Sequencing Batch Reactor Design and Operational Considerations

September 2005

Prepared by the

NEW ENGLAND INTERSTATE WATER
POLLUTION CONTROL COMMISSION
116 John Street ■ Lowell, MA 01852-1124

Tel: (978) 323-7929 ■ Fax: (978) 323-7919
mail@neiwpcc.org ■ www.neiwpcc.org

Ronald F. Poltak, Executive Director

Compact Member States

Connecticut
Maine
Massachusetts
New Hampshire
New York
Rhode Island
Vermont

For additional copies, contact NEIWPCC at the address above.
This document is also available for download at www.neiwpcc.org.

Printed on recycled paper

ACKNOWLEDGEMENTS

This manual was developed by the New England Interstate Water Pollution Control Commission. NEIWPCC is a not-for-profit interstate agency, established by an Act of Congress in 1947, that serves its member states (Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont) by providing coordination, public education, training, and leadership in water management and protection.

NEIWPCC's technical consultant for this project was Roland "Joe" Dupuis of D^3 Engineering.

NEIWPCC would like to thank the following people who contributed their time in reviewing this manual.

Alan Slater, MA DEP

David Boyer, MA DEP

Ning Chen, MA DEP

Margo Webber, MA DEP

Charles Conway, NEIWPCC

Tom Groves, NEIWPCC

Nelson Thibault, Hoyle, Tanner & Associates

Paul Clinghan, Hoyle, Tanner & Associates

Al Curran and staff at Woodard & Curran

Tom White, NH DES

Glen Calltharp, Fluidyne Corp

Ed Corriveau, PA DEP

New England and New York Regional 104(g) Workgroup

NEIWPCC Project Officers
Michael Jennings
John Murphy

Design and Production
Ricki Pappo, Enosis –
The Environmental Outreach Group

Editorial Support
Ellen Frye, Enosis –
The Environmental Outreach Group

CONTENTS

FOREWORD

This document is designed to be used by municipalities, engineers, regulators, operators, and other interested parties that use, design, or are thinking about implementing sequencing batch reactor (SBR) wastewater treatment systems. This document highlights enhancements to the design and operation of SBRs that will ultimately provide more effective wastewater treatment. This document can be used by municipalities in the process of planning to upgrade their current operations or reviewing treatment plant options, regulators that review SBR designs, and design engineers.

It is worth noting that many considerations should go into choosing whether or not to implement an SBR treatment system. Decisions should not be based solely on economics; they should also include process flexibility, ability to meet permit limits, and long-term viability.

In developing this document, a literature review was conducted to obtain current information on SBRs. Reference information is provided to allow users to obtain source documentation for additional details.

This reference was written to provide general information on SBR enhancements, and the recommendations will not apply to every SBR design. The document is not meant to be a substitute for professional advice in situations where it is warranted. SBRs are complex treatment systems that must be addressed on a case-by-case basis. If the information provided here does not specifically and sufficiently address your problem or concern, consult with industry professionals, service representatives, or regulatory officials.

If you find any mistakes or omissions, please notify NEIWPCC by using the feedback form provided at the end of this document.

INTRODUCTION

TR-16 Guides for the Design of Wastewater Treatment Works is one of the most requested documents produced by the New England Interstate Water Pollution Control Commission. However, there is a need for supplemental information to address the design of sequencing batch reactor (SBR) wastewater treatment facilities. SBRs are becoming popular wastewater treatment options in New England and across the country due to their ability to treat varying flow rates and allow control flexibility. In addition, they have a small footprint and are potentially less expensive to construct and operate.

Recognizing the need to address issues associated with the design and operation of SBR facilities, the Massachusetts Department of Environmental Protection Technical Assistance Section requested that NEIWPCC initiate this guide. NEIWPCC began by developing a 40-question survey and sending it to SBR facility operators in New England and New York. The survey questions covered design parameters, methods to improve overall plant function, type of discharge permit, and plant set-up. Responses received from the survey verified state concerns that there is no general design that is common to SBR facilities.

After the survey results were compiled, the next step in the development of this guide was to visit five SBR facilities in New England. The plants visited were chosen based on their unique characteristics, which included:

- A newly designed plant
- A plant at full capacity
- A plant with a varying wastewater flow rate
- A larger SBR plant with steady flow
- A plant receiving seasonally varying flows

At these facilities, operators, superintendents, design engineers, and laboratory technicians were interviewed. These visits provided valuable first-hand information on how these plants were operating and the types of adjustments made to operate at optimal conditions.

The goal of this document is to provide design considerations and operational information to enhance SBR performance. The guide is also an attempt to optimize SBR design and describe specific configurations and processes that will enhance treatment performance.

CHAPTER 1
CHARACTERISTICS OF SEQUENCING BATCH REACTORS (SBRs)

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 wastewaters, 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.

