Report for 2004PA29B: Nutrient Removal of a Sequencing Batch Reactor (SBR) Treating Wastewter with Potential for Water Reclamation

- Articles in Refereed Scientific Journals:
    - Li, B. and S. Irvin. 2005. Nitrogen removal in low/middle/high concentration wastewater using a SBR. Submitted to Environmental Engineering and Science.
    - Li, B. and S. Irvin. 2005. Alkalinity and ORP changes at nitrification and denitrification in a sequencing batch reactor (SBR). Water Environment Research (in preparation).
    - Li, B. and S. Irvin. 2005. The population of nitrifying bacteria in a SBR system at different nitrogen removal efficiency. Applied Environmental Microbiology (in preparation).
- Conference Proceedings:
    - Li, B. and S. Irvin. 2005. Optimizing nitrogen removal in the SBR system. Proceedings of International Water Association (IWA)Leading Environmental Technology (LET).
    - Li, B. and S. Irvin. 2005. ORP and alkalinity change in the SBR system for nitrogen removal. Proceedings of Water Environmental Federation (WEF) 2005 conference.

Report Follows

Abstract:

The overall vision for this research is to optimize a cost- and space-effective biological nutrient removal (BNR) system to remove nitrogen from wastewater for water reuse. The ultimate goal is to protect natural water resources and reduce energy consumption in wastewater treatment. Ammonia/nitrate pollution of surface water and groundwater has been a significant problem in Pennsylvania and the Chesapeake Bay watershed for many years. The deteriorated natural water resource is the main obstacle for water reuse necessary to save water consumption in Pennsylvania. Nitrification/denitrification in biological wastewater treatment is the approach commonly used to remove nitrogen from wastewater. However, this process needs large amounts of space, long treatment time, and has a high operational cost, and the performance is not stable.

It is critical to develop an innovative cost- and space-effective process in order to solve low nitrogen removal efficiency, and if possible, to provide high effluent quality for water reclamation. Current research conducted in the Environmental Engineering Laboratories at Penn State Harrisburg aims at enhancing nitrogen removal by the sequencing batch reactor (SBR). Compared with conventional biological wastewater treatment processes, the SBR has several distinct advantages: 1. the SBR process converts the conventional wastewater treatment processes from space-course to time-course, which substantially reduces the space occupation. This feature especially makes the SBR suitable for small community wastewater treatment. 2. the SBR operation sections (aeration, anoxic reaction, settling, etc.) are auto-controlled which offer the easiness and flexibility to adjust the SBR operation for different treatment requirements.

With the objective of enhancing nitrogen removal efficiency from wastewater, this research will be conducted in two phases. Phase 1 consists of laboratory studies to evaluate the SBR nitrogen removal efficiency when treating low concentration wastewater (municipal wastewater) and high concentration wastewater (agricultural wastewater). The optimization of nitrification/ denitrification by adjusting aeration intensity, aeration duration, and anoxic duration will be investigated. The study will establish the relationships between the SBR performance (including organic removal, nitrogen removal, and sludge settlebility), and oxygen consumption and operation cycles. Phase 2 consists of laboratory studies to examine the nitrogen removal in the SBR system under influent shock. Two inhibitors for nitrification will be added into influent to test the SBR nitrification stability. The study will provide information for the adjustment of SBR operation cycles, and test the feasibility of SBR handling nitrogen removal under influent shock.

Use of the SBR for nitrogen removal is currently applicable for community and agricultural wastewater treatment, but optimization of operation and on-line control is far from completion. The outcome of this research will provide useful guidance for the optimization of the SBR operation and energy savings for contaminant removal from wastewater with potential for water reuse. This project is supported by Penn State Harrisburg, Cromaglass Inc. (the equipment manufacture) and Skelly & Loy (the consulting firm supporting the equipment).

