PJN
ISSN 1680-5194

PAKISTAN JOURNAL OF NUTRITION

ANSInet
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
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Pakistan Journal of Nutrition, 6 (1): 11-19, 2007
ISSN 1680-5194

Review on Sequencing Batch Reactors

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Abstract: This review paper intends to provide an overall vision of SBR technology as an alternative method for treating wastewater. This technology has been gaining popularity through the years, mainly because of its single-tank design and ease of automation. The bibliographic review carried out here shows the efficiency and flexibility of this technology, as it is able to treat different kinds of effluents such as municipal, domestic, hyper saline, tannery, brewery, and dairy wastewater; landfill leachates; etc.; under different conditions. The review includes relevant experiments carried out at the laboratory, pilot-plant, and industrial scales.

Key words: Sequencing batch reactor, nutrient removal, laboratory SBR scale, pilot-scale SBR

Introduction

SBRs are used all over the world and have been around since the 1920s. With their growing popularity in Europe and China as well as the United States, they are being used successfully to treat both municipal and industrial wastewater, particularly in areas characterized by low or varying flow patterns. Municipalities, resorts, casinos, and a number of industries, including dairy, pulp and paper, tanneries and textiles, are using SBRs as practical wastewater treatment alternatives.

Improvements in equipment and technology, especially in aeration devices and computer control systems, have made SBRs a viable choice over the conventional activated-sludge system. These plants are very practical for a number of reasons:

In areas where there is a limited amount of space, treatment takes place in a single basin instead of multiple basins, allowing for a smaller footprint. Low total-suspended-solid values of less than 10 milligrams per liter (mg/l) can be achieved consistently through the use of effective decanters that eliminate the need for a separate clarifier.

The treatment cycle can be adjusted to undergo aerobic, anaerobic, and anoxic conditions in order to achieve biological nutrient removal, including nitrification, denitrification, and some phosphorus removal. Biochemical oxygen demand (BOD) levels of less than 5 mg/L can be achieved consistently. Total nitrogen limits of less than 5 mg/L can also be achieved by aerobic conversion of ammonia to nitrates (nitrification) and anoxic conversion of nitrates to nitrogen gas (denitrification) within the same tank. Low phosphorus limits of less than 2 mg/L can be attained by using a combination of biological treatment (anaerobic phosphorus absorbing organisms) and chemical agents (aluminum or iron salts) within the vessel and treatment cycle.

Older wastewater treatment facilities can be retrofitted to an SBR because the basins are already present.

Wastewater discharge permits are becoming more stringent and SBRs offer a cost-effective way to achieve lower effluent limits. Note that discharge limits that require a greater degree of treatment may necessitate the addition of a tertiary filtration unit following the SBR treatment phase. This consideration should be an important part of the design process.

The sequencing batch reactor (SBR) has received considerable attention since Irvine and Davis (1971) described its operation. The SBR system is a modem version of the fill and draw system, consisting of one or more tanks, each capable of waste stabilization and solids separation. The number of tanks may be varied, depending on the sophistication of the control system. Studies of SBR process were originally conducted at the University of Notre Dame, Indiana (Irvine and Busch, 1979). In biological wastewater treatment, each tank has several basic operational modes or periods. The periods are fill, react, settle, draw, and idle, in a time sequence. These operational modes can be modified, depending on the operational strategies desired.

Common SBR Characteristics

General: SBRs are a variation of the activated-sludge process. They differ from activated-sludge plants because they combine all of the treatment steps and processes into a single basin, or tank, whereas conventional facilities rely on multiple basins. According to a 1999 U.S. EPA report (Wastewater Technology Fact Sheet, 1999), an SBR is no more than an activated-sludge plant that operates in time rather than space.

Basic treatment process: 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 time periods: Fill, React, Settle, Draw and Idle as shown in Fig.1. 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. A detailed discussion of each period of the SBR is provided in the following subsections, along with a description of typical process equipment and hardware associated with each (Irvine and Ketchum, 2004).

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. While Fig. 1 suggests that 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 a continuous-flow activated-sludge aeration tank and passed through the clarifiers only to have a 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 that 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.