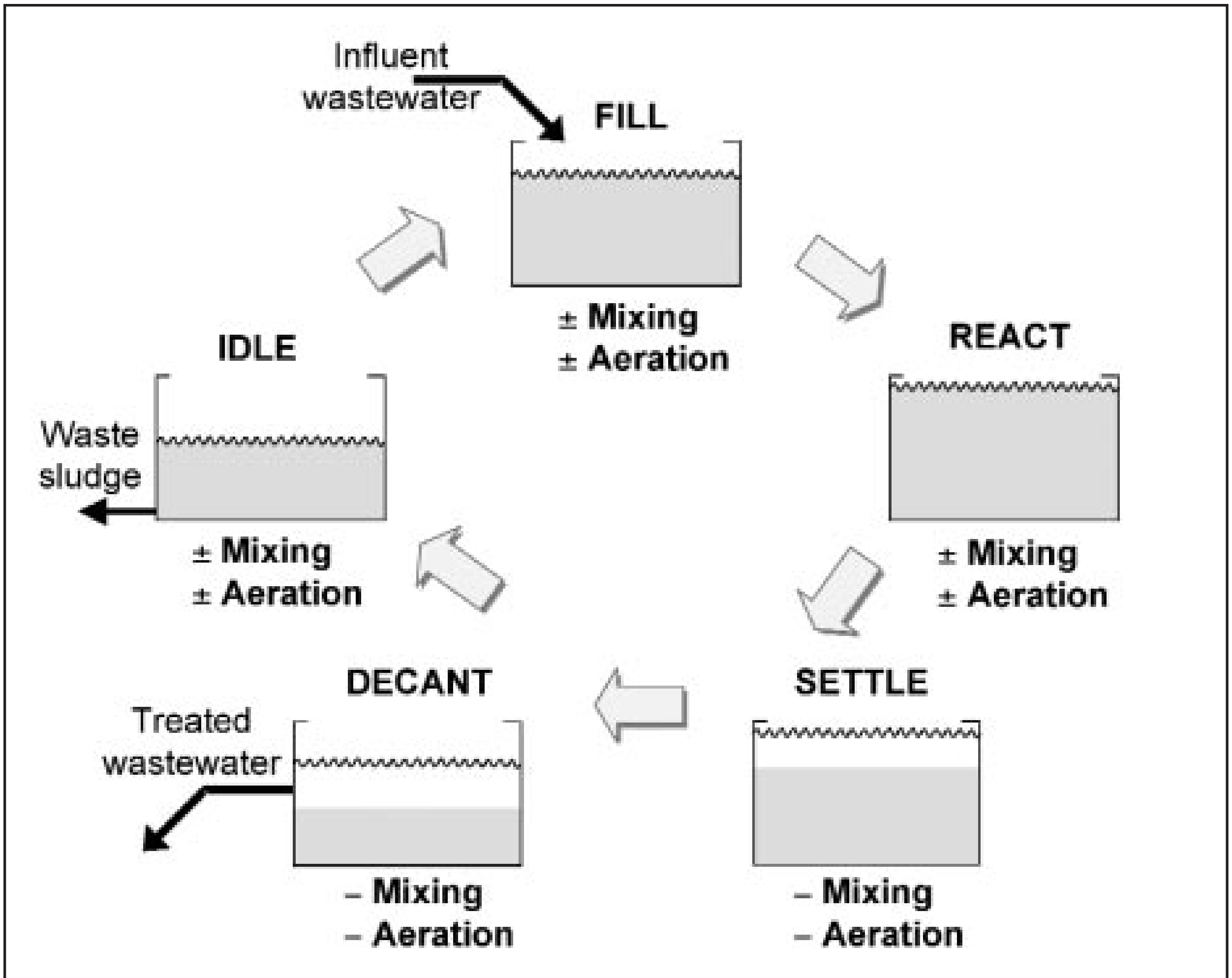
- Older wastewater treatment facilities can be retrofitted to an SBR because the basins are already present.

- 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.

1.1 Common SBR Characteristics

1.1.1 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, an SBR is no more than an activated-sludge plant that operates in time rather than space.



MAJOR PHASES OF THE SBR OPERATIONS CYCLE

Source: University of Florida TREEO Center's *Sequencing Batch Reactor Operations and Troubleshooting Manual*.

1.1.2 Basic Treatment Process

The operation of an SBR is based on a fill-and-draw principle, which consists of five steps—fill, react, settle, decant, and idle. These steps can be altered for different operational applications.

Fill

During the fill phase, the basin receives influent wastewater. The influent brings food to the microbes in the activated sludge, creating an environment for biochemical reactions to take place. Mixing and aeration can be varied during the fill phase to create the following three different scenarios:

Static Fill – Under a static-fill scenario, there is no mixing or aeration while the influent wastewater is entering the tank. Static fill is used during the initial start-up phase of a facility, at plants that do not need to nitrify or denitrify, and during low-flow periods to save power. Because the mixers and aerators remain off, this scenario has an energy-savings component.

Mixed Fill – Under a mixed-fill scenario, mechanical mixers are active, but the aerators remain off. The mixing action produces a uniform blend of influent wastewater and biomass. Because there is no aeration, an anoxic condition is present, which promotes denitrification. Anaerobic conditions can also be achieved during the mixed-fill phase. Under anaerobic conditions the biomass undergoes a release of phosphorous. This release is reabsorbed by the biomass once aerobic conditions are reestablished. This phosphorous release will not happen with anoxic conditions.

Aerated Fill – Under an aerated-fill scenario, both the aerators and the mechanical-mixing unit are activated. The contents of the basin are aerated to convert the anoxic or anaerobic zone over to an aerobic zone. No adjustments to the aerated-fill cycle are needed to reduce organics and achieve nitrification. However, to achieve denitrification, it is necessary to switch the oxygen off to promote anoxic conditions for denitrification. By switching the oxygen on and off during this phase with the blowers, oxic and anoxic conditions are created, allowing for nitrification and denitrification. Dissolved oxygen (DO) should be monitored during this phase so it does not go over 0.2 mg/L. This ensures that an anoxic condition will occur during the idle phase.

React

This phase allows for further reduction or "polishing" of wastewater parameters. During this phase, no wastewater enters the basin and the mechanical mixing and aeration units are on. Because there are no additional volume and organic loadings, the rate of organic removal increases dramatically.

Most of the carbonaceous BOD removal occurs in the react phase. Further nitrification occurs by allowing the mixing and aeration to continue—the majority of denitrification takes place in the mixed-fill phase. The phosphorus released during mixed fill, plus some additional phosphorus, is taken up during the react phase.

Settle

During this phase, activated sludge is allowed to settle under quiescent conditions—no flow enters the basin and no aeration and mixing takes place. The activated sludge tends to settle as a flocculent mass, forming a distinctive interface with the clear supernatant. The sludge mass is called the sludge blanket. This phase is a critical part of the cycle, because if the solids do not settle rapidly, some sludge can be drawn off during the subsequent decant phase and thereby degrade effluent quality.