Statement of Critical Need:

Nitrogen pollution in water resources is a long existing environmental and public health problem in Pennsylvania. Agriculture and farming are the main economy resources for Pennsylvania. However, waste generated by agriculture and farming is the major source of nutrient (nitrogen and phosphorous) to water resources. USGS studies in agricultural areas in the Susquehanna River Basin, which drains to Chesapeake Bay, have documented high concentrations of ammonia (NH3) and nitrate (NO3-) that create conditions detrimental to aquatic life. This is the leading cause of environmental degradation in the Chesapeake Bay, primarily because it fuels the runaway growth of algae. When algae decompose, it consumes oxygen, a crucial element for survival of the Chesapeake's famed shellfish and fish stocks. Moreover, high concentration of nitrogen in groundwater has posed potential human and livestock health hazards (PADEP, 1996). EPA regulates drinking water nitrogen concentration should be lower than 10 mg/L, but nitrogen is higher than 30 mg/L in some Pennsylvania areas, and citizens are worried about nitrate pollution of drinking water supply, since high levels of nitrates have been associated with (blue-baby) syndrome in infants (Susquehanna River Basin Commission, 1991). Pennsylvania aimed at reducing the levels of nitrogen entering the Susquehanna River by 40 percent by the year 2000 (PADEP 1996). However, efforts to meet this goal have been impeded by the nutrient pollution from new factory farms locating in the watershed.

Beside public health issues related to contamination of water resources, nitrogen pollution also causes the obstacles for water reuse in Pennsylvania. Pennsylvania has been suffering water shortages for over one decade due to the increasing water demand and dry weather conditions. The water shortage has caused billions of dollars economic losses for agriculture in Pennsylvania. In 1999, crop losses state-wide were estimated at $1.3 billion and milk production loss was $1.5 trillion. In order to solve the water shortage problem, reclaimed wastewater is a beneficial application. However, wastewater reclamation is impeded by high nitrogen concentration as a result of ineffective nitrogen removal in the wastewater treatment processes. In most wastewater treatment plants in Pennsylvania, treated wastewater still has high amount of organic/inorganic nitrogen. This is the main reason that water reuse is not allowed in some places in Pennsylvania. In order to solve water shortage by water reclamation and reuse, effective nitrogen removal should be employed to enhance the treated wastewater quality.

The commonly used process for nitrogen removal in biological wastewater treatment is aerobic nitrification/anoxic denitrification by different microorganisms. Nitrification has two steps: ammonia (NH3) is first oxidized to nitrite (NO2-) by autotrophic ammonia oxidizers, then nitrite is oxidized to nitrate (NO3-) by autotrophic nitrite-oxidizers. In anoxic denitrification, nitrite/nitrate is reduced to nitrogen gas (N2) by heterotrophic denitrifiers with the presence of extra carbon source (methanol) as electron donor. The reactions are listed below:

Aerobic nitrification:

$$2NH_4^+ + 3O_2 \xrightarrow{Ammonia-oxidizers} 2NO_2^- + 4H^+ + H_2O \qquad (1)$$

$$2NO_2^- + O_2 \xrightarrow{Nitrate-oxidizers} 2NO_3^- \qquad (2)$$

Anoxic denitrification:

$$CH_3OH + \tfrac{6}{5} NO_3^- - \xrightarrow{Denitrifier} \tfrac{3}{5} N_2 + CO_2 + \tfrac{6}{5} OH^- + \tfrac{7}{5} H_2O \qquad (3)$$

Nitrification/denitrification of the biological nutrient removal process is generally recognized as the most vulnerable activated sludge process, depending on many factors (influent contaminant concentration, sludge retention time, oxygen concentration, microbial phase in activated sludge, etc.)

which are often interconnected (Metcalf & Eddy, 2003). Because the growth rate of autotrophic nitrifiers is far slower than normal heterotrophic bacteria, nitrification could not occur in wastewater treatment systems unless cell retention time is long enough for nitrifiers to reproduce and grow. This causes a large space requirement for wastewater treatment. Moreover, heterotrophic bacteria dominate over autotrophic nitrifiers at medium/high contaminant concentration, which leads to low nitrogen removal efficiency when treating municipal and agricultural waste. In order to achieve an efficient nitrogen removal to protect natural water resources and provide good effluent for water reuse, an innovative biological cost and space-effective is pursued in this research.