Continuous-flow system: SBR facilities commonly consist of two or more basins that operate in parallel but single basin configurations under continuous-flow conditions. In this modified version of the SBR, flow enters each basin on a continuous basis. The influent flows into the influent chamber, which has inlets to the react basin at the bottom of the tank to control the entrance speed so as not to agitate the settled solids. Continuous-flow systems are not true batch reactions because influent is constantly entering the basin. The design configurations of SBR and continuous-flow systems are otherwise very similar. Plants operating under continuous flow should operate this way as a standard mode of operation. Ideally, a true batch-reaction SBR should operate under continuous flow only under emergency situations.

Plants that have been designed as continuous-inflow systems have been shown to have poor operational conditions during peak flows. Some of the major problems of continuous-inflow systems have been

Table 1: Operating conditions of the bench scale reactors (Keller *et al.*, 1997)

	Reactor Q	Reactor N
Pond 1 : Pond 2 feed mixture	1 : 1	3 : 1
HRT (hours)	18	24
SRT (days)	20	20
Reactor Sequence (hours)		
Non-aerated, non-mixed Fill	2.5	2.5
Aerated, mixed React 1	1.0	1.0
Non-aerated, non-mixed React	0.5	0.5
Aerated, mixed React 2	1.5	1.5
Settle	0.33	0.33
Decant	0.17	0.17

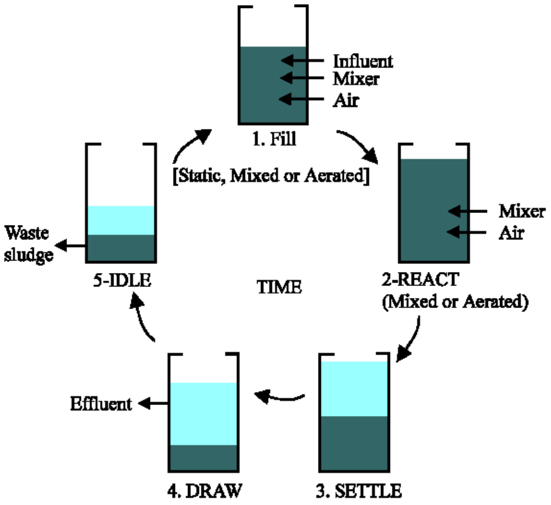

Fig. 1: SBR operation for each tank for one cycle for the five discrete time periods of Fill, React, Settle, Draw, and Idle (Irvine and Ketchum, 2004).

overflows, washouts, poor effluent, and permit violations (New England Interstate Water Pollution Control Commission, 2005).

Application SBR to treatment various wastewater (New SBR Technology): The Sequencing Batch Reactor (SBR) is an activated sludge process designed to operate under non-steady state conditions. An SBR operates in a true batch mode with aeration and sludge settlement both occurring in the same tank. The major differences between SBR and conventional continuous-flow, activated sludge system is that the SBR tank carries out the functions of equalization aeration and sedimentation in a time sequence rather than in the conventional space sequence of continuous-flow systems. In addition, the SBR system can be designed with the ability to treat a wide range of influent volumes whereas the continuous system is based upon a fixed influent flow rate. Thus, there is a degree of flexibility associated with working in a time rather than in a space sequence (Norcross, 1992). SBRs produce sludges with good settling properties providing the influent wastewater is admitted into the aeration in a controlled manner. Controls range from a simplified float and timer based system with a PLC to a PC based SCADA system with color graphics using either flow proportional aeration or dissolved oxygen controlled aeration to reduce aeration to reduce energy consumption and enhance the selective pressures for BOD, nutrient removal, and control of filaments (Norcross, 1992). An appropriately designed SBR process is a unique combination of equipment and software. Working with automated control reduces the number of operator skill and attention requirement.

In this investigation we will overview recent experiments carried out by the laboratory SBR and pilot – scale plant SBR to treatment various wastewater.

Laboratory SBR scale: In recent times, the use of sequencing batch reactors (SBRs) in the biological treatment of wastewater has been widely extended from lab-scale studies to real WWTPs (wastewater treatment plants) (Mace and Mata-Alvarez, 2002; Steinmetz *et al.*, 2002). While lab-scale SBRs have been used for research on carbon and nutrient removal and the development of urban/industrial wastewater biodegradability assays, real plant applications are still mainly focused on carbon removal. Nevertheless, when operating real plant SBRs the efficiency of nitrogen removal sometimes turns out to be better than the legally required effluent standards (Teichgraber *et al.*, 2001).

