Part I

Overview

1

Introduction

The sequencing batch reactor (SBR; see Figure 1.1) is a suspended-growth, wastewater treatment process. It is a modification of the activated sludge process (Figure 1.2) and may be described as simply a holding tank for receiving a batch of wastewater for treatment. Once the batch is treated, a portion of the batch is discharged and another batch of wastewater is collected, treated, and discharged and another batch may then be sequentially collected, treated, and discharged. There are two classifications of SBR: the intermittent flow or "true batch reactor" (Figure 1.3) and the continuous flow (Figure 1.4). The intermittent flow SBR may be operated as a single-feed or a multiple-feed reactor (Figure 1.5).

The intermittent-flow SBR accepts wastewater or influent only at specified intervals and uses time sequences or five phases over a cycle (Figure 1.6) to perform numerous treatment operations that the conventional, activated sludge process performs in numerous tanks. There are usually two reactors in parallel. Because one reactor is closed to influent during the treatment of a batch of wastewater, two reactors may be operated in parallel with one reactor receiving influent while the other reactor operates through its cycle of phases. The cycle of the SBR can be designed or modified to (1) vary operational strategy to provide for aerobic, anoxic, and anaerobic/fermentative conditions and proliferation of desirable bacteria and (2) enhance the removal of ammonia, nitrogen, and phosphorus.

Modifications or changes in phases permit the SBR to treat fluctuating quantities and compositions of wastewater while maintaining a high-quality effluent or decant. The intermittent-flow SBR may be filled once with wastewater to its normal operating level, and the wastewater then is treated through all phases of a cycle. The intermittent-flow SBR may also be filled several small batches of wastewater until the normal operating level is reached. However, after each small batch is placed in the SBR, the batch is treated or aerated before the next small batch is placed in the

Troubleshooting the Sequencing Batch Reactor, by Michael H. Gerardi

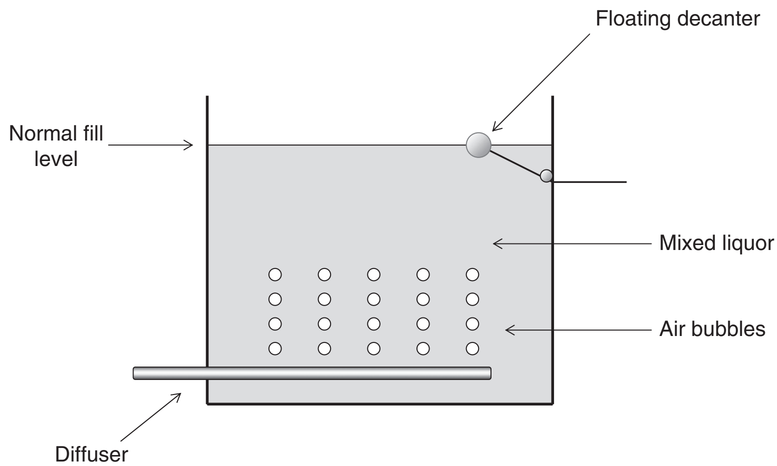

Figure 1.1 *Sequencing batch reactor. The typical sequencing batch reactor consists of a rectangular or square basin. Aeration and mixing is provided with fine air diffusers. After completion of a Fill Phase, a React Phase, and a Settle Phase, the supernatant or decant is removed during the Decant Phase with a floating decanter. In the sequencing batch reactor, one basin serves as the aeration tank for a period of time and then serves as the sedimentation basin or clarifier for a period of time.*