With the objective of enhancing biological nitrogen removal efficiency, the research team will investigate the optimization of nitrogen removal in the sequencing batch reactor (SBR)—a recently adopted process converting traditional wastewater treatment from space-course to time course. The research goal is to achieve good nitrogen removal from low/high concentration wastewater with short retention time and low/medium oxygen concentration in order to save energy cost. The research contributes to establishing multi-disciplinary Environmental Engineering research at Penn State. The education goal is to create opportunity for students to study the innovative wastewater treatment process and understand the importance of nutrient removal. Along with this, it will bring a professional view to sustainable water environmental development. The SBR system studied in the research project is a part of graduate-level course “wastewater treatment design” at Penn State Harrisburg.

Statement of Results of Benefits:

The proposed SBR project will optimize two important criteria for nitrification/denitrification:
1. oxygen concentration, and
2. aeration duration under different influent organic loadings.

The nitrogen removal efficiency at different influent qualities (municipal sewer, agricultural waste) and SBR operation conditions (oxygen, aeration duration, anoxic duration) will be studied. The optimal condition with respect to nitrogen removal, contaminant removal, and solid removal will be obtained to balance good treatment and energy consumption. Moreover, the performance of the SBR nitrogen removal will be tested under influent shocks to provide information for the stability of the SBR treating municipal and agricultural waste. This full-scale SBR study will provide valuable information for nitrogen removal from wastewater for protecting water environment and water reuse.

The optimization of the SBR will provide a far more efficient nitrogen removal technology for wastewater treatment and reuse, and is expected to achieve effluent nitrogen concentration lower than 5 mg/L. The small space requirement, flexible operational modes, and low energy cost of the SBR will significantly reduce the cost of nitrification/denitrification. After optimization of the SBR for nitrogen removal, it could be used in communities, agricultural areas, and farms to treat municipal sewage and high concentrated agricultural waste. This economic and highly efficient treatment technology can help to solve the nitrogen contamination in Pennsylvania.

Nature, Scope and Objectives:

A full scale SBR system (treatment capacity 500 gallon per day) is being studied in the

Environmental Engineering Laboratories at Penn State Harrisburg. The distinct feature of the SBR is its inherent flexibility of cycle phasing, providing different operational modes on time sequence, and not being as space dependent as the traditional activated sludge process. SBR is perfectly suited for small wastewater flows (<10 MGD, Irvine et al. 1987). In an SBR operation, the wastewater is fed for a period of time. It goes through a sequence of treatment processes in the same basin and is drawn periodically. A typical cycle involves five operational phases: fill, react, settle, decant and idle/waste sludge (Figure 1). Among the several advantages that the SBR offers compared to a CFR are flexibility in operation, quiescent or carefully controlled mixing during settling, no need for separate clarifier, and space saving (Norcross, 1992).

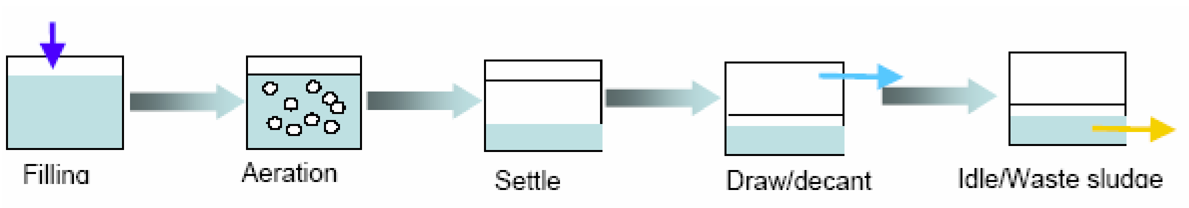

Figure 1. Operation timeline of the SBR system

Although the SBR has several advantages compared with traditional wastewater processes, several areas still need to be developed for the nitrogen removal of the SBR:

1. Real-time monitoring for the SBR operation beside dissolved oxygen (DO) and pH in order to get the on-line information of nitrification/denitrification;
2. Simultaneous nitrification/denitrification which might be achieved at low DO (DO< 1mg/L). How to keep good sludge settlebility at a low DO condition is a challenge;
3. How to optimize SBR to get good effluent quality for water reuse to save water resources;
4. Very limited knowledge is available in terms of the change of microbial activity at different operational cycles of SBR and how it can be used to optimize operation.

In order to give answers to above questions, a comprehensive test is being conducted through the collaboration of Penn State Capital College, Skelly & Loy and Cromaglass, Inc.