Two bench scale SBR's were used by Keller *et al.* (1997) to investigate the effect of pretreatment abattoirs and process variations on the BNR (Biological Nutrient Removal) capacity. The operating conditions are shown in Table 1 the reactors were operated at room temperature (20±2°C) the maximum operating volume of the reactors was approximately 5 liters.

The summary of the effluent quality achieved in the two reactors is shown in Table 2. The overall removal efficiency of the incoming carbon was very good, particularly in terms of the effluent BOD which reached very low values during the whole reactor operation. The remaining COD has to be regard as nonbiodegradable. This fraction in fact quite small, representing around 2% of the COD initially present in the wastewater.

Ros and Vrtovsek (2004) also found that the removal of N was not dependent on initial P concentration, but P removal was related to P concentration in the original wastewater by using SBR laboratory pilot plant used in the study consisted of a 70 L rectangular reactor and operation of the pilot plant is monitored by five on-line measurements, i.e. pH, Redox potential (ORP), dissolved oxygen (DO) concentration, temperature (T) and water level. All experiments were carried out with synthetic wastewater to which different amounts of P were added. The optimal COD: N: P ratio was 100:11:2

Table 2: Effluent quality of the reactors (Keller *et al.*, 1997)

Parameters		Reactor Q	Reactor N
TCOD	(mg/L)	92-118	80-105
SCOD	(mg/L)	80-104	70-92
BOD5	(mg/L)	5-10	5-10
SS	(mg/L)	13-35	17-39
NH4-N	(mg/L)	1-5	0.2-3.0
NOX-N	(mg/L)	4-12	2-7
TN	(mg/L)	14-22	11-19
PO4-P	(mg/L)	3-10	0.5-5
TP	(mg/L)	5-14	2-7
pH		7.0-7.5	6.8-7.6

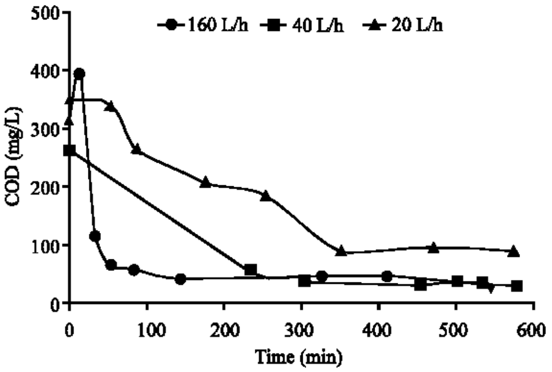

Fig. 2: Variation of COD with time under different air flux (Hu *et al.*, 2004).

Table 3: Ratios of COD: N: P and BOD5: N: P for different series of experiments (Ros and Vrtovsek, 2004).

Parameter	Series 1	Series 2	Series 3	Series 4
COD	100	100	100	100
N	10.1	10.3	10.5	11.1
P	1.0	1.9	2.0	2.2
BOD5	100	100	100	100
N	15.2	15.9	14.7	15.4
P	1.5	3.0	2.8	3.0

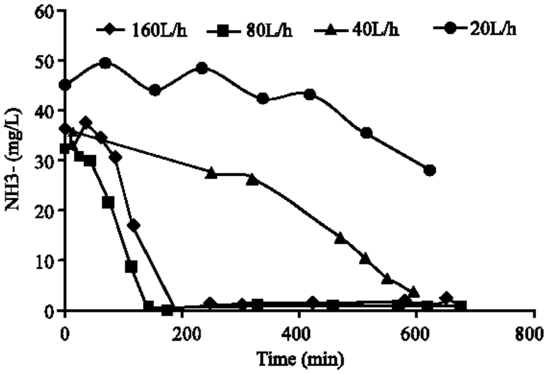

Fig. 3: Variation of NH4+-N with operation time under different air flux (Hu *et al.*, 2004).

and the BOD5: N: P ratio was 100:15:2.6 as shown in Table 3.

