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Review Paper

SEQUENCING BATCH REACTOR: A PROMISING TECHNOLOGY IN WASTEWATER TREATMENT

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ABSTRACT

Discharge of domestic and industrial wastewater to surface or groundwater is very dangerous to the environment. Therefore treatment of any kind of wastewater to produce effluent with good quality is necessary. In this regard choosing an effective treatment system is important. Sequencing batch reactor is a modification of activated sludge process which has been successfully used to treat municipal and industrial wastewater. The process could be applied for nutrients removal, high biochemical oxygen demand containing industrial wastewater, wastewater containing toxic materials such as cyanide, copper, chromium, lead and nickel, food industries effluents, landfill leachates and tannery wastewater. Of the process advantages are single-tank configuration, small foot print, easily expandable, simple operation and low capital costs. Many researches have been conducted on this treatment technology. The authors had been conducted some investigations on a modification of sequencing batch reactor. Their studies resulted in very high percentage removal of biochemical oxygen demand, chemical oxygen demand, total kjeldahl nitrogen, total nitrogen, total phosphorus and total suspended solids respectively. This paper reviews some of the published works in addition to experiences of the authors.

Key words: Sequencing batch reactor, domestic wastewater, industrial wastewater, organic removal, nutrients removal

INTRODUCTION

In recent year, sequencing batch reactor (SBR) has been employed as an efficient technology for wastewater treatment, especially for domestic wastewaters, because of its simple configuration (all necessary processes are taking place time-sequenced in a single basin) and high efficiency in BOD and suspended solids removal. SBRs could achieve nutrient removal using alternation of anoxic and aerobic periods (Rim *et al.*, 1997). The SBR has received considerable attention since Irvine and Davis described its operation (Irvine and Davis, 1971) and studies of SBR process were originally conducted at the University of Notre Dame, Indiana (Irvine and Busch, 1979).

The sequencing batch reactor (SBR) is a fill-and draw activated sludge system for wastewater treatment. In this system, wastewater is added to a single "batch" reactor, treated to remove undesirable components, and then discharged. Equalization, aeration, and clarification can all be achieved using a single batch reactor. To optimize the performance of the system, two or more batch reactors are used in a predetermined sequence of operations. SBR systems have been successfully used to treat both municipal and industrial wastewater. They are uniquely suited for wastewater treatment applications characterized by low or intermittent flow conditions (USEPA, 1999). Fill-and-draw batch processes similar to the SBR are not a recent development as commonly thought. Between 1914 and 1920, several full-scale fill-and draw systems were in operation. Interest in SBRs was revived in the late 1950s and early 1960s, with the development of new equipment and technology. Improvements in aeration devices and controls have allowed SBRs to successfully compete with conventional activated sludge systems (USEPA, 1999).

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The unit processes of the SBR and conventional activated sludge systems are the same. A 1983 USEPA report summarized this by stating that "the SBR is no more than an activated sludge system which operates in time rather than in space". The difference between the two technologies is that the SBR performs equalization, biological treatment, and secondary clarification in a single tank using a timed control sequence. This type of reactor does, in some cases, also perform primary clarification. In a conventional activated sludge system, these unit processes would be accomplished by using separate tanks (USEPA, 1999).

A modified version of the SBR is the Intermittent Cycle Extended Aeration System (ICEAS). In the ICEAS system, influent wastewater flows into the reactor on a continuous basis. As such, this is not a true batch reactor, as is the conventional SBR. A baffle wall may be used in the ICEAS to buffer this continuous inflow. The design configurations of the ICEAS and the SBR are otherwise very similar (USEPA, 1999).

An SBR treatment cycle consists of a timed sequence which typically includes the following steps: FILL, REACT, SETTLE, DECANT, And IDLE. When biological nutrient removal (BNR) is desired, the steps in the cycle are adjusted to provide anoxic or anaerobic periods within the standard cycles (USEPA, 1992).

Aeration in an SBR may be provided by fine or coarse bubble diffusers, floating aerator/mixers or jet aeration devices. The SBR process is usually preceded by some type of preliminary treatment such as screening, comminution or grit removal. Because the SBR process operates in a series of timed steps, reaction and settling can occur in the same tank, eliminating the need for a final clarifier (USEPA, 1992).

Common modifications

SBRs can be modified to provide secondary, advanced secondary treatment, nitrification, denitrification and biological nutrient removal. SBR manufacturers have adapted the sequence of batch treatment cycles described above in various ways. Some systems use a continuous inflow and provide a baffle to minimize short-circuiting. SBRs were originally configured in pairs so that one reactor was filling during half of each cycle (while the wastewater in the other reactor was reacting, settling and being decanted). The modified configurations available include one SBR with an influent surge/holding tank; a three SBR system in which the fill time is one third of the total cycle time; and a continuous inflow SBR (USEPA, 1992).

In recent years, some modifications of SBR has been used by researchers, such as continuous flow SBR (Mahvi *et al*., 2004.a), sequencing batch biofilm reactor (SBBR) (Speitel and Leonard, 1992), anaerobic sequencing batch reactor (ASBR) (Dague *et al*., 1992) and anaerobic–aerobic sequencing batch reactor (Bernet *et al*., 2000). An anaerobic sequencing batch reactor (ASBR) is similar to aerobic SBR, except that ASBR is not aerated during reaction phase and has a cover to exclude air (Fu, *et al*., 2001). A schematic of SBBR is illustrated in Fig. 1.

Applications

Sequencing batch reactor technology is applicable for any municipal or industrial waste where conventional or extended aeration activated sludge treatment is appropriate. SBR sizes can range from 3,000 gpd to over 5 MGD (USEPA, 1992). The more sophisticated operation required at larger SBR plants tends to discourage the use of these plants for large flowrates (USEPA, 1999).