The research will be conducted in two phases. Phase 1 consists of laboratory studies to optimize nitrogen removal by adjusting aeration intensity, aeration duration, anoxic duration. Phase 2 consists of laboratory studies to examine the nitrogen removal in the SBR system under influent shock. The anticipated schedule, along with major milestones, is presented in Table 1.

Table 1. Proposed project schedule (with starting state of March 1, 2004)

	Oct. 2003- Mar. 2004	**Mar.2004- June.2004**	**July.2004- Sept. 2004**	**Oct. 2004 – Dec. 2004**	**Jan. 2005- Feb.2005**
Phase 1A. Operation mode and influent quality on nitrogen removal *	*				
Phase 1B. oxygen concentration on nitrogen removal					
Phase 1C. ORP on-line monitor *	*				
Phase 2. Nitrogen removal under					

influent shock					
Write report					

*: The PSH research team has been working on nitrogen removal at laboratory since Sept. 2003 (shown in brown slots). The results from this phase will contribute to the SBR project proposed for 2004-2005.

Methods, Procedures and Facilities:

Phase 1: Optimize nitrogen removal in SBR operation

In this phase of the study, nitrogen removal in the SBR system will be studied in the laboratory by using synthetic wastewater (representing municipal wastewater: low organic and low ammonia concentration; and agricultural wastewater: high organic and high ammonia concentration). The preset SBR operation cycle is fill: 0.5 hr, aeration: 2.5 hr, anoxic mixing 1.5 hr, settling 1 hr, and decant 0.5 hr. The experimental set-up is shown in Figure 2. Based on the SBR operation from experience by Skelly & Loy field-work, nitrification/denitrification is not stable. Therefore, the phase I will be aimed at improving nitrogen removal in the SBR. In the first step, nitrogen removal will be evaluated through a series of tests of different operational cycles, hydraulic retention times, and influent organic loadings in order to find the optimal operation for nitrogen removal. In the second step, the oxygen concentration for nitrification/denitrification will be studied to find the optimal aeration condition for contaminant removal, and nitrogen removal. The redox potential (ORP) will also be tested as an on-line monitor for contaminant removal and nitrification/denitrification. The detailed plan for Phase I study is stated below:

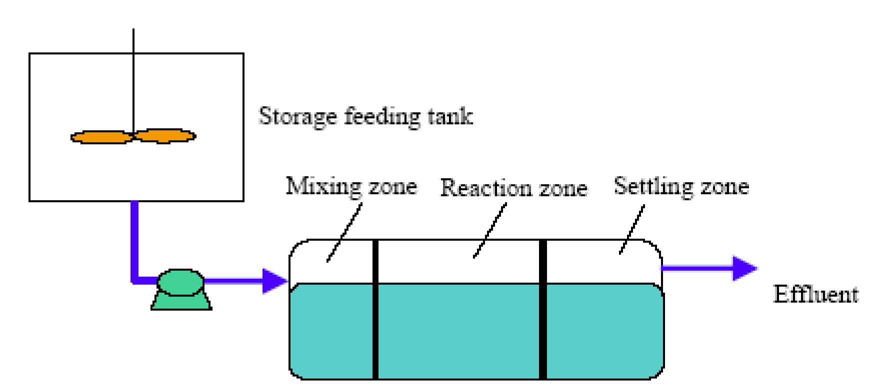

Figure 2. The SBR experimental set-up diagram

1A. Effects of operation mode and influent quality on nitrogen removal

The research currently being conducted is testing the adjustment of operational modes to get high nitrogen removal efficiency. The hypothesis of this research is: due to the flexibility of the SBR, the duration of aerobic and anoxic reactions can be adjusted to achieve good nitrification/denitrification performance. The SBR system is run at various aeration and anoxic durations. It is anticipated that long aeration is good for carbonaceous removal and nitrification, and long anoxic duration is good for denitrification, but nitrogen gas generated may interfere with the settlebility of activated sludge. By adjusting aerobic/anoxic duration, we hope to find the optimal operation mode for achieving carbonaceous removal, nitrogen removal, and good effluent quality. The SBR influent and effluent will be tested for chemical oxygen demand (COD), ammonia, nitrite, nitrate, and suspended solid according to Water Standard Method. Also, the ammonia, nitrite and nitrate will be measured at the end of aeration and anoxic mixing steps to test nitrification and denitrification efficiency. The tested operation modes to be tested are list in Table 2. The test period for each mode will last two weeks.