The performance of sequence batch reactor (SBR) was studied under four different air fluxes. Special attention was paid to the operating characteristics of SBR under limited aeration or low dissolved oxygen (DO) conditions. At the air flux of 40 l/h, COD and NH4-N had been removed just before the cycle was over, and during the cycle DO was about 0.5 mg/l most of the time Fig. 2, 3 and 4. Operational parameters, such as DO, ORP and pH, were monitored during the whole cycle. The effect of these parameters on the removal efficiency of COD and NH4-N was discussed (Hu *et al.*, 2004).

In a laboratory scale sequencing batch reactor (SBR) granules were cultured under aerobic conditions Fig. 5. To enhance the growth of granular the SBR was operated with very short sedimentation and draw phases resulting in the washout of slow biomass. Fast settling granules were retained in the reactor and thus had an advantage over flocs with a slower settling velocity. After 40 days of operation granules were the dominant from of microbial aggregates in the reactor, even though some pin- point flocs remained in the system. Granules taken from the reactor were stored for weeks without disintegrating. After about 130 days of operation the granule quality and COD- removal worsened. The reasons for that are yet to be investigated (Morgenroth *et al.*, 1997).

Kargi and Uyur (Kargi and Uygur, 2003) operated laboratory SBR to Nutrient removal from synthetic wastewater by sequencing batch operation was studied at different specific nutrient loading rates (SNLR). Nutrient removal in a sequencing batch reactor (SBR) was a five-step process consisting of anaerobic (An), anoxic (Ax), oxic (Ox), anoxic (An) and oxic (Ox) phases with hydraulic residence times (HRT) of 2/1/4.5/1.5/1.5 h, respectively. The settling step used at the end of the operation was 45 min for all experiments. The initial COD concentration was varied between 600 and 4800 mg/l at eight different levels with constant COD/N/P ratio of 100/3.33/0.7. Effects of SNLRs on COD, NH4-N and PO4-P removal were investigated. Percent nutrient removals decreased and effluent nutrient levels increased with increasing nutrient loading rates. The highest COD (99%), NH4-N (99%) and PO4-P (97%) removal efficiencies were obtained with the initial COD concentration of 600 mg/l at COD loading rate of nearly 40 mg COD /(g biomass)/ h. However, the sludge volume index (SVI) decreased with increasing COD loading rate resulting minimum SVI of 46 mg/l at COD loading rate of nearly 86 mg COD /(g biomass)/ h. Biomass concentration increased with increasing SNLR resulting in biomass concentration of 3.84 mg/l at COD loading rate of 86 mg COD /(g biomass) /h.

Sarioglu (Sarioglu, 2005) investigates the effect of pure cultures on the enhancement of biological phosphorus removal capability of a Sequencing Batch Reactor (SBR) inoculated initially with a mixed culture. For this purpose, three anaerobic/aerobic SBRs with mixed cultures were

Table 4: Chemical and biochemical properties of the influent and effluent (Zhu *et al.*, 2004).

Parameters	Influent	Effluent	Reduction (%)
TS (%)	1.053	0.237	77.5
TVS (%)	0.540	0.016	97.0
TSS (%)	0.766	0.001	99.9
TVSS (%)	0.442	0.004	99.1
COD (%)	8800	226	97.4
BOD (%)	3660	0	100
Turbidity (FTU)	2175	120	94.5

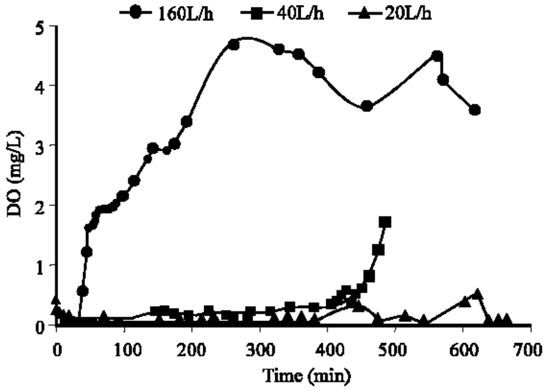

Fig. 4: Variation of DO with operation time under different air flux (Hu *et al.*, 2004).