The technology is applicable for BOD and TSS removal, nitrification, denitrification and biological phosphorus removal. The technology is especially applicable for industrial pretreatment and for smaller flow (<1.0 MGD) applications as well as for applications where the waste is generated for less than 12 hours per day (USEPA, 1992).

As these systems have a relatively small footprint, they are useful for areas where the available land is limited. In addition, cycles within the system can be easily modified for nutrient removal in the future, if it becomes necessary. This makes SBRs extremely flexible to adapt to regulatory changes for effluent parameters such as nutrient removal. SBRs are also very cost effective if treatment beyond biological treatment is required, such as filtration (USEPA, 1999).

Limitations

SBRs require oversize effluent outfalls because the entire daily wastewater volume must be discharged during the decant period(s), which is

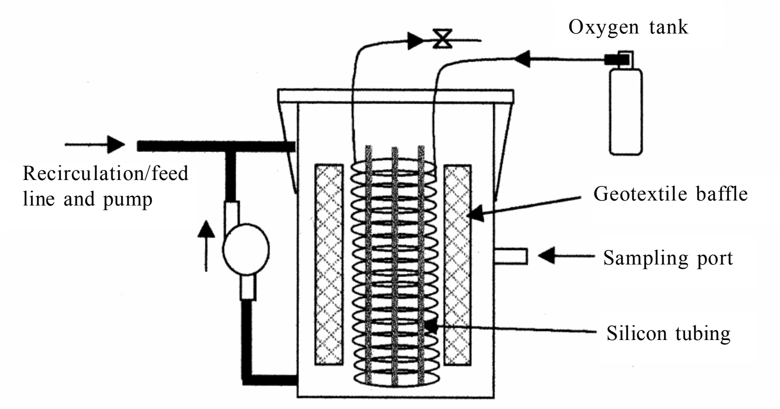

Fig. 1: Schematic drawing in profile of the sequencing batch biofilm reactor (White *et al.*, 2000)

typically 4 to 6 hours per day. Aeration systems must be sized to provide the total process air requirements during the AERATED FILL and REACT steps. The cost effectiveness of SBRs may limit their utility at design flow rates above 10 MGD.Earlier SBRs experienced maintenance problems with decant mechanisms but these have largely been resolved with present day designs (USEPA, 1992).

Performance

The performance of SBRs is typically comparable to conventional activated sludge systems and depends on system design and site specific criteria (USEPA, 1999). The average performance based on data from 19 plants is summarized below (USEPA, 1992):

- BOD Removal	89–98%
- TSS Removal	85–97%
- Nitrification	91–97%
- Total Nitrogen Removal	>75 %
- Biological Phosphorus Removal	57–69%

SBR manufacturers will typically provide a process guarantee to produce an effluent of less than (USEPA, 1999):

- 10mg/L BOD
- 10mg/L TSS
- 5-8mg/L TN
- 1-2mg/L TP

Affecting factors

The major factors affecting SBR's performance include organic loading rate, HRT, SRT, dissolved oxygen, and influent characteristics such as COD, solids content, and C/N ratio. Depending controlling of these parameters, the SBR can be designed to have functions such as carbon oxidation, nitrification and denitrification, and phosphorus removal (Hisset *et al.*, 1982; Hanaki *et al.*, 1990). SBRs are considered to be a suitable system for wastewater treatment in small communities (Irvine *et al.*, 1989), but are a relatively new technology for agricultural applications. Previous research on the SBR for animal waste was primarily concentrated on swine wastewater treatment (Li and Zhang,2002).

Chemicals required

Chlorination and dechlorination chemicals are required for applications which involve the direct discharge of domestic waste (unless UV disinfection is utilized). Also, some facilities have found it necessary to add alum or ferric chloride to meet stringent effluent phosphorus limits (USEPA, 1992).

Residuals generated

Secondary sludge is generated at quantities similar to the activated sludge process depending on the system operating conditions (SRT and organic load) (USEPA, 1992).

Environmental impact

Solid waste, odor and air pollution impacts are similar to those encountered with standard activated sludge processes (USEPA, 1992).

Toxics management

The same potential for sludge contamination upsets and pass-through of toxic pollutants exists for SBR systems as with standard activated sludge processes (USEPA, 1992).

Flow diagram

Fig. 2 illustrates a typical SBR over one cycle (USEPA, 1992).

Advantages

The primary advantages of the SBR process are (Washington Department of Ecology, 1998, USEPA,1999):

- 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.

A significant advantage of the SBR process is the space savings that results from providing treatment in single tanks (as opposed to separate aeration tanks, clarifiers, and RAS pumping facilities), which are generally square or rectangular in shape. This can allow for common-wall construction, reduced site requirements, and the ability to design the facility to be readily expanded in modular steps (Washington Department of Ecology, 1998).

A second significant advantage of the SBR process is process control and flexibility. Because the "react" time is not flow dependent, it can be adjusted to meet process objectives. By manipulating oxygen supply and mixing regimes, alternating aerobic and anoxic reactor environments can be created for nitrogen and phosphorus removal (Washington Department of Ecology, 1998).

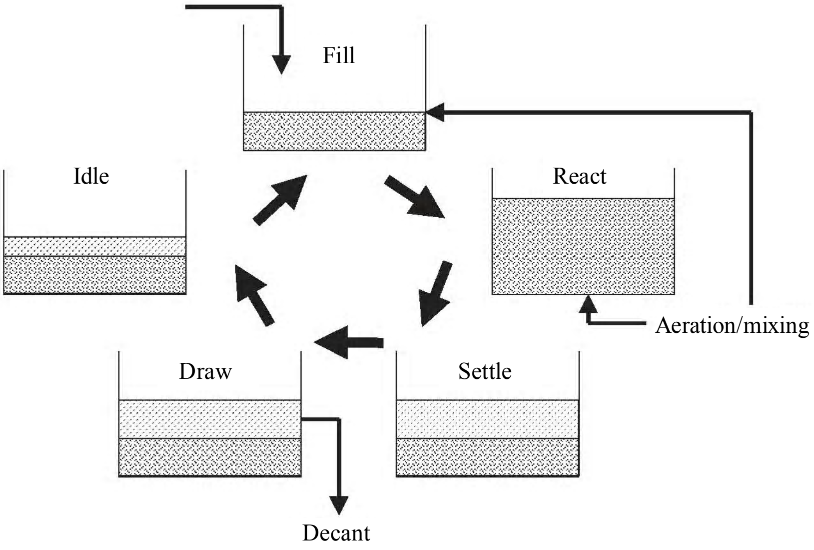

Fig. 2: Typical cycles in SBRs (1998, U.S.EPA, 1999)

Disadvantages

The primary disadvantages of the SBR process are (Washington Department of Ecology, 1998, USEPA,1999):

-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 oxic of the treatment time.