Table 2. SBR operation modes (influent COD: 300-400 mg/L simulating municipal wastewater)

	Fill	Aeration	Anoxic mixing	Settling	Decant
Preset	Aerobic, 0.5 hr	2.5 hr	1.5 hr	1 hr	0.5 hr
Mode 1	Aerobic 0.5 hr	3.5 hr	1hr	1 hr	0.5 hr
Mode 2	Aerobic 0.5 hr	4.5 hr	1.5hr	1 hr	0.5 hr
Mode 3	Anoxic 0.5 hr, Aerobic 0.5 hr	2 hr	1.5 hr	1 hr	0.5 hr
Mode 4	Aerobic 0.5 hr, Anoxic 0.5 hr	2 hr	1.5 hr	1 hr	0.5 hr

Besides the study of operational modes, hydraulic retention time (HRT) will also be tested for the SBR nitrogen removal. HRT will be adjusted by the influent flow rate, ranging from 80, 125, 250, and 500 gallon per day. It is anticipated that long HRT leading to low organic loading for biomass might be favorable for autotrophic nitrifier growth and nitrification. We will test whether the low flow rate can enhance the nitrogen removal efficiency in SBR.

Since the SBR process can be used for communities, agricultural areas and farms, the next study is to change the influent organic concentration from simulating municipal wastewater (low organic and low ammonia concentration) to agricultural wastewater (high organic and high ammonia concentration). The SBR system will be run at high organic concentration levels (COD: 1000 mg/L). It is known that in traditional activated sludge processes, nitrification can be severely inhibited at high COD concentration due to the domination of heterotrophic bacteria (Metcalf and Eddy Inc., 2003). We will test whether the SBR can achieve desirable nitrogen removal at high organic concentration. In the mean time, we will adjust the aeration/anoxic duration to find optimal operation mode for treating agricultural waste.

1B. Effects of oxygen concentration on nitrogen removal

Oxygen is a critical operational parameter for contaminant and nitrogen removal, and nitrification is especially sensitive to oxygen concentration. However, the aeration system accounts for more than half of total energy consumption in biological wastewater treatment systems. To balance good treatment efficiency and energy consumption is an important issue for sustainable wastewater treatment. In STEP 1B, the SBR system will be run at three oxygen levels in aeration sections (2, 3-4, and 5-6 mg/L) to evaluate the impact of oxygen concentration on nitrification. Moreover, the aeration duration will be adjusted for different oxygen levels to examine the possibility of shortening SBR operation cycle and still keeping good nitrogen removal.

Low oxygen concentration for simultaneous nitrification/denitrification (SNdN) will also be investigated for the possibility of skipping the denitrification step but still achieving good nitrogen removal. Currently, most conventional wastewater treatment processes separate nitrification and denitrification into two zones: aerobic and anoxic, in order to create the proper environment for the different microorganisms responsible for nitrogen removal. However, this separation neglects the interaction between the aerobic nitrifier and anoxic denitrifier. In nitrification, extra alkalinity has to be added to keep a stable pH, and in denitrification, an external carbon source (methanol) might be needed for the reduction of nitrate if organic matters are not sufficient in water. This will cause difficulties for operation and maintenance. The occurrence of nitrification/denitrification in a single tank can resolve this problem, since alkalinity produced in denitrification can neutralize the hydrogen ion produced in nitrification, as such, save alkalinity dosage. The wastewater can serve as an internal carbon source for denitrification, thus saving the organic dosage. SNDN might be achieved at low oxygen concentration (DO<1-2 mg/L) (Moriyama et al. 1993). However, this raises another issue: how to prevent sludge bulking at this low oxygen condition, since filamentous bacteria can cause lose and light activated sludge which is difficult to settle, and lead to the high solid concentration in effluent (Metcalf & Eddy, 2003). Therefore, our research will test SNDN at low oxygen concentration and compare the nitrogen removal efficiency with separate nitrification/denitrification in STEP 1A. The SBR influent and effluent will be tested for ammonia, nitrite, nitrate, and suspended solids. Sludge settlebility will be test by sludge volume index (SVI). The STEP 1B will provide information for achieving good nitrogen removal and good effluent quality, saving aeration energy at same time.