Decant

During this phase, a decanter is used to remove the clear supernatant effluent. Once the settle phase is complete, a signal is sent to the decanter to initiate the opening of an effluent-discharge valve. There are floating and fixed-arm decanters. Floating decanters maintain the inlet orifice slightly below the water surface to minimize the removal of solids in the effluent removed during the decant phase. Floating decanters offer the operator flexibility to vary fill and draw volumes. Fixed-arm decanters are less expensive and can be designed to allow the operator to lower or raise the level of the decanter. It is optimal that the decanted volume is the same as the volume that enters the basin during the fill phase. It is also important that no surface foam or scum is decanted. The vertical distance from the decanter to the bottom of the tank should be maximized to avoid disturbing the settled biomass.

Idle

This step occurs between the decant and the fill phases. The time varies, based on the influent flow rate and the operating strategy. During this phase, a small amount of activated sludge at the bottom of the SBR basin is pumped out—a process called wasting.

1.1.3 Continuous-Flow Systems

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 overflows, washouts, poor effluent, and permit violations.

CHAPTER 2
DESIGN GUIDELINES

2.1 Preliminary/Primary Treatment

Preliminary treatment includes screening, grit removal, and flow monitoring. Primary treatment includes sedimentation and floatation. SBRs generally do not have primary settling tanks; therefore, effective removal or exclusion of grit, debris, plastics, excessive oil or grease, and scum, as well as screening of solids should be accomplished prior to the activated-sludge process.

2.1.1 Screening Influent Wastewater

Bar screens or mechanical screens should be used instead of grinders or shredders. Screening influent wastewater is a positive means of removing rags, sticks, and other debris before they can enter the treatment process. Grinders and shredders pass this material into the SBR where it can become woven together, making it difficult to remove. Removing debris from the wastewater stream before it reaches the basins is beneficial to both the treatment process and the settling phase—excess debris is not present to interfere with the solids that need to settle, resulting in a high-quality sludge blanket. Screens also provide protection for the pumps.

2.1.2 Influent-Flow Equalization

Flow equalization is critical where significant variations in flow rates and organic mass loadings are expected. Flow equalization is also important if a plant is expected to receive a significant amount of septage or is taking in a significant amount of industrial wastes. Flow equalization is strongly recommended when a plant needs to achieve nitrification and denitrification. It is important to note, however, that the size of the influent equalization basin must be carefully considered because an oversized basin can cause negative downstream-treatment-process impacts. A plant utilizing an influent equalization basin will be able to have a true batch reaction.

Influent-flow equalization benefits the SBR process in the following ways:

- Allows for a smaller SBR-basin size because it allows for storage until the process cycle is complete.

- Allows for one basin to be taken off line for maintenance or for seasonal variations. Routine maintenance is necessary for all tanks. For plants that have seasonal variations, taking one basin off line is cost-effective due to a reduced need for electricity, staff hours, and tank maintenance.

- Allows for scum and grease removal at a single point before it enters the SBR tank. Entrainment by mixing should not be the sole means of scum control. A mechanism or process for removing scum, grease, and floatables should be provided in the equalization tank.

- Allows plants that must denitrify to ensure that an adequate amount of carbon is available in the denitrification fill phase.

- Allows for an equal flow volume into the basin, keeping the food to microorganism ratio (F/M) fairly stable.

With the use of influent-flow equalization and bar or mechanical screens, the wastewater stream entering the SBR is free of grease, scum, rags, sticks, floatables, and other debris, making it easier to treat.

As stated previously, each SBR design is unique and in some situations influent-flow equalization basins may not be required to obtain optimum treatment. Examples of where influent-flow equalization is not needed include (but are not limited to) plants designed with three or more SBR basins and plants that do not need to nitrify and denitrify.

If a plant is operating with a two-basin system without influent-flow equalization, then it should have an adequate supply of essential spare parts onsite. This will allow broken components to be returned quickly to service without the need to wait for back-ordered parts.

The influent-equalization basin should have a form of agitation or mixing to keep the solids in suspension. A mechanical-mixing unit can be used for this purpose. Maintenance on this basin should be minimal as the solids are in suspension due to the agitation; however, a means to bypass the equalization basin and to dewater the basin should be provided. Pumps that direct influent to the SBRs should be in duplicate. Influent-flow equalization should be designed to hold peak flows long enough to allow the active treatment cycle to be completed.

2.1.3 Piping for Alkalinity Addition

Ideally, facilities should provide piping for adding alkalinity at both the influent-equalization basin and the SBR basin. It is also desirable to be able to measure alkalinity at each location. Alkalinity addition should be based on the amount measured during the decant phase, not on incoming flow. Alkalinity should be kept in a range of 40-70 mg/L as $CaCO_3$ prior to the decant phase to be sure the nitrification cycle is complete. Consider implementing a method of alkalinity addition even if a facility is not designed to nitrify.

Alkalinity

Alkalinity is a measure of how much acid must be added to a liquid without causing a great change in pH. Expressed another way, alkalinity is the capacity of water or wastewater to neutralize acids. This capacity is dependent on the content of carbonate, bicarbonate, and hydroxide in wastewater. Alkalinity is expressed in mg/L of equivalent calcium carbonate (mg/L $CaCO_3$). Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have high alkalinity.

When nitrification occurs at SBR facilities, it often occurs during periods of diurnal low flow (e.g., very late evening or very early morning) when a plant is not staffed. If no testing or chemical addition is available to compensate for an alkalinity drop, pH in the SBR unit will drop and cause process upsets.

2.1.3.1 Options for Adding Alkalinity

Sodium Bicarbonate, a.k.a. Baking Soda ($NaHCO_3$) - Sodium bicarbonate is most often recommended for alkalinity addition because it is not a strong base and it has a pH of 8.3. It is beneficial to alkalinity addition by providing the bicarbonate species at a pH near neutrality.