started in parallel and operated for a while. At the end of this period, pure cultures of Acinetobacter lwoffii, A. lwoffii-Pseudomonas aeruginosa mixture and P. aeruginosa were added into the first, second and third reactors, respectively. All reactors were operated at a constant solid retention time (SRT) of 10 days and the food/microorganism (F/M) ratio was changed between 0.43-0.50 mg COD /mg VSS /day. The total cycle time was 14 h throughout the experimental study. The addition of A. lwoffii to the mixed culture in the first reactor significantly enhanced the biological phosphorus removal (EBPR) rate. Complete removal (E = 100%) of 20 mg /l PO4-P was achieved within 35 days of operation. Corresponding removal efficiencies obtained using A. lwoffii-P. aeruginosa mixture (second reactor) and P. aeruginosa alone (third reactor) were 25% and 20%, respectively. The COD removal efficiency was 90% in all reactors. Fig. 6 shows change of daily phosphate profile with the development of phosphorus removal during full cycle by using A. lwoffii culture and wastewater.

Zhu *et al.* (2004) developed and evaluated a lab-scale, $(AO)_2$ SBR for treating swine wastewater aiming at removing nutrients and organic materials. The SBR was operated on 3 cycles per day with 8 hours per cycle at constant 20°C. Unlike previous research, this SBR employs two alternating anaerobic/oxic phases to enhance nitrification and phosphorus removal. At the same time, sodium acetate is used as the external carbon source to promote denitrification in the latter part of each cycle. Other than nitrogen and phosphorus removal, discussions are also presented on changes resulted from the treatment in total solids (TS), total volatile solids (TVS), total suspended solids (TSS), total volatile suspended solids (TVSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) as shown in Table 4.

An SBR operated with anaerobic and aerobic cycle stages could be considered a suitable technology for organic load removal from wool dyeing effluents. Soluble COD and BOD5 degradation efficiencies of 85 ± 6% and 95 ± 4%, respectively, were achieved. The residual suspended solids levels were in general acceptable (lower than 100 mg/l), and could be attributed to the operation with no biomass wastage, which led to high MLVSS concentrations (Goncalves *et al.*, 2005).

De Sousa and Foresti (De Sousa and Foresti, 1996) investigated treating domestic sewage in tropical regions by using a combined anaerobic-aerobic system composed of an USAB reactor followed by two sequencing batch reactors (SBR). In such a system, the USAB reactor removes considerable fraction of the influent organic matter, while the SBRs oxidize part of the remaining organic matter and ammonium nitrogen. A proper system operation would also permit the removal of nutrients (N and P). This system was efficient in removing COD (95%), TSS (96%) and TKN (85%). In order to investigate on the performance of this system for sewage treatment, a bench scale installation fed with synthetic substrate simulating domestic swage was operated continuously during 38 weeks. The results permit to confirm the hypothesis proposed, since the system has consistently produced high quality effluents (BOD5 and VSS lower than 10 mg/l). The result also indicates that such combined anaerobic-aerobic system compete favorably with conventional aerobic systems in three essential cost features: energy consumption, excess sludge production and nutrient removal.

A study was undertaken to examine the feasibility of biologically treating a combined waste stream of landfill leachate and municipal sewage. The ratio of sewage to leachate was 9 to 1 by volume. The combined waste had an average BOD5 430 mg/l, COD 1090 mg/l, and TKN 133 mg/l (80% of which was in the form of ammonia). A laboratory-scale sequencing batch activated sludge reactor was used to carry comparative performance evaluations of biological treatment, including nitrification and dentrification. The SBR reactor was operating in daily time cycles employing the following sequential operation phases: filling phase, anoxic phase, aeration reaction phase, settling phase, and drain phase. In particular, the anoxic and aeration periods were tailored

Table 5: Adjustment of phases duration according to the organic load in the activated sludge SBR (Rodrigues *et al.*, 1998)

Organic Load (kgCODt/kgTSS.d)	Influent Per cycle (l)	Fill (min)	Anaerobic-Anoxic phase (min)	Aerobic Phase (min)	Settling (min)	Draw (min)
0.13	212	7	218	218	30	7
0.25	421	15	210	210	30	15
0.35	602	25	200	200	30	25