1C. On-line monitor for contaminant and nitrogen removal

Along with the SBR operational testing in STEP 1A and 1B, parameters for on-line monitoring SBR performance will be evaluated. Currently, the most commonly used parameters are pH and oxygen. However, when oxygen is lower than 0.5 mg/L, the concentration is too low for measurement to be reliable. In order to get the on-line information for aerobic nitrification/anoxic denitrification, it is for critical to find a parameter which could reflect reaction status at both aerobic and anoxic conditions.

In this study, redox potential (ORP, $E=E0+ \ln([\text{oxidized form}]/[\text{reduced form}])*RT/nF$, where n is the electron transferred in a redox reaction) will be tested as an on-line monitoring parameter, since nitrification/denitrification are redox reactions involving electron donors and electron acceptors (reaction 1-3, page 6). The P.I. has done extensive work on ORP control for wastewater treatment and found a clear correlation of ORP with different biodegradation processes. For instance, nitrification needed higher ORP (360 mV) values than does carbonaceous compound oxidization (200-300 mV) (Li and Bishop 2002, 2003a). In addition, aeration tank effluent quality could be indicated by on-line ORP values much faster than COD measurement (Li and Bishop 2003b). The correlation of ORP and nitrification was also verified by the microelectrode and molecular biology studies (Fluorescent in situ hybridization, FISH) (Li and Bishop 2003c). The number of nitrifiers at higher redox condition is significantly greater than at lower ORP. Based on the success of using ORP to indicate wastewater quality, it is promising to evaluate ORP as an indicator of nitrification/denitrification.

ORP monitoring will be evaluated with pH and oxygen in experiments conducted in STEP 1A and 1B. It is expected to obtain the correlation between ORP and nitrogen removal, and find the setpoints of ORP values for the completion of nitrification and denitrification. If this correlation can be established, the extent of nitrogen removal could be monitored on line, and the aeration duration can be adjusted immediately to ensure the good nitrogen removal efficiency.

Upon the completion of the Phase 1 study, the optimal SBR operational mode for nitrogen removal can be obtained, and optimal oxygen concentration for nitrification or simultaneous nitrification/denitrification can also be gotten for balancing good nitrogen removal and energy saving. The nitrogen removal of low/high concentrated wastewater can test the feasibility of SBR treating municipal and agricultural wastewater. The relationship of ORP and the extent of nitrification/denitrification will be established for the on-line monitoring of SBR performance, which is critical for improving SBR nitrification/denitrification.

Phase 2: Nitrogen removal efficiency under shock

While the Phase 1 study is conducted in steady operational status. Phase 2 will evaluate the stability of SBR performance under influent shock, since there are a variety of compounds in wastewater that could inhibit nitrifier activity and interfere with the nitrification/denitrification. Two chemicals NaClO3 and allylthiourea (ATU) will be used to represent the inhibitors in wastewater. ATU inhibits ammonium oxidation (Reaction 1, page 6), while NaClO3 inhibits nitrite oxidation (Reaction 2, page 6) (Gorska et al., 1996). ATU and NaClO3 will be added separately to SBR influent at the dosage of 5 mg/L and 2.5 g/L respectively. The ORP values in SBR system and effluent ammonia, nitrite and nitrate will be tested for the response of microorganisms to inhibitors, and check the feasibility of ORP for on-line indicator of influent shock. Also, the oxygen uptake rate (OUR) of microorganism in aeration section will be measured for the impact of inhibitors in nitrifier activity. These results will be compared with the stable status in Phase 1 study. Moreover, the oxygen concentration, aeration duration, and anoxic duration will be adjusted for influent shock in order to find the operational mode to keep good nitrogen removal under shock conditions. The recovery of the SBR system after influent shocks will also be evaluated to check the time necessary for recovering to steady-state conditions. The recovery time is important for the development of robust systems capable of rapidly returning to steady-state condition after environmental shock.