Sodium Carbonate, a.k.a. Soda Ash (Na_2CO_3) - Soda ash is safer to handle than other alkalis and tends to maintain stable prices over time, hence more and more treatment plants are choosing soda ash for their alkalinity needs. While soda ash is less expensive than sodium bicarbonate, it is generally less effective than sodium bicarbonate and sodium hydroxide. Soda ash is a moderately fast-acting agent, but it generates carbon dioxide, which can lead to foaming problems.

Calcium Oxide, a.k.a. Lime ($Ca(OH)_2$) – Lime is available in various forms and is relatively inexpensive. Lime compounds dissolve slowly and require longer contact times than the other chemical options. The use of lime causes more sludge production due to calcium sulfate precipitation. This results in maintenance problems within the basin, especially with pH, DO, and ORP probes.

2.2 Sequencing Batch Reactor

2.2.1 Basin Design

Ideally, plant designs should have a minimum of two SBR basins and one flow-equalization basin; however, every design is unique and one configuration does not fit all situations. All SBR designs should have a minimum of two basins to allow for redundancy, maintenance, high flows, and seasonal variations. Two basins allow for redundancy throughout the plant. If one basin is off line, the plant is still able to treat influent wastewater because of the equalization basin. If the basin microbiology becomes depleted in one basin, the biomass from the remaining basin can be used to restock the basin with depleted biomass. For this to happen, a means of transferring sludge between the two basins must be provided.

During storm events and high-flow periods, instead of bypassing the basins or blending the stormwater, an additional basin can act as storage, or certain cycles can be shortened. In particular, the react cycle can be shortened under wet-weather conditions because of the diluted flow and the reduced time needed to treat the BOD. With higher flows, the fill phase and the idle cycle can also be shortened. A two-basin design also allows the plant to take one basin off line for draining and cleaning while the pre-flow basin and the one on-line basin remain fully operational.

For plants that have seasonal flow variations, a design that includes two treatment basins and an influent-flow-equalization basin allows one basin to be taken off line during the off season. This is important for seasonal plants, as it can save money by cutting electricity costs and reducing staff hours (fewer hours are spent on overall basin maintenance). The basin that remains on line is able to reseed the biomass in the off-line basin when the influent flow pattern peaks.

2.2.2 Flow-Paced Batch Operation

Flow-paced batch operation is generally preferable to time-paced batch or continuous-inflow systems. Under a flow-paced batch system, a plant receives the same volumetric loading and approximately the same organic loading during every cycle. The SBR basin already has stabilized supernatant in it, which dilutes the batch of incoming influent.

Under a time-paced mode, each basin receives different volumetric and organic loading during every cycle, and the plant is not utilizing the full potential of this treatment method—the ability to handle variable waste streams. After each loading, the plant faces a whole new set of treatment conditions, making the operator's job more difficult.

Time-paced operation (if you are not adjusting the cycle time) can lead to under-treated effluent. A plant that receives heavy morning loadings, with a flow pattern that drops off after the first cycle, must deal with two different biologies in the basin unless adjustments are made to the cycle time. For example, one basin could be receiving an early morning load, which has a high organic and volumetric loading. The second basin could be receiving the afternoon loading, which has a lower organic and volumetric loading. Unless the time cycle is adjusted, it becomes difficult to operate under these conditions because the operator is essentially running two separate plants.

Another problem with time-paced operation is that if the plant is required to denitrify, it may not bring in an adequate carbon source needed for the bacteria to strip oxygen from the nitrate. This scenario would be especially problematic during periods of low flow.

For an SBR to be effective, the plant must have proper monitoring, allow operators to adjust the cycle time, and have knowledgeable operators who are properly trained to make the necessary adjustments to the cycle.

Lessons from the Field

An operator with a full understanding of the SBR process and operations can overcome design limitations. For example, an operator at a plant operating under time-paced configuration was able to overcome operational restrictions by reprogramming the programmable logic controller (PLC) so that the decant phase would not be initiated until the high-water level (HWL) was reached. If the basin did not reach the HWL during the cycle it would not decant and would take in the next load until the HWL was reached. It would then complete the cycle and decant. This is not a recommended mode of operation, but it demonstrates how skilled operators with thorough knowledge of how their plant operates can make adjustments to benefit the process. Operators need the flexibility to fully control and operate their plant, since they are the ones who are responsible for it.

2.2.3 Blower Design

Several smaller blowers are preferable to one large unit. It is not uncommon for SBR designs to incorporate a single blower per basin to provide aeration. However, operational efficiency can be enhanced when plants utilize several smaller blowers, instead of one large blower.

When a single blower per basin is used, it should be sized to provide maximum aeration under worst-case conditions. These conditions typically occur in the summer months, when higher temperatures decrease the amount of oxygen that can be dissolved in wastewater. For facilities that utilize a single blower per basin, a variable frequency drive should be considered.

> **Variable Frequency Drives – VFDs**
>
> In wastewater facilities, pumping and aeration account for a majority of energy consumption. These applications are well suited to the use of VFDs. A VFD is an electronic controller that adjusts the speed of an electric motor by varying the amount of power supplied. A VFD varies both the frequency (hertz) and amplitude (volts) of the alternating current waveform. This allows the motor to continually adjust in order to work just hard enough, rather than running full speed all the time. Wastewater facilities that have installed VFDs have seen a 25 percent reduction in energy costs for pumping and aeration, as well as increased equipment life and decreased maintenance costs.

In a plant configured with only one blower per basin, it is difficult to scale back on the aeration provided. With multiple smaller blowers, units can be taken off line when maximum aeration is not required. This results in electrical cost savings.

Fine-bubble membrane diffusers are preferable to coarse-air bubble aeration. Fine-bubble diffusers transfer more oxygen to the water due to increased surface area in contact with water. The same amount of air introduced in a big bubble has less surface area in contact with water than an equal amount of air divided into smaller bubbles. The amount of surface area in contact with water is proportional to the amount of oxygen transferred into water. Depth of aerators also plays a part in oxygen transfer, due to contact time. The deeper the aerator, the longer it takes for the bubble to come to the surface. Aerator depth is deepest when a tank is filled to the high-water level. If a plant is utilizing time-paced batch reactions, aerator depth is not optimal and oxygen contact time is not maximized.