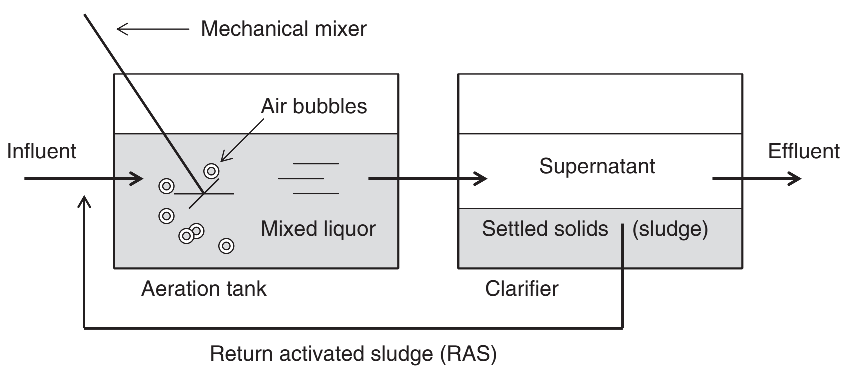

Figure 1.2 *Conventional, activated sludge process. The conventional, activated sludge process consists of at least one upstream tank, the aeration tank, and at least one downstream tank, the sedimentation basin or clarifier. Although the clarifier provides for the separation and settling of solids from the suspending medium, it differs greatly from the sequencing batch reactor, because a continuous flow of wastewater enters the clarifier and a return pump is required to remove the settled solids from the clarifier and return them (return activated sludge or RAS) to the aeration tank. In the aeration tank, aeration may be provided by coarse or fine air mechanism systems, and mixing may be provided through aeration or with a mechanical mixer.*

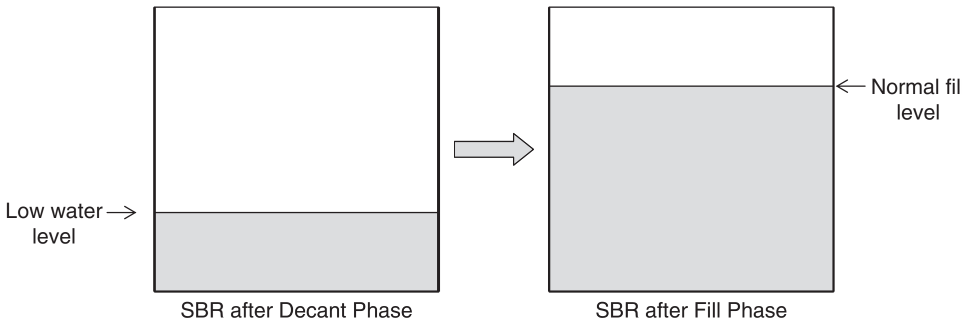

Figure 1.3 *SBR, intermittent flow. Typically, the intermittent flow or "true batch reactor" is filled once with wastewater to its normal fill level, and the wastewater is then treated. After filling the reactor to its normal fill level, no additional wastewater is added to the sequencing batch reactor until all phases have been completed and sufficient decant has been removed to permit the discharge of another batch of wastewater to the reactor.*

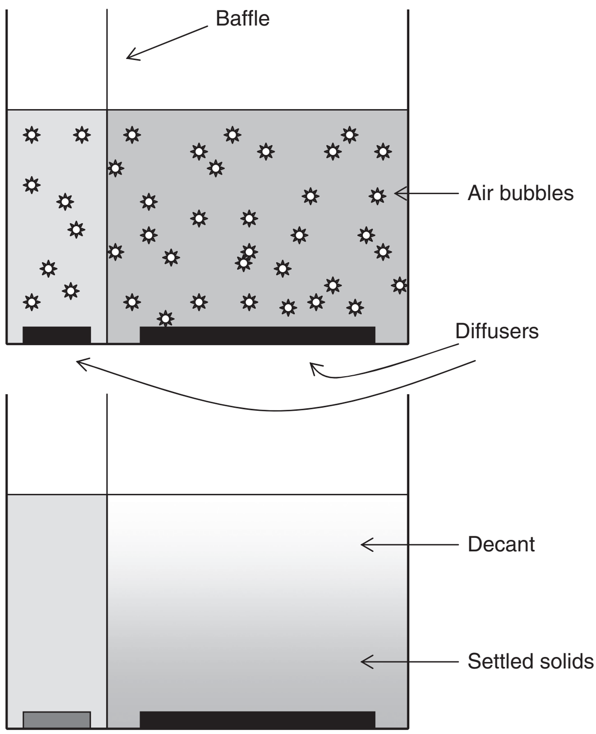

Figure 1.4 *SBR, continuous flow. In the continuous-flow, sequencing batch reactor, influent always enters the reactor. There are two chambers in the reactor that are divided by a baffle. The smaller chamber receives the influent, and from here the influent slowly moves into the larger chamber. The larger chamber acts as the sequencing batch reactor. However, the sequencing batch reactor only has a limited number of phases: React, Settle, and Decant.*