References

1. Cartstensen J., Haremors P., and Madsen H., (1995). Statistical identification of Monodkinetic parameters from on-line measurements. Wat. Sci. Tech. 31 (2), 125-133.
2. Demouline, G. and Goronszy, M. (1997). Co-current nitrification denitrification and biological P-removal in cycle activated sludge plants by redox controlled cycle operation. Wat. Sci. Tech. 35 (1), 215-224.
3. Fujii S. (1995). Theoretical analysis on nitrogen removal of the step-feed anoxic-oxic activated sludge process and its application for the optimal operation. Wat. Sci. Tech. 34 (12), 459-466.
4. Gorska J., Gernaey K., Demuynck C., Vanrolleghem P., Verstraete W., (1996). Nitrification monitoring in activated sludge by oxygen uptake rate (OUR) measurements. Wat. Res. 30: 1228-1236.
5. Irvine R.L., Murthy D.V.S., Arora M.L., Copeman J.K., and Heidman J.A., (1987). Analysis of full-scale SBR operation at Grundy Center, Iowa. J. Wat. Poll. Control Fed. 59 (3), 132-138.
6. Katsogiannis A., Kornaros M., and Lyberatos G., (1999). Adaptive optimization of a nitrifying sequencing batch reactor. Wat. Res. 33: 3569-2576.
7. Kuenen, J.G., and Roberson L.A. (1994). Combined nitrification-denitrification processes. FEMS Microbiol.Rev. 15: 109-117.
8. Lazarova V., Bellahcen D., Manem J., Stahl D.A., and Rittmann B. (1999). Influence of operating conditions on population dynamics in nitrifying biofilms. Wat. Sci. Tech. 39: 7.
9. Lee D., Joen C., Park J.M., (2001). Biological nitrogen removal with enhanced phosphate

uptake in a sequencing batch reactor using single sludge system. Wat. Res. 35, 3968-3976.
10. Li B., Bishop P. L. (2002). Oxidation-reduction potential (ORP) regulation of nutrient removal in activated sludge wastewater treatment plants, Wat. Sci. & Tech. 46 (1-2): 35-39
11. Li, B. and Bishop, P.L. (2003a) ORP changes in aeration tanks and microprofiles of activated sludge floc in medium and low strength wastewaters Water Environment Research (accepted).
12. Li, B. and Bishop, P.L. (2003b) Structure-function dynamics and modeling analysis of the micro-environment of activated sludge floc in wastewater treatment processes studied using microelectrodes Water Science and Technology, 47 (11): 267-273, 2003.
13. Li, B. and Bishop, P.L. (2003c) Micro-profiles of activated sludge floc determined using microelectrodes. Water Research, (accepted).
14. Martins A., Heijnen J., Van Loosdrecht M., (2003). Effect of feeding pattern and storage on the sludge settleability under aerobic conditions. Wat. Res. 30: 2555-2570.
15. Metcaf &Eddy, Inc. “Wastewater Engineering: Treatment, Disposal, and Reuse”. McGraw-Hill, Inc., NY, 2003. P: 695-698. 749-754
16. Mobarry, B. K.; Wagner, M.; Urbain, V.; Rittmann, B. E.; Stahl, D. A. (1996) Phylogenetic Probes for Analyzing Abundance and Spatial Organization of Nitrifying Bacteria. Appl. Environ. Microbiol., 62 (6), 2156-2162.
17. Moriyana K., Takahashi M., Haraha Y., (1993). Retrofitting and operation of small extended aeration plants for advanced treatment—some experiences in Japan. Wat. Sci. Tech. 28 (10), 377-385.
18. Norcross K.L. (1992). Sequencing batch reactors-an overview. Proceedings of 16th Biennial Conference of the International Association on Water Pollution Research & Control.
19. Pennsylvania Department of Environmental Protection, (1996). “Pennsylvania’s Chesapeake Bay nutrient reduction strategy, bureau of land and water conservation and bureau of water quality management” P: 1
20. Salem S., Berends D., Heijnen J., Van Loosdrecht M., (2003). Bio-augmentation by nitrification with return sludge. Wat. Res. 37: 1794-1804.
21. Seviour, R.J. and Blackall, L.L. (1999). The Microbiology of Activated Sludge. Kluwer Academic Pub. Netherlands. P: 219-220.
22. Susquehanna River Basin Commission, (1991). “Loads and yields of nutrients and suspended sediment transported in the Susquehanna river basin” P: 141-143.