Blowers in multiple units should be sized to meet the maximum total air demand with the single largest blower out of service.

2.2.4 Decanting

During the decant phase, operating under a flow-paced batch operation, no more than one-third of the volume contained in the basin (i.e., the tank contents) should be decanted each time in order to prevent disturbance of the sludge blanket. The decant phase should not interfere with the settled sludge, and decanters should avoid vortexing and taking in floatables. The problem with decanting more than one-third is that it increases the chance that solids will be decanted into the effluent, thereby impairing the effluent quality. For the plant to run optimally, it is important that the decant volume is the same as the volume added during the fill phase. The length of the decant weir can have an impact that is very similar to that of the over-flow weir found in a clarifier. The flux (upward forces) caused by the discharge of the decant creates an upward force that may pull poorly settled solids up and out the discharge.

2.2.5 Bottom Slope

All basins should have a sloped bottom with a drain and sump for routine tank maintenance and ease of cleaning. Slope rectangular basins slightly to one corner to allow for hosing down the unit. Circular basins should be sloped toward the middle for maintenance. All SBR designs should include a means for completely emptying each SBR unit of all grit, debris, liquid, and sludge.

Lessons from the Field

Tank maintenance is an intensive process and can use up valuable maintenance hours. In one situation, a 0.75 million gallon, flat-bottomed, rectangular basin took close to 24 man-hours to dewater and clean. By slightly sloping the floor to one corner, this process would have been much less labor intensive and would have saved significant maintenance time.

2.3 Post Basin

2.3.1 Post-Basin Effluent Equalization

Post-basin effluent equalization smoothes out flow variations prior to downstream processes, such as disinfection. By providing storage and a constant smooth flow, the disinfection process will be more effective. If post-flow equalization is not utilized, the effluent might not receive the designed amount of treatment. Post-basin effluent equalization also allows downstream processes to be sized smaller, since the flow from the basin is metered out and does not hydraulically surge the downstream processes.

Effluent equalization also ensures that there are not large variations in operating ranges for the metering pumps and the chlorine analyzers. Ideally, the basin should be of sufficient size to hold a minimum of two decantable volumes. There should be a means of returning the liquid from the post-flow equalization basin to the headworks if a poor decant occurs. These basins should also have a means of removing solids from the bottom of the unit, such as a sloped bottom with a drain or sump.

Chapter 3

Operational Suggestions

3.1 Parameters to Be Monitored by the SCADA System

Oxidation reduction potential (ORP), dissolved oxygen (DO), pH, and alkalinity are parameters that should be monitored by the Supervisory Control and Data Acquisition (SCADA) system. Manufacturers determine what parameters can be monitored and controlled by the SCADA system. Monitoring of certain parameters is important, and the ability to adjust these parameters from a remote location is ideal. The operator needs to be able to add chemicals to raise the alkalinity and subsequently the pH. The set point should be an alkalinity value rather than pH-based. The operator should have the ability to fully control (i.e., modify) the plant-operating parameters, such as (but not limited to) cycle times, volumes, and set points.

> SCADA is a computer-monitored alarm, response, control, and data acquisition system used by operators to monitor and adjust treatment processes and facilities.

Alkalinity monitoring and addition ensures that a pH of less than 7.0 does not occur. Nitrification consumes alkalinity, and with a drop in alkalinity, pH also drops. If a plant has adequate alkalinity, pH does not change, so it does not need to be raised. Chemicals that raise alkalinity, such as sodium bicarbonate and soda ash, are recommended over sodium hydroxide. Sodium hydroxide does not raise alkalinity; it does raise pH. See section 2.1.3.1 for a discussion of the pros and cons of various chemicals used to increase alkalinity.

> The management of both pH and alkalinity are critical to the effective operation of an SBR. Sufficient alkalinity must be present to allow complete nitrification and result in a residual of at least 50 mg/L in the decanted effluent. The pH must be maintained in a manner to prevent it from falling below 7.0 in the reactor basin. Based on the characteristics of the wastewater, designers should carefully consider the need for both alkalinity and pH management.

For plants that nitrify and denitrify, ORP monitoring is desirable. ORP is the measure of the oxidizing or reducing capacity of a liquid. DO varies with depth and location within the basin. ORP can be used to determine if a chemical reaction is complete and to monitor or control a process.

Operators need the ability to make changes that will modify these readings to achieve appropriate nutrient removal. ORP readings have a range and are site specific for each facility. General ranges are: carbonaceous BOD (+50 to +250), nitrification (+100 to +300), and denitrification (+50 to -50).

On-line dissolved oxygen meters are very useful in SBR operation. They allow operators to adjust blower times to address the variable organic loads that enter the plant. Lack of organic strength reduces the react time during which aeration is needed to stabilize the wastewater. DO probes can be used to control the aeration-blower run time during the cycle, which in turn reduces the energy cost of aeration.

Oxidation Reduction Potential – ORP

ORP measures the electrical potential required to transfer electrons from one compound or element to another compound or element. ORP is measured in millivolts, with negative values indicating a tendency to reduce compounds or elements and positive values indicating a tendency to oxidize compounds or elements.

It is desirable to locate DO, pH, and/or ORP probes in a place that can be reached easily by operators. These probes often clog or foul and need cleaning and calibration. If they are not easily accessible, proper maintenance may not occur.

The plant operator should have the knowledge and the ability to program the SCADA system to increase or decrease blower speed. Allowing the operator to adjust the blower speed, through the SCADA system, gives the operator much more control over the DO in the SBR.

3.2 Cold-Climate Adjustments

In general, sewage temperatures are above freezing, but the batch mode of operation exposes the SBR basin to cold winter temperatures. The long, cold ambient air temperature in winter cools the content of a basin below the optimal temperature of 20-25 ºC, which is the ideal temperature for advanced treatment to occur.