-Batch feeding from storage or bioselectors required to control bulking.

A significant concern with the use of SBRs is the need to depend on automatic controls and motor operated control valves. The design should consider the reliability of the control systems and components (Washington Department of Ecology, 1998).

Because of the need for careful coordination of the controls, process design, and equipment, most SBR designs are supplied as complete “packages” from a single manufacturer. The equipment procurement process should be carefully considered (Washington Department of Ecology, 1998).

Because the SBR process discharges in “batches” with flow rates several times higher than average flow rates, the impact on downstream unit processes (such as disinfection and outfall hydraulics) must be considered, or a post-SBR flow equalization tank should be considered. Consider and review the impact on receiving waters of this batch process (i.e. water quality, mixing zones, etc.) (Washington Department of Ecology, 1998).

Because the SBR process decants from a common tank, the drop in water surface elevation can be significant (several feet). The impact on overall process hydraulics should be considered in the design (Washington Department of Ecology, 1998).

Literature review

SBRs are an excellent tool to treat a variety of wastewaters; they could be applied to treat domestic wastewater, landfill leachate, industrial wastewater, biological phosphorus and nitrogen removal, etc. There are too literature mentioning the applicability of this promising process.

SBR Applications for domestic wastewater treatment (BOD, TSS, N and P removal). As mentioned previously, SBRs are applicable for BOD and TSS removal, nitrification, denitrification and biological phosphorus removal. There are many literatures mentioning these capabilities.

The SBRs application in synthetic wastewater treatment has been studied by the authors in a continuous flow SBR for treating synthetic wastewater. This experiment was carried out using a pilot scale and in 3 stages (Operational conditions: solids retention time (SRT): 12.5-24 days, hydraulic retention time (HRT): 12.4-16.7 h, reactor MLSS: 6002-6146mg/L). The reactor was seeded with sludge from the return line of aerobic basin of a domestic wastewater treatment plant. An air pump and diffusers provided sufficient aeration and mixing of the mixed liquor.

Wastewater was introduced into pre-react zone, using a diaphragm dosing pump, and flowed through openings at the bottom of the baffle wall and into the main react zone where BOD removal and nitrification occur. Effluent was discharged by gravity though a solenoid valve. Analog timers controlled the operation of the system. A schematic of pilot is shown in Fig. 3. The results of this study are presented in Fig. 4 (Mahvi *et al.*, 2004.b and *et al.*, 2005).

After this research, which conducted in 3 stages (Operational conditions: solids retention time (SRT): 12.5-24 days, hydraulic retention time (HRT): 12.4-16.7h, reactor MLSS: 6002-6146mg/L), the authors studied the performance of continuous flow SBR for treating of domestic wastewater. The results are presented in Fig. 5 (Mahvi *et al.*, 2004.a; Karakani *et al.*,2005).

The SBRs performance is satisfactory in treating domestic wastewater. The quality of effluent is reported 20 and 5mg/L of COD and BOD by

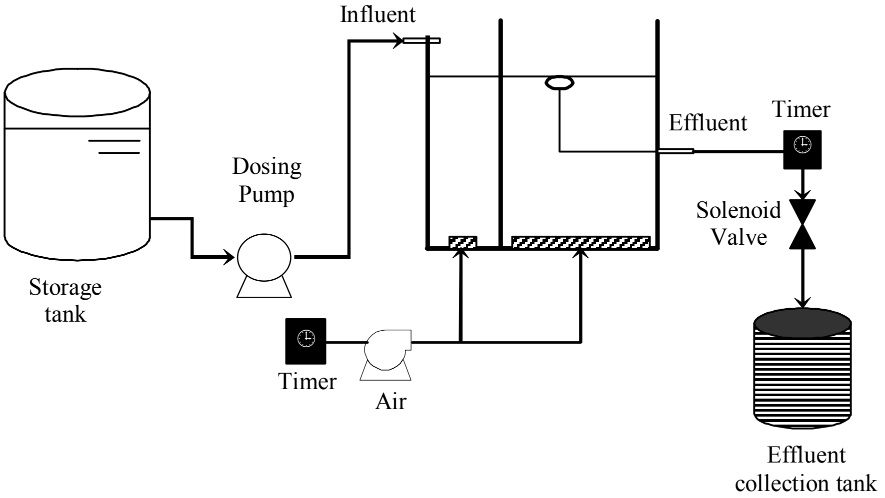

Fig. 3: Schematic of designed pilot (Mahvi *et al.*, 2004.b)