Principal Findings and Significance:

An extensive study of chemical oxygen demand (COD) and nitrogen removal in a sequencing batch reactor (SBR) system (treatment capacity: 450 gallon per day), funded by PA Water Resource Center, was conducted at Penn State Harrisburg wastewater treatment lab from Sept. 2003-May 2005.

The major goal of the project was to achieve nitrogen removal in the SBR system for wastewater reuse. During the study, nitrogen removal was tested at different operation conditions (influent COD, influent NH3 concentration, oxygen concentration, and flow rate). The overall performance of SBR for nitrogen removal was good under most conditions, with effluent nitrogen concentration less than 5 mg/L. Several parameters (alkalinity, pH, and redox potential) were tested as on-line indicators for nitrogen removal. It was found that alkalinity was the best indicator of nitrogen removal efficiency. Moreover, nitrogen removal efficiency of the SBR system was tested under shock, which was supposed to inhibit NH3 oxidization. The comparison between batch test and the SBR for the toxic shock indicated that SBR system can tolerate toxic shock in terms of nitrification. In the mean time, the population of nitrifying bacteria in the SBR system under different operation conditions was observed by fluorescent in situ hybridization (FISH). The results indicated the different nitrifying bacterial groups were present in activated sludge.

This SBR project has a great significance for wastewater treatment and water reuse. Starting in September 2005, the Pennsylvania Department of Environmental Protection will require that wastewater treatment facilities in Pennsylvania need to meet effluent total nitrogen less than 10 mg/L. This regulation sets a higher standard for total nitrogen than the current requirement for wastewater treatment facilities. The results from this project indicate that SBR systems can be used to help meet this new requirement and provides guidance for manufacturers and customers for the SBR operation. Nitrogen removal is critical for wastewater reuse. This project has provided solid support for nitrogen removal from small wastewater treatment systems.

Besides this application significance, the graduate student in this project learned a lot in biochemistry, wastewater treatment. Moreover, the SBR system has been widely used for high school students, undergraduate, and graduate education in the past 2 years. It is also used for wastewater treatment plant operator's training. Molecular biology technology (FISH) applied in this project has laid a solid preparation for a graduate student course "Environmental Biotechnology", set to open in Spring 2006.

Overall, the successful completion of this SBR project has a great application and education significance. Because of the high quality work, the SBR manufacturer has showed a great interest in continuing the collaboration with the Principal Investigator for nitrogen an phosphorous removal research.

Students Supported:

Shannon Irvin, M. S. in Environmental Pollution Control, Penn State Harrisburg, May 2005.

Presentations and Other Information Transfer Activities:

Shannon Irvin, Baikun Li. Factors affecting nitrogen removal in a SBR system. *2004 PSU graduate student exhibition. University Park, PA. March 2004*

Shannon Irvin, Baikun Li. The optimization of nitrogen removal in a SBR system. *2005 PSU graduate student exhibition. University Park, PA. March 2004*

Shannon Irvin, Baikun Li. Nitrogen removal from wastewater in a SBR system. *2005 Innoventure, Hershey, PA April 2005*

Baikun Li. The overview of nitrogen removal in the Cromaglass CA-5 SBR system. *Presented for Cromaglass Inc. Skelly&Loy Inc., Middletown Wastewater treatment plant, and Harrisburg International Airport Wastewater treatment plant. April 2005.*

Shannon Irvin, Baikun Li. The optimization of nitrogen removal in a SBR system. 2005 *Pennsylvania Environmental Association (PAEA) Annual Conference. Spring Valley, PA. June 2005.*

Shannon Irvin, Baikun Li. Nitrogen removal from wastewater in a SBR treating low/mid/high wastewater. *International Water Association (IWA) LET2005 Conference. Sapporo, Japan, June 2005.*

Shannon Irvin, Baikun Li. Nitrogen removal in a SBR system under ATU shock. *Water Environmental Federation (WEF TEC) Annual Conference 2005. Washing DC. Sept. 2005 (accepted).*

Awards:

Student Research Award (Pennsylvania Environmental Association (PAEA) 2005) for Shannon Irvin. Advisor: Baikun Li