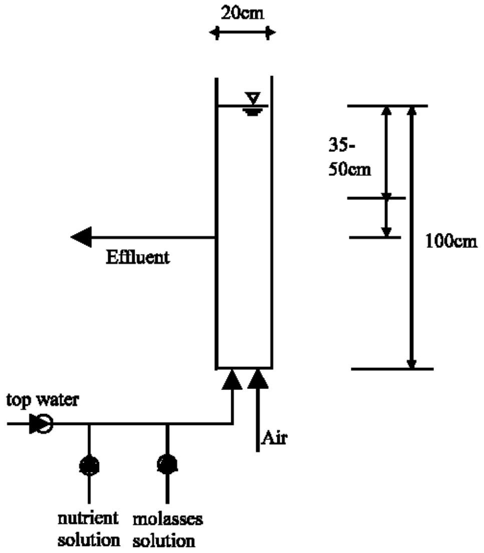

Fig. 5: Laboratory scale SBR (Morgenroth *et al.*, 1997).

in order to develop conditions conductive to desired nitrification and dentrification. During the reaction period, the process was operated under an extended aeration mode with the MLSS concentration being around 3500 mg/l the results indicated that successful biotreatment of combined leachate and sewage was possible, with the treated effluent being low in BOD5 and COD. The system was capable of BOD5 removal efficiencies exceeding 95%. Furthermore, nitrate removal during the anoxic phase was approximately 99% due to dentrification. However, the overall nitrogen removal during a full cycle was about 50%. The inclusion of an anoxic period right after the aeration phase enhanced the nitrogen removal efficiency, yet this phase required the addition of an external carbon source to the reactor due the low concentration of biodegradable carbon, and at the same time the process became less efficient in BOD removal (Diamadopoulos *et al.*, 1997).

Pilot-Scale SBR: Sequencing batch reactor (SBR) activated sludge processes are known to have several advantages over conventional continuous flow systems. Biological nitrogen and phosphorus removal is possible in a single tank SBR if operating conditions are selected to introduce anaerobic, anoxic and aerobic reactions during a cycle without any addition of separate reactors, recycling lines or clarifiers.

Previously, the laboratory scale SBRs and process conditions have shown a very high degree of biological nutrient removal (both N and P) even on very unfavorable domestic wastewater that was low in biodegradable COD (Ho *et al.*, 1993). Similarly, under conditions with extremely high nitrogen and phosphorus concentrations, such as in wastewater from abattoirs, very good preliminary results have been achieved (Subramaniam *et al.,* 1994).

Lin and Cheng (2001) investigated treatment of municipal sewage wastewater for possible agricultural reuse. The treatment method consisted of chemical coagulation and sequencing batch reactor (SBR) system. A new SBR reactor was designed based on this concept for treatment of municipal sewage wastewater, and experimental tests were performed to evaluate the performances of the modified SBR reactor for comparison with the traditional one Fig. 7. In addition, the final level of purification obtained with both chemical coagulation and SBR was evaluated in light of possible agricultural reuse.

To determine whether continuous flow SBR could provide efficient pollutant removal in synthetic wastewater. The experiment was carried out using pilot scale at Tehran University of Medical Sciences the reactor was separated into two zones (pre-react and main react) by a baffle wall Fig. 8. The pre-react zone acts as a biological selector enhancing the proliferation of the most desirable organisms while limiting the growth of filamentous bacteria, as an equalization tank and as a grease trap. In conventional SBRs there are five phases: fill, react, settle, draw and idle; but in this system there is only three phases: react, settle and draw. It must be noted again that influent never disrupts in any phase. The purpose of this research was to determine the best cycle capable to remove BOD, COD, N, P and TSS from synthetic wastewater. The results showed that the removal efficiency that has been achieved by the system were 97.7, 94.9, 85.4, 71.4 and 55.9% for BOD, COD, TKN, Total N and Total P, respectively could be achieved by the system. Maximum TSS concentration in final effluent was 6.3 mg /l (Mahvi *et al.*, 2005).