SBRs in the northeastern United States should respond appropriately against extreme cold temperatures. Where practical, basins for small or very small systems or facilities should be housed in a garage-type structure to ensure that there is no freezing. Larger basins can also be covered to minimize heat loss; however, when covering basins, ensure that adequate access for maintenance is provided. Consider maximum use of earthen-bank insulation. Exposed piping should be wrapped in heat tape and insulated to protect from freezing. Consider implementing provisions to minimize the freezing of discharge pipes, decanter valves, and chemical lines. Provisions should be considered to minimize ice buildup on decanters. Controllers should be placed in dry areas that are not exposed to extreme temperatures.

The smaller the design of a plant, in terms of flow, the more problematic temperature becomes. The smaller the design flow, the greater the likelihood that between 11:00 PM and 6:00 AM there will be little or no flow. This contributes to a loss of heat from the SBR basins to the surrounding atmosphere. Plants that have flow throughout this time frame lose less heat, because the incoming flow sustains higher temperatures.

3.3 Sampling

3.3.1 Proper Sampling Points

As with all wastewater treatment plants, SBR samples are collected and analyzed for both process control and compliance reporting. Sampling locations must be carefully considered. SBRs that utilize influent-equalization basins have more representative flow-paced composite samples because the discharge is consistent in volume. In other words, flow equalization and true batch reactions allow for easier composite sampling because the same volume is entering and exiting the basin during each cycle.

Twenty-four-hour effluent composite samples should be flow-paced and include samples collected at the beginning and end of each decant event.

3.3.2 Parameters to Monitor

Numerous parameters can be monitored for process control. Testing and monitoring of process control parameters requires planning and organization so that variances from the targeted performance goals are easily recognized. A list of typical process control parameters is provided in Appendix A.

3.4 Solids Retention Time – SRT

Solids retention time is the ratio of the mass of solids in the aeration basin divided by the solids exiting the activated sludge system per day. Exiting solids are equal to the mass of solids wasted from the system plus the mass of solids in the plant effluent.

Ensuring an adequate SRT is very critical to the SBR biological nutrient-removal design process. The design SRT for nitrifying systems should be based on the aeration time during the cycle, not the entire cycle time.

3.5 Sludge Wasting

Sludge wasting should occur during the idle cycle to provide the highest concentration of mixed-liquor suspended solids (MLSS). The plant should be operated on pounds of MLSS and not concentration.

Sludge from the SBR basins can be wasted to a digester and/or holding tank for future processing and disposal. The digester-tank and sludge-holding-tank capacity should be sized appropriately, based on the sludge treatment and disposal method.

Supernatant from the sludge digester and/or holding tank should be returned to the headworks or influent equalization basin so that it will receive full treatment. The facility should be designed so that the supernatant volume and load do not adversely affect the treatment process.

A high-level alarm and interlock should be provided to prevent sludge-waste pumps from operating during high-level conditions in the digester and/or holding tanks.

Controls should be provided to prevent overflow of sludge from digester tanks and/or holding tanks.

3.6 Troubleshooting

A number of troubleshooting tips are contained in Appendix B.

Chapter 4

Other Suggestions

4.1 On-Site Manufacturer Training

A complete and comprehensive SBR operation and maintenance manual should be provided for these treatment facilities. Formal training specific to SBR functions and operations is essential.

Adequate on-site manufacturer's training (specific to the SBR) should be provided for operators. Details of the training program should be provided in the engineer's design report and the operation and maintenance manual. A facility design engineer should be retained to provide technical assistance and modify the SBR operation and maintenance manual and/or plant controls, as needed, during the first year of operation or until consistent compliance is achieved.

4.2 Wet/Cold-Weather Operating Plans

Communities that have combined collection systems or that are subject to sanitary-sewer overflows during wet weather should consider developing wet-weather operating plans or standard operating procedures (SOPs). A wet-weather operating plan or SOP also benefits facilities subject to process upset during wet-weather periods. This plan provides operators with a guide to minimize the discharge of pollutants during wet weather and protect their facility from upset.

These plans or SOPs typically focus on determining performance during wet weather as compared to dry weather, determining a facility's capability to operate at incremental increases in wet-weather flow, and assessing whether unused facilities at the plant can be used to store or treat wet-weather flows. Also, by keeping accurate records, correlations can be developed between weather events and flows, which is helpful in predicting the impacts of storm events and preparing for expected weather conditions.

Snow melt, rain, and infiltration and inflow (I&I) can drastically affect the way an SBR functions from a microbial standpoint. Influent oxygen levels as high as 5 mg/L, diluted BOD, and cold sewerage temps are all long-term spring occurrences and need to be given serious consideration during the SBR design process. The function of the SBR for nutrient removal requires control over the oxygen level during the various SBR phases. Loss of this control due to long periods of I&I can limit the effectiveness of the nutrient-removal process.

Likewise, a facility may want to develop cold-weather operating plans or SOPs to mitigate treatment impacts during winter months.

References

AquaSBR Design Manual. Mikkelson, K.A. of Aqua-Aerobic Systems. 1995.

Wastewater Technology Fact Sheet: Sequencing Batch Reactors. U.S. Environmental Protection Agency. Washington, D.C., 1999. EPA 832-F-99-073.

Sequencing Batch Reactors for Nitrification and Nutrient Removal. U.S. Environmental Protection Agency. Washington, D.C., September 1992.

Sequencing Batch Reactor Operations and Troubleshooting. University of Florida, TREEO Center. 2000.

A Regulatory Guide to Sequencing Batch Reactors. Kirschenman, Terry L. and Hameed, Shahid. Iowa Department of Natural Resources. 2000.

SBR Design Criteria (Draft). Pennsylvania Department of Environmental Protection. 2003.