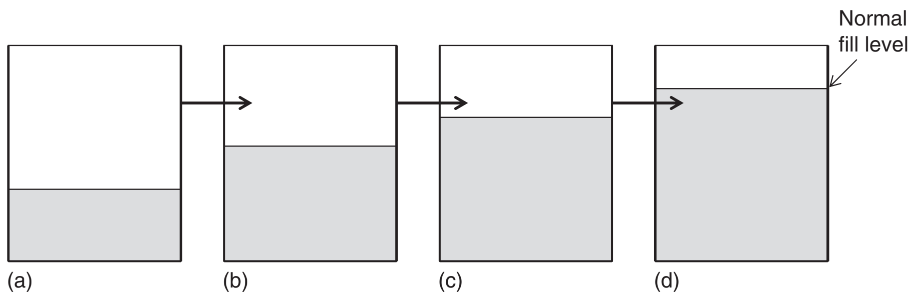

Figure 1.5 *SBR, multiple flow. In the multiple-feed, sequencing batch reactor, there are several fill periods before the normal fill level is reached. After the Decant Phase the sequencing batch reactor is at its normal low water level (**a**) and the first batch of wastewater is discharged to the sequencing batch reactor (**b**). After this batch of wastewater is received, the sequencing batch reactor then enters a React Phase. After the React Phase a second batch of wastewater is discharged to the sequencing batch reactor (**c**) and the React Phase is repeated. Again, an additional batch of wastewater is discharged to the sequencing batch reactor (**d**), and the React Phase is repeated once more. This process of multiple feeds is continued until the sequencing batch reactor is at its normal fill level. From this level the sequencing batch reactor would enter another React Phase, then Settle Phase, and finally Decant Phase.*

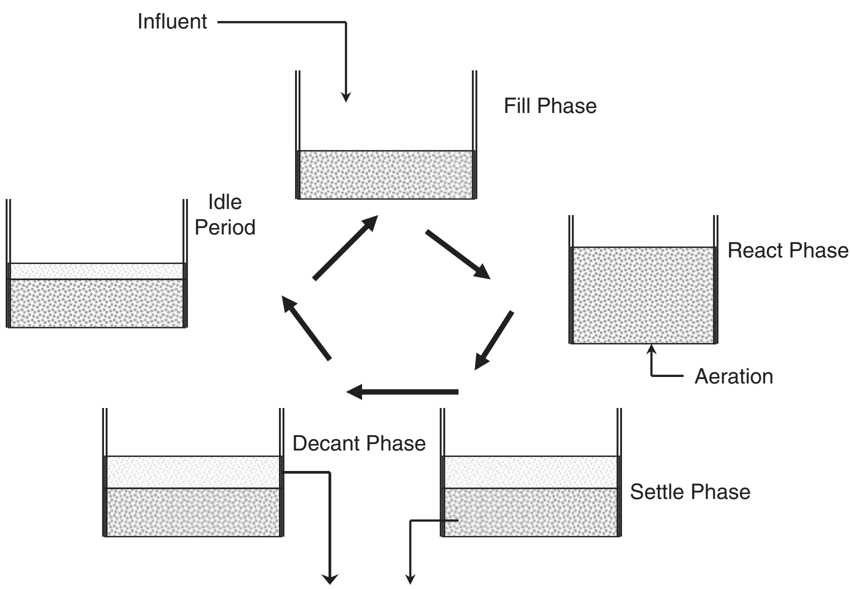

Figure 1.6 *Five phases of an SBR. There are five phases of an SBR. These phases consist of the Fill Phase, the React Phase, the Settle Phase, the Decant Phase, and the Idle Phase or Idle Period. During the Fill Phase, influent is discharged to the SBR. The Fill Phase may consist of an Aerated Fill, Mix Fill, and/or Static Fill. Once the normal fill level is reached, the SBR enters the React Phase or aerated period of the cycle. After aeration, the SBR enters the Settle Phase, where a quiescent condition is established (no aeration and no mixing) and solids settle in the reactor to produce a high-quality supernatant or decant. After the Settle Phase, supernatant or decant is removed during the Decant Phase. Wasting of solids may be performed during the React Phase, the Settle Phase, or the Decant Phase. If time permits before the start of the next Fill Phase, the SBR may be "parked" or placed in an Idle Phase or, more appropriately, Idle Period.*