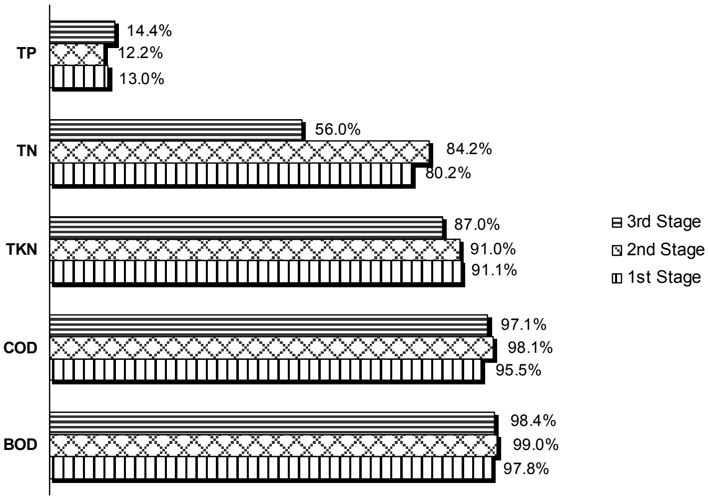

Fig. 4: Results of study on synthetic wastewater (Mahvi *et al.*, 2005)

Lamine (Lamine *et al.*, 2007); also Ouyang and Juan studies showed well BOD removal (<15 mg/L), nitrogen and phosphorus removal (<4 and <3mg/L) and suspended solids less than 10mg/L (Ouyang and Juan,1993).

There are some dedicated studies on nutrient removal by SBRs. In 1999, Chong and Flinders, 1999 retrofitted 3 IDEA plants with capacity ranging from 4000 to 55000 persons in Australia for enhanced biological phosphorus removal (EBPR). The results showed that the process can remove 50-90% phosphorus (1-2mg/L remaining) (Chong and Flinders, 1999).

Hamamoto has been carried out a research in laboratory, pilot plant and in a full scale wastewater plant. Mean nitrogen and phosphorus removal in pilot was 86 and 82% and in large scale was 96 and 93% respectively (Hamamoto *et al.*, 1997).

Surampalli conducted, a study to evaluate the biological nutrients removal performance of three

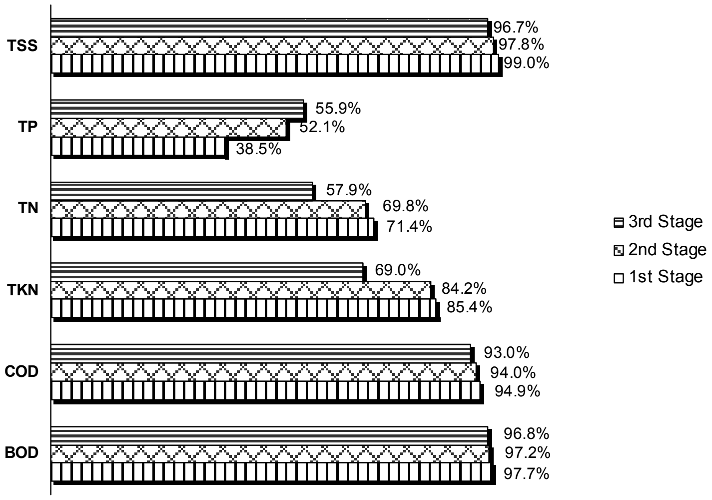

Fig. 5: Results of study on domestic wastewater (Mahvi *et al.*, 2004.a, Karakani *et al.*, 2005)

full-scale SBR plants. The data showed that typical designs can meet effluent $CBOD_5$ and TSS concentrations of less than 10mg/L, and with some design modifications, can successfully achieve of 1-2mg/L NH_3-N. With these modifications, phosphorus removal without chemical addition could be achieved to less than 1.0mg/L (Surampalli *et al.*, 1997). Design modifications could increase the ratio of the anoxic phosphate uptake to the aerobic phosphate uptake capacity from 11% to 64% by introducing an anoxic phase in an anaerobic–aerobic SBR. The result of this modification is 92, 88% and 100% removal efficiencies of TOC, total nitrogen, and phosphorus (Lee *et al.*, 2001).

Step feeding in the SBRs could greatly improve the nitrogen removal efficiency, as total nitrogen in the effluent reach to lower than 2mg/L and the average TN removal efficiency is more than 98%, while only requiring small amount of external carbon source (Guo *et al.*, 2007).

In another study conducted by Obaja *et al.*, initial content of ammonia and phosphate was 900 and 90. The results showed 99.8 and 97.8% removal for nitrogen and phosphorus respectively (Obaja *et al.*, 2005).

In a study Umble and Ketchum used a SBR to biological treatment from municipal wastewater. At 12h cycle time, BOD_5, TSS, and NH_3-N removal was 98, 90 and 89%, respectively (Umble and Ketchum, 1997).

In another study Chang and Hao studied nutrient removal for identifying process variables affecting performance of an SBR. With SRT of 10 days, system efficiency for COD, total nitrogen and phosphate removals was 91, 98, and 98%, respectively, for at a solids retention time of 10 days (Chang and Hao, 1996).

De Sousa and Foresti (De Sousa and Foresti, 1996) investigated the treatment of wastewater from tropical regions using combination of an USAB and two SBR. The results of study showed that COD, TSS and TKN removal was 95, 96 and 85% respectively (De Sousa and Foresti, 1996).

Application of SBR in leachate treatment

SBR is capable of treating landfill leachate. Usually, conventional biological treatment of landfill leachate has lower removal rates for nutrients because of higher COD, higher ammonium-N content and the heavy metals being present in the leachate (Uygur and Kargi, 2004).

Uygur and Kargi pretreated the high COD landfill leachate by coagulation flocculation with lime and then treated it by air stripping of ammonia at pH=12. The SBR unit with 21h cycle time, with the addition of domestic wastewater and powdered carbon resulted in COD, NH_4-N and PO_4-P removal of 75%, 44% and 44%, respectively (Uygur and Kargi,2004).

In another study by Lin and Chang, treatment of old-aged landfill leachate was carried out with electro-fenton process followed by chemical coagulation and then by SBR was capable of resulting a higher quality of treated leachate. The overall performance of these combined treatment units provided an efficient and economic method of landfill leachate (Lin and Chang,2000).