TR-16 Guides for the Design of Wastewater Treatment Works. New England Interstate Water Pollution Control Commission. 1998.

Recommended Standards for Wastewater Facilities. Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers. 2004.

Operation of Wastewater Treatment Plants, Volume 1, Fifth Edition. California State University, Sacramento, College of Engineering and Computer Science Office of Water Programs. 2002.

Operation of Wastewater Treatment Plants, Volume 2, Sixth Edition. California State University, Sacramento, College of Engineering and Computer Science Office of Water Programs. 2003.

Small Wastewater System Operation and Maintenance, Volume 1, First Edition. California State University, Sacramento, Office of Water Programs. 1997.

Small Wastewater System Operation and Maintenance, Volume 2, First Edition. California State University, Sacramento, Office of Water Programs. 2002.

Design Criteria for Sewerage Systems. Texas Natural Resources Conservation Commission. Chapter 217/317, Rule Log No. 95100-317-WT. 1994.

Design and Retrofit of Wastewater Treatment Plants for Biological Nutrient Removal, Volume 5. Randall, Clifford, Barnard, James and Stensel, H. David. Water Quality Management Library. 1992.

APPENDIX A

PROCESS CONTROL TESTS AND CALCULATIONS

The following Process Control Tests and Calculations chart (page 19) was obtained, with permission, from the University of Florida TREEO Center's *Sequencing Batch Reactor Operations and Troubleshooting Manual.*

Acronyms Used:

COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
TOC	Total Organic Carbon
MLSS	Mixed-Liquor Suspended Solids
MLVSS	Mixed-Liquor Volatile Suspended Solids
MCRT	Mean Cell Residence Time
WAS	Waste-Activated Sludge
F/M	Food-to-Microorganism Ratio
SSV	Settled-Sludge Volume
TSS	Total Suspended Solids
VSS	Volatile Suspended Solids
DOB	Depth of Blanket
SVI	Sludge Volume Index
NO_3-N	Nitrate-Nitrogen
NO_2-N	Nitrite-Nitrogen
NH_3-N	Ammonia-Nitrogen
PO_4-P	Phosphate-Phosphorus
OUR	Oxygen-Uptake Rate
SOUR	Specific Oxygen-Uptake Rate
ORP	Oxidation Reduction Potential
mg/L	milligram per liter

PROCESS CONTROL TESTS AND PROCESS CALCULATIONS				
	DATA REQUIRED/ ANALYSIS			UNIT
ORGANIC LOADING				
COD	Colorimetric analysis			mg/L
BOD, CBOD	Bioassay			mg/L
TOC	Colorimetric analysis			mg/L
SOLIDS INVENTORY				
MLSS	Gravimetric analysis			mg/L
MLVSS	Gravimetric analysis			mg/L
Centrifuge Spin	Volumetric analysis			%
SOLIDS INVENTORY CALCULATIONS				
MCRT	MLSS	WAS TSS	WAS Flow	days
Sludge Age	AT%	CL%	WAS%	days
F/M	MLVSS	#BOD/COD/day		#BOD/day/#MLVSS
SLUDGE QUALITY				
SSV_X	Physical analysis			ml/L or %
SSV_5	Physical analysis			
Supernatant TSS or Turbidity	Gravimetric or scattered light			mg/L or NTU
DOB	Physical measurement			ft
Microscopic Analysis	Visual analysis			N/A
SLUDGE QUALITY CALCULATIONS				
SVI	SSV_{30}	MLSS		ml/g
NUTRIENTS				
NO_3-N, NO_2-N	Colorimetric or electrometric analysis			mg/L
NH_3-N	Colorimetric or electrometric analysis			mg/L
PO_4-P	Colorimetric analysis			mg/L
TROUBLESHOOTING ANALYSES				
OUR	Analysis			mg O_2/L/hr
SOUR	OUR	MLVSS		mg O_2/g/hr
pH	Electrometric analysis			SU
ORP	Electrometric analysis			mV
Alkalinity	Titrimetric analysis			mg/L

APPENDIX B
SEQUENCING BATCH REACTOR TROUBLESHOOTING CHART

The following Sequencing Batch Reactor Troubleshooting Chart (pages 21–23) was adapted from the University of Florida TREEO Center's *Sequencing Batch Reactor Operations and Troubleshooting Manual.*

Sequencing Batch Reactor Troubleshooting Chart

PROBLEM OR OBSERVATION	CONDITION	PROCESS CONTROL ANALYSIS	POSSIBLE CAUSES	CONTROL ACTION
I. Loss of solids from reactor due to a high blanket	Poor sludge settling velocity and compaction	SSV_X, SSV_5, SVI, diluted SSV_X, microscopic examination, NH_3 - N, COD, D.O., SOUR	• Glutting (old sludge)	• Decrease MCRT.
			• Classic bulking (young sludge)	• Increase MCRT.
			• Filamentous bulking	• Identify conditions contributing to filamentous growth and correct. See comments in narrative below.
			• Slime bulking	• Add nutrients.
			• Foam Trapping	• Optimize pretreatment removal of oil and grease.
			• Highly nitrified or oxidized sludge	• Increase anoxic cycle, reduce aerobic cycle.
			• Toxicity	• Isolate or split flow, identify source of toxic influent and eliminate, increase aeration cycle, increase MCRT.
			• High organic loading	• Short-term, increase aerobic cycle; long-term, increase MCRT.
II. Rapidly settling blanket leaving particulate. Difficulty in maintaining waste concentration	Rapid sludge settling velocity and compaction	SSV_X, SSV_5, SVI, F/M, SOUR	• Low F/M ratio	• Increase F/M ratio by decreasing MLVSS.
III. Turbid or cloudy effluent, disinfection problems	**A.** High effluent BOD or TS	MLSS, MLVSS, D.O., pH, temperature, Influent COD or TOC, Influent NH_3 –N, D.O., SOUR	• Low MLSS or MLVSS	• Increase MLSS/MLVSS.
			• Low D.O., temperature or pH	• Increase aeration cycle in fill react, increase MLSS, add alkalinity.
			• High organic loading	• If long-term, increase MLSS/MLVSS and aeration cycle.
			• High nitrogenous loading	• If long-term, increase MLSS/MLVSS and aeration cycle.
			• Toxicity	• Isolate or split flow, identify source of toxic influent and eliminate, increase aeration cycle, increase MCRT.
	B. High effluent NH_3 – N (Incomplete nitrification)	Influent and process NH_3 – N, influent and process alkalinity, pH, temperature, SOUR, D.O.	• Influent NH_3-N overload	• Increase aerobic cycle.
			• Low D.O.	• Increase aerobic cycle.
			• Low temperature	• Increase aerobic cycle.
			• Inadequate aerobic retention time	• Increase aerobic cycle.
			• Low pH or alkalinity	• Add alkalinity.
			• Low MLVSS (nitrifiers)	• Increase MLVSS.
			• Toxicity	• Isolate or split flow, identify source of toxic influent and eliminate, increase aeration cycle, increase MCRT.