Mahvi *et al.* (2004) using the same pilot scale as mentioned before to determine whether continuous flow SBR could provide efficient nitrogen removal in synthetic and domestic wastewater. The experiment was carried out using pilot scale at Tehran University of Medical Sciences; into first stage at laboratory with synthetic wastewater and second stage in treatment plant with

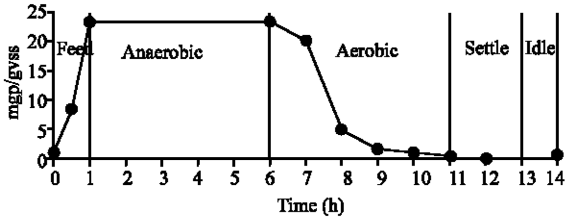

Fig. 6: Change of daily phosphate profile with the development of phosphorus removal (Sarioglu, 2005).

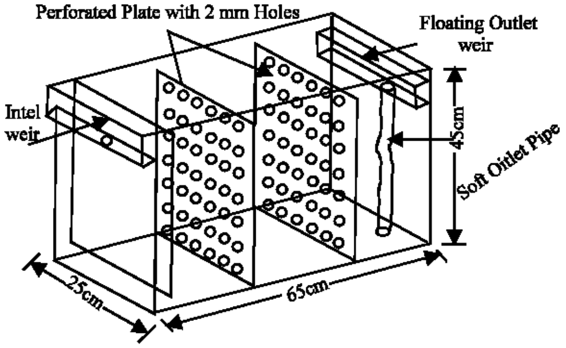

Fig. 7: Design of modified sequencing batch reactor (Lin and Cheng, 2001).

domestic wastewater. The results showed that in laboratory and treatment plant 80 and 70% of total nitrogen removal, respectively and 95 and 85% of total kjeldahl nitrogen removal, respectively could be achieved by the system.

Another pilot plant SBR investigated by Bernardes and Klapwijk (1996) aims to monitor a strategy for biological nutrient removal (nitrogen and phosphorus) in a Sequencing Batch Reactor (SBR) treating domestic wastewater. For this, the performance of an SBR with nitrification, dentrification, carbon oxidation and phosphorus removal is evaluated. During this study the influent used was pre-settled domestic wastewater from Bennekom Municipal Treatment Plant (The Netherlands). The average influent COD, TKN and phosphate were 443 mg COD/l, 71 mg N/l and 7 mg P/l, respectively. Acetic acid was added to this influent from a feed solution, to increase the COD by an extra 100 mg COD/l. in this study, a pilot plant SBR was operated during 5 months in order to have: i) a mixed culture able to perform carbon oxidation, nitrification, dentrification and biological phosphorus removal and ii) long term assessment of the biological nitrogen and phosphorus removal processes. Pilot plant SBR consists of two cylindrical polystyrene vessels, the first with total volume of 0.35 m^3 (reactor 1) and the second with total volume of 1.3 m^3 (reactor 2). The effluent had, in average, phosphate concentration lower than 1 mg P/l and nitrogen concentration lower than 12 mg N/l.

Rodrigues *et al.* (1998) project was conducted to analyze the performance of a SBR reactor when being fed with an aerobically fermented wastewater. Important was to determine the capacity of the system to remove nitrogen and phosphorus. Two SBR reactors, each one with a volume of 980 liters, were used: one used as fermented and the other as activated sludge SBR. Using 8-hour cycles, the reactors were operated and studied during 269 days. The fermented produced an effluent with an average value of 223±24 mg/l of volatile fatty acids. The activated sludge SBR was tested under 3 organic loading rates of 0.13, 0.25, and 0.35 kg COD total/kg TSS.d. Table 5. For three tested organic loading rates, PO4-P concentration under 1.1 mg/l and COD between 37 and 38 mg/l were consistently achieved. Exceptionally high NH4-N influent values not reaching in this case full nitrification. Dentrification was observed during the fill phase in every cycle. SVI values between 40 and 70 were determined during the experimental runs.

Wastewater originating from road and rail car cleaning installations is known to be potentially toxic/inhibitory. As a first step in the design procedure a pilot test was run for a period of 8 months. This pilot showed the SBR to be an appropriate technology for the treatment of the wastewater, with an option for powdered activated carbon (PAC) dosing, was selected The PAC option was not feasible. Based on the pilot results a full scale installation, comparing a batch reactor with a diameter of 10.4 m and a maximum water depth of 17.3 m, was designed and successfully started up. This paper presents the highlights of the total project (Zilverentant, 1997).