The efficiency of anaerobic SBR for the treatability municipal landfill leachate was studied by Timur and Zturk. This study showed that up to 83% of COD content decreased and converted to CH_4 (Timur and Zturk, 1999).

Zhou *et al.*, studied the capability of SBR in treating landfill leachate containing high concentration of NH_4^+-N. The study resulted in up to 94, 98, 85 and 99% in COD, BOD_5, TN, and NH_4^+-N, respectively. This study showed high nitrification and denitrification achievement (Zhou *et al.*, 2006).

In another study by Laitinen *et al.*, Finnish municipal waste landfill leachate from a composting field was treated by SBR followed by MBR. As result of this combined process 89% reduction in suspended solids was achieved (Laitinen *et al.*, 2006).

Application of SBR in industrial wastewater treatment

In the field of industrial wastewater treatment, sequencing batch reactors are applied for different kinds of wastewater. Many researchers have studied this process for both biodegradable and non-biodegradable contaminations, and also for treatment of wastewater containing different types of heavy metals.

Lim *et al.*, evaluated the efficiency of sequencing batch reactor in treating copper and cadmium containing wastewater. As a result of this system, 85% removal in COD was obtained with the addition of powdered activated carbon (PAC) and the same unit with 60% reduction in COD without the PAC addition, in industrial wastewater containing Cu (II) and Cd (II) (Lim *et al.*,2002).

In another study conducted by White and Schnabel, carried out in sequencing batch biofilm reactor (SBBR), with 24h cycle, a mixed culture organisms on a silicone tubing media were introduced to a cyanide containing wastewater as a carbon and nitrogen source with a concentration of 20mg/L of cyanide. The SBBR system was capable of up to 98% removal in cyanide (White and Schnabel, 1998).

Lin and Jiang investigated the treatment of a high-strength semiconductor; a wastewater with a strong dark color, high COD concentration, high refractory VOCs and low biodegradability, which is impossible to treat by traditional activated sludge method. They utilized a combination of physical, chemical and biological methods treat the wastewater. The method efficiency was capable of reduce the COD from 80,000mg/L to below 100mg/L (99.875%) and completely reducing the color (Lin and Jiang, 2003).

Sirianuntapiboon and Ungkaprasatcha used living bio-sludge of domestic wastewater treatment plant to adsorb $Pb^{2+}$and Ni^{2+}. To do this, they compare a SBR system and a GAC-SBR system, and the result showed that SBR system has higher removal efficiency than GAC-SBR system with same loading. Removal efficiencies of Pb^{2+}, Ni^{2+}, BOD_5, COD and TKN was 88.6±0.9%, 94.6±0.1%, 91.3±1.0%, 81.9±1.0% and 62.9±0.5%, respectively (Sirianuntapiboon and Ungkaprasatcha, 2007).

Schwarzenbeck *et al.*, studied the treating of malting processing wastewater with high particulate organic matter contents with SBR. The system removed 50% in COD_{total} and 80% in $COD_{dissolved}$ at COD_{total} load of 3.2 $kg/m^3.d$ (Schwarzenbeck *et al.*, 2004).

Li and Zhang studied the SBR performance for treating dairy wastewater with various organic load and HRTs. At 1day HR and 10000mg/L COD, the removal efficiency of COD, total solids, volatile solids, TKN and total nitrogen was 80.2, 63.4, 66.3, 75 and 38.3% respectively (Li and Zhang,2002).

Ammary used a lab scale ASBR to treat olive mills. The COD:N:P ratio wastewater was about 900:5:1.7. The results showed more than 80% of COD removal at 3 d HRT (Ammary, 2005).

Dyes and polyvinyl alcohols (PVOH) in textile effluents could not be removed easily by conventional biological treatment. Shaw *et al.*, used a six phase anaerobic/aerobic SBR to treat this type wastewater. The unit removed 66% total organic carbon, and 94% of color, but aromatic amines from the anaerobic breakdown of the azo dyes did not completely mineralized by the aerobic phase (Shaw *et al*., 2002).

In another study conducted by Goncalves *et al*., a SBR unit operated for organic removal from wool dyeing effluents. COD and BOD_5 removal was 85±6% 95±4%, respectively. The residual SS was lower than 100mg/L (Goncalves *et al*.,2005).

Keller *et al*., studied the abattoir effluent treatment by SBR. They founded that anaerobic pretreatment can reduce a part of carbon concentration efficiently while required COD for BNR could be remained. Nitrogen and phosphorus in influent was about 190 and 50mg/L, and removal efficiency was about 85.5 and 90.0% respectively. The also founded that operation of the small SBR systems is simple and reliable (Keller *et al*.,1997).

Soluble cyanide arise from the spent ore heaps of gold mines. To protect the receiving water it is essential to recover and treat the leachates. White *et al* had been tested a SBBR system capable of treating the cyanide waste streams. The results showed that the SBBR with a cycle time of 48 hours is capable to remove 20mg/L of cyanide (White *et al*.,2000).

Chromium is an inhibiting compound which found in tannery wastewater. Farabegolia *et al*., carried out an experiment out to determine the feasibility of treating wastewater containing chromium. Their experiments confirmed that SBRs are able to produce a more resistant biomass. This biomass acclimates quickly to inhibiting conditions and large amount of chromium is found in the sludge from the reactor, and effluent is devoid of the inhibiting metal. They found that bacterial activity does not inhibited by chromium up to concentration of 180mg/L, while nitrifying bacteria are inhibited at concentration of 120mg/L (Farabegolia *et al*., 2004).

Carucci *et al*., carried out a study on a lab scale SBR with tannery wastewater. During this study, denitrifcation was always performed without any additional carbon source. This research showed the suitability SBR for tannery wastewater treatment (Carucci *et al*., 1999).

In another study on tannery effluent treatment by Ganesh *et al*., removal of COD, TKN, and NH_3-N was 80-82, 78-80 and 83-99% respectively (Ganesh *et al*.,2006).