Source: University of Florida TREEO Center's *Sequencing Batch Reactor Operations and Troubleshooting Manual.*

Sequencing Batch Reactor Troubleshooting Chart (continued)

PROBLEM OR OBSERVATION	CONDITION	PROCESS CONTROL ANALYSIS	POSSIBLE CAUSES	CONTROL ACTION
IV. High-effluent TSS	Individual particle washout	Effluent and recycle TSS or turbidity, F/M, microscopic exam, SOUR	• Pin floc – low F/M,	• Increase waste cycle, decrease MLSS.
			• Pin floc – denitrification	• Increase waste cycle, decease MLSS, increase anoxic cycle.
			• Pin floc – solids recycle	• Optimize solids handling.
			• Straggler floc – high F/M	• Decrease waste cycle, increase MLSS, increase aeration cycle.
			• Straggler floc – filamentous	• Identify filamentous organism (see filamentous control above).
			• Straggler floc – hydraulic	• See mechanical troubleshooting section.
			• Individual bacterial cells in effluent	• Decrease waste cycle, raise MLSS, increase aeration cycle, if toxicity, remove source of toxic influent.
V. High-effluent NO_3 - N	High effluent NO_3 – N	NO_3 – N, pH, TOC or COD	• Lack of or inadequate anoxic conditions	• Increase anoxic cycle (may require decreasing oxic cycle).
			• Lack of or inadequate carbon source	• Add carbon (methanol or acetic acid).
			• Low pH, temperature or MCRT	• Add alkalinity, increase MCRT.
VI. Difficulty in maintaining chlorine residual	Chlorine (Cl_2)residual fluctuation, no chlorine residual	Cl_2 residual, supernatant NH_3-N., NO_2-N, turbidity or TSS	• Incomplete nitrification/denitrification resulting in high NO_2-N in supernatant.	• High NO_2-N in supernatant will result in increased demand. Optimize nitrification and denitrification processes.
			• High TSS in supernatant	• High TSS in supernatant will result in increased demand. See Problems I, III, IV.
			• Reducing agents in supernatant	• Reducing agents such as H_2S, Fe, Mn in supernatant. Investigate source and eliminate. Increase chlorine feed rate to overcome demand.
VII. High fecal coliform values	Sufficient chlorine (Cl_2)residual, but high fecal coliform values	Supernatant TSS, free and total Cl_2 residual, supernatant NH_3-N, theoretical and actual CCC detention time	• Excessive TSS in supernatant	• High TSS in supernatant can result in “blinding” of disinfection process. See Problems I, III, IV.
			• Short circuiting of chlorine contact chamber (CCC)	• Calculate the theoretical CCC detention time. Conduct dye testing to determine actual detention time.
			• Chloro-organic compounds	• If there is no NH_3-N in effluent but organic nitrogen is present, then false residual (DPD)may be present due to formation of chloro-organic compounds. Use free chlorine to establish residual not total chlorine. Reduce aeration cycle to de-optimize nitrification rate.

Source: University of Florida TREEO Center's *Sequencing Batch Reactor Operations and Troubleshooting Manual.*

SEQUENCING BATCH REACTOR TROUBLESHOOTING CHART (CONTINUED)

PROBLEM OR OBSERVATION	CONDITION	PROCESS CONTROL ANALYSIS	POSSIBLE CAUSES	CONTROL ACTION
VIII. Foam	Excessive foam or scum on surface of SBR, flow EQ tank or chlorine contact chamber	Microbiological examination, NO_3-N, C-N-P ratio, SRT, oils and grease, D.O.	• Excessive filamentous bacteria.	• The presence of hydrophobic filamentous bacteria may lead to excessive scum and foam. See section I.5.
			• Denitrification	• Denitrification can result in sludge and foam on surface of SBR.
			• Nutrient deficiency	• Foam may also indicate a possible nutrient deficiency. This type of foam may be due to bacteria producing a natural polymer when subjected to nutrient deficient conditions for an excessive period of time.
			• SRT	• Both too low and too high an SRT can cause foam problems.
			• Fats, oil or grease	• Fats, oils grease and other non-degraded surface active organics can cause foam problems.
			• Overaeration	• Excessive (D.O. > 4.0 mg/L) may cause foaming.

Source: University of Florida TREEO Center's *Sequencing Batch Reactor Operations and Troubleshooting Manual*.

We Value Your Feedback

Please notify us if you discover mistakes or omissions in this document. Submissions can be sent electronically, mailed, or faxed to:

New England Interstate Water Pollution Control Commission
ATTN: SBR Guide
116 John Street
Lowell, MA 01852
Tel: 978/323-7929
Fax: 978/323-7919
mail@neiwpcc.org

Brief description of error or omission:

____

____

____

____

Suggested improvement:

____

____

____

____

General comments:

____

____

____

____

Can we contact you for additional information? If so please provide contact information:

____

____

____

Thank You.