A pilot plant of SBR (Sequencing Batch Reactor) and MF (microfiltration) process was operated in order to treat and reuse the greywater produced from an office building. The performance of SBR for greywater was satisfactory as the effluent had 20 mg/l, 5 mg/l, and 0.5 mg/l of SCOD, BOD, and ammonia, respectively. The cyclic operation of SBR used in this study proved more effective in nitrification and dentrification than the conventional SBR operation. However, the most effective mode was step-feed SBR for dentrification. The decanting system of this SBR discharged the effluent fairly well without sludge washout. However, it was difficult to maintain constant concentration of suspended solid from the SBR process. Thus, additional filtration was needed to get adequate water quality for water reuse. MF could remove residual suspended solids and pathogens as well from the SBR effluent. The suspended solids of final effluent were around 1 mg/l and allowed using the treated water for some purpose (Shin *et al.*, 1998).

The design and operation of wastewater treatment systems for single houses, farms, hotels, leisure centers, small communities and small businesses are

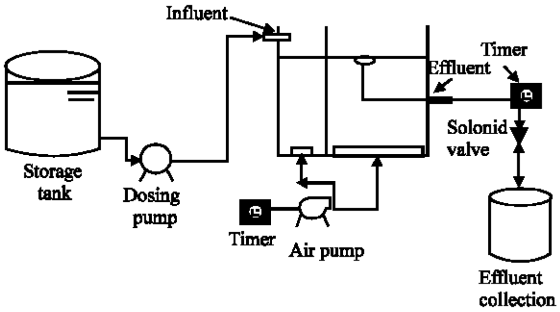

Fig. 8: Schematic of designed pilot (Mahvi *et al.*, 2005).

a challenge to wastewater engineers. A pilot-scale system comprising a vertically moving biofilm reactor (VMBR) followed by a stratified sand filter was constructed and its performance was evaluated. The vertically moving biofilm reactor was operated as a sequencing batch biofilm reactor (VMSBBR). The results show that the VMSBBR unit efficiently removed 94.8% of the filtered chemical oxygen demand (CODf) from a synthetic wastewater with the influent CODf of 1096 ± 425 mg/l, leaving 45 ± 16 mg/l CODf in the effluent, at an organic loading rate of 0.9 kg COD/m^3 day. After the system had been operated for 133 days, the removal efficiency of orthophosphate (PO4-P) reached 90%. A sand filter polished the effluent from the VMSBBR unit and reduced suspended solids (SS) to 4.4 mg/l and total bacterial by 3 log 10 units. The advantages of the treatment system studied for small wastewater flows include: (1) simple operation and maintenance-sludge was only disposed of once on Day 206 during the 7.5-month study period; clogging, which often happens in other attached-growth biofilm systems, did not take place; (2) efficient removal of COD and phosphorus; and (3) low-energy consumption-the electricity consumption was 4.6 kWh/population equivalent (p.e.) year, or 0.6 kWh/m^3 wastewater treated or 0.6 kWh/kg COD removed (Rodgers *et al.*, 2005).

Conclusion: Wastewater treatment has been a challenge throughout the years due to varying influent chemical and physical characteristics and stringent effluent regulations. Treatment systems using activated sludge have been able to handle many of these difficulties. Given the lack of on-line computer controls, continuous flow systems have been mostly used for these purposes versus sequencing batch processes. The availability of artificial intelligence has now made the option of a SBR process more attractive thus providing better controls and results in wastewater treatment. This is coupled by the flexibility of a SBR in the treatment of variable flows, minimum operator interaction required, option for anoxic or anaerobic conditions in the same tank, good oxygen contact with microorganisms and substrate, small floor space, and good removal efficiency. Sequencing batch reactors operate by a cycle of periods consisting of fill, react, settle, decant, and idle. The duration, oxygen concentration, and mixing in these periods could be altered according to the needs of the particular treatment plant. Appropriate aeration and decanting is essential for the correct operations of these plants. The aerator should make the oxygen readily available to the microorganisms. The decanter should avoid the intake of floating matter from the tank. The many advantages offered by the SBR process justifies the recent increase in the implementation of this process in industrial and municipal wastewater treatment.

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