Hypersaline wastes are generated during activities such as chemical manufacturing, oil and gas production and waste minimization practices. These wastes contain organic compounds and high concentrations of salt (>3.5%). Treating these wastes by conventional microorganisms typically found in wastewater facilities is difficult and halophilic organisms are required to treat them. These organisms have special adaptations for survival at high salinities. Woolard, and Irvine used these organisms to develop a halophilic sludge in SBR operated at 15% salt in a 7 month period. Average phenol removal was over 99.5% (Woolard, and Irvine, 1995).

Table 1 related studies on polutant removal by SBR technology.

DISCUSSION

Wastewater treatment has been a challenge throughout the years due to varying influent chemical and physical characteristics and stringent effluent regulations.

As it mentioned in literature review and summary table, SBR is very effective in treatment of various wastewater; domestic, industrial, high organic loading wastewater, etc. These capabilities are achieved only by some design and operational modifications. While proprietary processes could achieve these with more operational units and too complexities in operation and maintenance.

It is obvious that SBR efficiency in organic and nutrients removal and even in industrial pollutants is high. Land fill leachate has a high content of BOD, tannery effluent has inhibitory constituents, and hypersaline wastes needs to halophile organisms. SBRs are capable to treat these wastewaters.

BOD removal in SBR is more than 90%, while conventional modifications of activated sludge are capable to remove 60-95% of BOD (Metcalf and Eddy,1991).

Nitrogen content of process is low. The high nitrogen removals indicates that during settle and decant phases dissolved oxygen reached to zero and anoxic conditions become predominant, so that denitrification occurred (Mulbarger, 1971). It is demonstrated that high nitrogen removal in sequencing batch reactor could be achieved. High MLSS concentration in aeration tank aids to create

Table 1: Summary of studies on SBR (Removal efficiency)

BOD	COD	N	P	TSS	Cyanide	Color	Pb^{2+}	Ni^{2+}	Phenol	Reference
Synthetic wastewater										
97.8-99%	95.5-98.1%	56-84.2% (Total) 87-91.1% (TKN)	12.2-14.4%	-	-	-	-	-	-	Mahvi *et al.*, 2005
Domestic wastewater										
96.8-97.7%	93-94.9%	57.9-71.4% (Total) 69-85.4% (TKN)	68.5-55.9%	96.7-99%	-	-	-	-	-	Mahvi *et al.*, 2004.a
5mg/L	20mg/L	-	-	-	-	-	-	-	-	Lamine *et al.*, 2007
15mg/L	-	4mg/L (NH_3-N)	3mg/L	10mg/L	-	-	-	-	-	Ouyang and Juan, 1993
	-		50-90		-	-	-	-	-	Chong and Flinders, 1999
	-	96% (NH_3-N)	93%		-	-	-	-	-	Hamamoto *et al.*, 1997
10mg/L	-	1-2 mg/L (NH_3-N)	1mg/L	10mg/L	-	-	-	-	-	Surampalli *et al.*, 1997
	-	88% (Total)	100%		-	-	-	-	-	Lee *et al.*, 2001
	-	98% (NH_3-N)	-		-	-	-	-	-	Guo *et al.*, 2007
	-	99.8% (NH_3-N)	97.8%		-	-	-	-	-	Obaja *et al.*, 2005
98%	-	89% (NH_3-N)	-	90%	-	-	-	-	-	Umble and Ketchum, 1997
91%	-	98% (NH_3-N)	98%		-	-	-	-	-	Chang and Hao, 1996
95%	-	85% (TKN)	-	96%	-	-	-	-	-	De Sousa and Foresti, 1996
Landfill Leachate										
83%	75%	44% (NH_4-N)	44%	-	-	-	-	-	-	Uygur and Kargi, 2004
83%	-	-	-	-	-	-	-	-	-	Timur and Ztturk, 1999
98%	94%	85% (Total) 99% (NH_4^+-N)	-	-	-	-	-	-	-	Zhou *et al.*, 2006
-	-	-	-	89%	-	-	-	-	-	Laitinen *et al.*, 2006
Industrial wastewater										
85%	-	-	-	-	-	-	-	-	-	Lim *et al.*, 2002
	-	-	-	-	98%	-	-	-	-	White and Schnabel, 1998
99.875%	-	-	-	-	-	100	-	-	-	Lin and Jiang, 2003
81.9%	91.3%	62.9% (TKN)	-	-	-		88.6%	94.6%	-	Sirianuntapiboon and Ungkaprasatcha, 2007
50% (Total) 80% (Dissolved)	-	-	-	-	-	-	-	-	-	Schwarzenbeck *et al.*, 2004
80.2%	-	75% (TKN) 38.3% (Total)	-	-	-	-	-	63.4%	-	Li and Zhang
80%	-	-	-	-	-	-	-	-	-	Ammary, 2005
	-	-	-	-	-	94%	-	-	-	Shaw *et al.*, 2002
85±6%	95±4%	-	-	-	-	-	-	-	-	Goncalves *et al.*, 2005
	-	85.5% (NH_3-N)	90.0%	-	-	-	-	-	-	Keller *et al.*, 1997
80-82%	-	78-80% (TKN) 83-99% (NH_3-N)	-	-	-	-	-	-	-	Ganesh *et al.*, 2006
	-	-	-	-	-	-	-	-	99.5%	Woolard, and Irvine, 1995

anoxic conditions as soon as after aeration phase to achieve denitrification for nitrogen removal.

As mentioned, in SBRs P concentration in effluent arrives even to below 1mg/L (more than 90%). Maximum efficiency of conventional activated sludge systems in phosphorus removal is 10-20 percent (Bitton, 1999). From point view of required time for treatment, in proprietary processes such as PhoStrip and Modified Bardenpho, required HRT for phosphorus removal is 10 and 11.5-23h, respectively (Metcalf and Eddy, 2003), whereas in this system which is not proprietary, is in less than about 20h. This shows that system is capable to phosphorus removal in almost similar time, with difference that has not complexities and alternating aerobic-anaerobic stages related to proprietary processes.

