huang X, Zhou H, Chen J, Xue W. Removal of typical endocrine disrupting chemicals by membrane bioreactor: in com- parison with sequencing batch reactor. Water Sci Technol. 2011;64(10):2096–102.

151. Ye X, Guo X, Cui X, Zang X, Han Z, Wang MK, et al. Occurrence and removal of endocrine-disrupting chemicals in wastewater treatment plants in the three gorges reservoir area, Chongqing, china. J Environ Monit. 2012;14:2204.

152. Muz M, Aka S, Komesliab OT, Gokcaya CF. Removal of endocrine disrupting compounds in a labscale anaerobic/aerobic sequencing batch reactor unit. Environ Technol. 2014;35(9):1055–63.

153. Braga O, Smythe GA, Schäfer AI, Feitz AJ. Steroid estrogens in primary and tertiary wastewater treatment plants. Water Sci Technol. 2005;52(8):273–8.

154. Siegrist H, Joss A, Ternes T, Oehlmann J. Fate of EDCs in waste- water treatment and EU perspective on EDC regulation. Water Environ Fed. 2005.