Low TSS concentration in effluent indicates that settling of sludge is completely efficient. The high TSS removal is because of high sludge settleability velocity, as average sludge volume index is below 100 mL/g. This could be attributed to granular sludge formation, that prevent sludge washout and. Almost all aerobic granules can perform only in SBR (Mulbarger, 1971,Schwarzenbeck *et al*., 2005).

Another important point in relation with SBRs is cost. As mentioned, wastewater is received directly from grit chamber and aeration and settling are occurred in same tank. So there are not primary and secondary settling tanks which are a necessity in conventional processes and have high initial investment to construct settling tank, return pumps and also operation and maintenance costs. Also because of absence of primary and secondary settling tanks, eliminates need further land.

REFERENCES

Ammary, B.Y., (2005). Treatment of olive mill wastewater using an anaerobic sequencing batch reactor, Desalination., **177**: 157-165.

Bernet, N., Delgenes, N., Akunna, J. C., Delgenes, J. P., Moletta, R., (2000). Combined anaerobic-aerobic SBR for the treatment of piggery wastewater, Wat. Res., **34** (2): 611–619.

Bitton, G., (1999). Wastewater Microbiology, John Willey, N. Y. USA.

Carucci, A., Chiaola, A., Majone, M., Rolle, E., (1999). Treatment of tannery wastewater in a sequencing batch reactor, Wat. Sci. Tech., **40** (1): 253-259.

Chang, C. H., Hao, O. J., (1996) Sequencing batch reactor system for nutrient removal: ORP and pH profiles, J Chem. Tech. Biotech., **67**: 27-38.

Chong, R. W., Flinders, A., (1999). Retrofitting of intermittent decanted extended aeration (IDEA) plant for enhanced biological phosphorus removal, Wat. Sci. Tech., **39** (6): 151-158.

Dague, R. R., Habben, C. E., and Pidaparti, S. R., (1992). Initial studies on the anaerobic sequencing batch reactor, Wat. Sci. Technol., **26** (9-11): 2429–2432.

De Sousa, J. T., Foresti, E., (1996). Domestic sewage treatment in an upflow anaerobic sludge blanket-sequencing batch reactor system. Wat. Sci. Tecnol., **33**: 73-84.

Farabegolia, G., Caruccib, A., Majonec, M., Rollea, E., (2004). Biological treatment of tannery wastewater in the presence of chromium, J Environ. Mgnt., **71**: 345-349.

Fu, L. Y., Wen, X. H., Lu Q. L., Qian, Y., (2001) Treatment of dyeing wastewater in two SBR systems, Process Biochemistry., **36**: 1111–1118.

Ganesh, R., Balaji, G., Ramanujam, R. A., (2006). Biodegradation of tannery wastewater using sequencing batch reactor -Respirometric assessment, Bioresource Tech., **97**: 1815–1821.

Goncalves, I., Penha, S., Matos, M., Satos, A., Franco, F., H. Pinheiro, (2005). Evaluation of an integrated anaerobic/aerobic SBR system for the treatment of wool dyeing effluents, Biodegradation., **16**: 81-89.

Guo, J., Yang, Q., Peng, Y., Yang, A., Wang, H., (2007). Biological nitrogen removal with real-time control using step-feed SBR technology, Enzyme Microb. Tech., **40**: 1564–1569.

Hamamoto, Y., Tabata, S., Okubo Y., (1997). Development of the intermittent cyclic process for simultaneous nitrogen and phosphorus removal, Wat. Sci. Technol., **35** (1): 145-152.

Hanaki, K., Wantawin, C., Ohgaki, S., (1990). Nitrification at low level of dissolved oxygen with and without organic loading in a suspended-growth reactor. Wat. Res., **12**: 297–302.

Hisset, R. E., Deans, A., Evans, M. R., (1982). Oxygen consumption during batch aeration of piggery slurry at temperatures between 5 and 50°C, Agric. Wastes., **4**: 447–487.

Irvine, R. L., Busch, A. W., (1979). Sequencing batch biological reactor: an overview, J. Wat. Pol. Cont. Fed., **51**: 235.

Irvine, R. L., and Davis, W. B., (1971). Use of sequencing batch reactor for wastewater treatment, CPC International, Corpus Christi, TX. Presented at the 26th Annual Industrial Waste Conference, Purdue, University, West Lafayette, IN.

Irvine, R. L., Lloyd, H., and Ketchum, L. H. Jr., (1989). Sequencing batch reactor for biological wastewater treatment. CRC Crit. Rev. Environ. Control., **18**: 255–294.

Karakani, F., Mahvi, A. H., (2005). Wastewater phosphorus removal in an intermittent cycle extended aeration system, Pakistan. J. Bio. Sci., **8** (2): 335-337.

Keller, J., Subramaniam, K., Gosswein, J., Greenfield, P. F., (1997). Nutrient removal from industrial wastewater using single tank sequencing batch reactors, Wat. Sci. Technol., **35** (6): 137-144.

Lamine M., Bousselmi, L., Ghrabi, A., (2007). Biological treatment of grey water using sequencing batch reactor, Desalination., **215**: 127–132.

Laitinen, N., Luonsi, A., Vilen, J., (2006). Landfill leachate treatment with sequencing batch reactor and membrane bioreactor, Desalination., **191**: 86–91.

Lee, D. S., Heon C. O., Park J. M., (2001). Biological nitrogen removal with enhanced phosphate uptake in a sequencing batch reactor using single sludge system, Wat. Res. **35** (16): 3968–3976.

Li, X., Zhang, R., (2002). Aerobic treatment of dairy wastewater with sequencing batch reactor systems, Bioprocess Biosyst Eng., **25**: 103–109.

Lim, P., Ong, S., Seng, C., (2002), Simultaneous adsorption and biodegradation processes in sequencing batch reactor (SBR) for treating copper and cadmium-containing wastewater, Wat. Res., **36**: 667–675.

Lin, S. H., Chang, C. C., (2000). Treatment of landfill leachate by combined electro-fenton oxidation and sequencing batch reactor method, Wat. Res., **34** (1): 2423-2249.

Lin, S. H., Jiang, C. D., (2003). Fenton oxidation and sequencing batch reactor (SBR) treatments of high-strength semiconductor wastewater, Desalination., **154**: 107-116.

Liu, Y., Wang, Z. W., Qin, L., Liu, YO. and Tay, J. H., (2005) Selection pressure-driven aerobic granulation in a sequencing batch reactor, Appl. Microbiol. Biotech., **67**: 26-32.

Mahvi, A. H., Brown, P., Vaezi, F., Karakani, F., (2005). Feasibility of continuous flow sequencing batch reactor in synthetic wastewater treatment, J. App. Sci., **5** (1): 172-176.

Mahvi, A. H., Mesdaghinia, A., Karakani, F., (2004.a). Feasibility of continuous flow sequencing batch reactor in domestic wastewater treatment, American J. App. Sci., **1** (4): 348-353.

Mahvi, A. H., Mesdaghinia, A., and Karakani, F., (2004.b). Nitrogen removal from wastewater in a continuous flow sequencing batch reactor, Pakistan J Bio. Sci., **7** (11): 1880-1883.

Metcalf and Eddy, Inc. (1991), Wastewater Engineering: Treatment, Disposal and Reuse, McGraw-Hill, N. Y. USA.

Metcalf and Eddy, Inc., (2003). Wastewater Engineering: Treatment and Reuse, McGraw-Hill, ., N. Y. USA.

Mulbarger, M. C., (1971). Nitrification and denitrification in activated sludge system, J WPCF, **43** (10): 120-127.

Obaja, D., Mac, S., Mata-Alvarez, J., (2005). Biological nutrient removal by a sequencing batch reactor (SBR) using an internal organic carbon source in digested piggery wastewater, Bioresource Tech., **96**: 7–14.

Ouyang, C. F., Juan, C. T., (1993). A study of a modified process for the intermittent cycle extended aeration system, Wat. Sci. Tech., **34** (9): 173-180.

Rim, Y. T., Yang, H. J., Yoon, C. H., Kim, Y. S., Seo, J. B., Ryu, J. K., Shin, E. B., (1997). A full-scale test of a biological nutrients removal system using the sequencing batch rector, Wat. Sci. Technol., **35**: 241-247.

Shaw, C. B., Carliellb, C. M., Wheatley, A. D., (2002). Anaerobic/aerobic treatment of colored textile effluents using sequencing batch reactors, Wat. Res. **36**: 1993–2001.

Schwarzenbeck, N., Erley, R., Mc Swain B. S., Wilderer, P. A., Irvine, R. L., (2004). Treatment of malting wastewater in a granular sludge sequencing batch reactor (SBR), Acta hydrochim. hydrobiol. **32** (1): 16"24.

Schwarzenbeck, N., Borges, J M., Wilderer, P. A., (2005) Treatment of dairy effluents in an aerobic granular sludge sequencing batch reactor, Appl. Microbio. Biotech., **66:** 711–718.

Sirianuntapiboon, S., Ungkaprasatcha, O., (2007). Removal of Pb^{2+} and Ni^{2+} by bio-sludge in sequencing batch reactor (SBR) and granular activated carbon-SBR (GAC-SBR) systems, Bioresource Tech., **98**: 2749–2757.

Speitel, G. E., Leonard, J. M., (1992). A sequencing biofilm reactor for the treatment of chlorinated solvents using methanotrophs, Wat. Enviro. Res., **64** (5): 712–719.

Surampalli, R. Y., Tyagi, R. D., Scheible O. K., Heidman, J. A., (1997). Nitrification, denitrification and phosphorus removal in a sequencing batch reactors, Bioresource Tech., **61**: 151-157.

Timur, H., Zturk, I. E., (1999). Anaerobic sequencing batch reactor treatment of landfill leachate, Wat. Res., **33** (15): 3225-3230.

U.S.EPA, (1992). Sequencing Batch Reactors for Nutrifications and Nutrient Removal, U.S. Environmental Protection Agency, EPA 832 R-92-003.

U.S.EPA, (1999). Wastewater, Technology Fact Sheet: Sequencing Batch Reactors, U.S. Environmental Protection Agency, Office of Water, Washington, D.C., EPA 932-F-99-073.

Umble, A. K., Ketchum, A. L., (1997) A strategy for coupling municipal wastewater treatment using the sequencing batch reactor with effluent nutrient recovery through aquaculture, Wat. Sci Tech., **35**: 177-184.

Uygur, A., Kargi, F., (2004). Biological nutrient removal from pre-treated landfill leachate in a sequencing batch reactor, J. Environ. Mgnt., **71**: 9-14.

Washington Department of Ecology, (1998) Criteria for Sewage Works Design, Olympia, 98504

White, D. M., Schnabel, W., (1998). Treatment of cyanide waste in a sequencing biofilm batch reactor, Wat. Res., **32** (1): 254-257.

White, D. M., Pilon T. A., Woolard, C., (2000). Biological treatment of cyanide containing wastewater, Wat. Res., **34** (7): 2105-2109.

Woolard, C. R., Irvine. R. L., (1995). Treatment of hypersaline wastewater in the sequencing batch reactor, Wat. Res., **29** (4): 1159-1168.

Zhou, S. Q., Zhang, H. G., Shi, Y., (2006). Combined treatment of landfill leachate with fecal supernatant in sequencing batch reactor, J Zhejiang University SCIENCE B., **7** (5): 397-403.