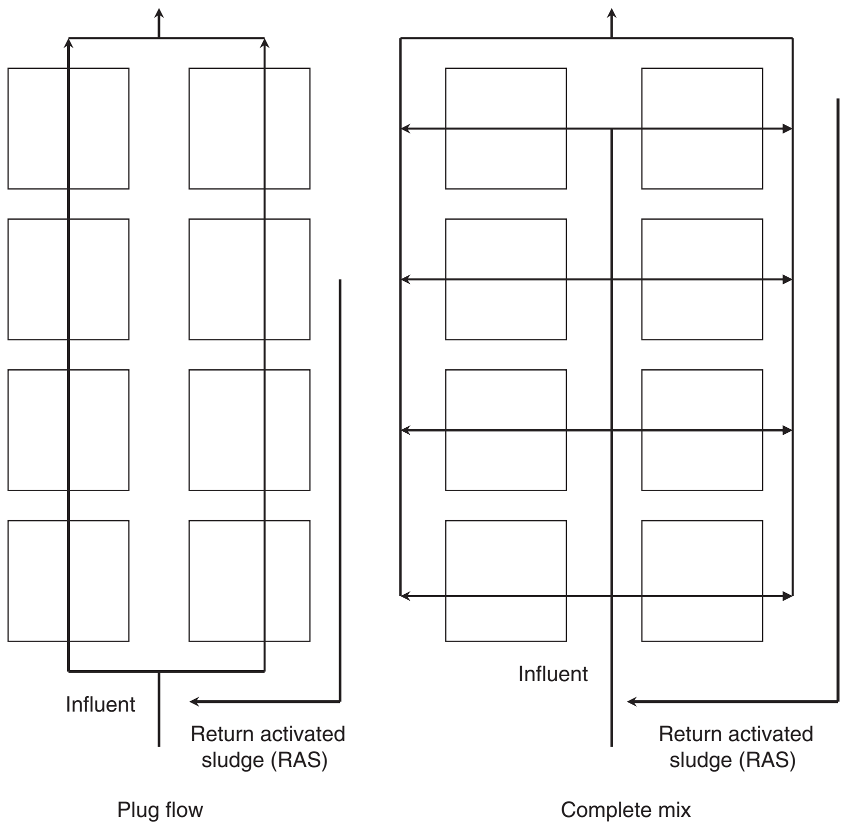

Figure 1.7 *Modes of operation of the conventional, activated sludge process. Although there are several modes of operation of the conventional, activated sludge process, two of the more commonly used modes are (1) plug flow and (2) complete mix. In the plug flow mode of operation, influent wastewater is mixed with return activated sludge (RAS) and then discharge in "train-like" fashion through a series of aeration tanks. Plug flow mode of operation established a nutrient gradient and substrate (food) gradient throughout all tanks that are in-line. In the complete mix mode of operation, influent wastewater is mixed with return activated sludge (RAS) and then discharged equally through all aeration tanks in-line. In the complete mix mode of operation, substrate and toxic components are diluted in each aeration tank.*

SBR. This mode of operation is referred to as multiple or step feed and is used to treat wastewater having high-strength BOD.

In the continuous-flow SBR, influent flows continuously during all phases of the cycle. To reduce short-circuiting of pollutants, a partition or baffle typically is added to the SBR to separate the turbulent aeration zone from the quiescent zone.

SBR operate on a fill-and-draw (batch feed and batch draw or decant) method for the treatment of wastewater. The fill-and-draw method was developed in the early 1900s in the United Kingdom, has been widely used in the United States, Canada, and Europe since the 1920s and has undergone much improvement since the 1950s. However, due to the high degree of operator attention and automation required by SBR as well as the clogging of aeration diffusers when aeration blowers shut off for the periodic settling of solids, the "conventional," activated sludge process was favored over the SBR. Although the conventional, activated sludge process can be operated in several different modes (Figure 1.7), the SBR

TABLE 1.1 Comparison of SBR and Conventional, Activated Sludge Process

	Treatment Process	
Parameter	Sequencing Batch Reactor	Conventional, Activated Sludge Process
Influent	Periodic feed	Continuous feed
Discharge	Periodic discharge	Continuous discharge
Organic loading	Cyclic	Continuous
Aeration	Intermittent	Continuous
Mixed liquor	Reactor only	Aeration tank and clarifier; Recycled from tank to clarifier
Clarification	Ideal, no influent flow	Nonideal, influent flow from aeration tank
Flow pattern	Plug-flow	Complete mix, approaching plug-flow or other
Equalization of flow	Yes	No
Flexibility	Adjustment of aerobic, anoxic, and anaerobic/fermentative periods as well as settling period	Limited ability to adjust aerobic, anoxic, and anaerobic/fermentative periods of settling period
Clarifier required	No	Yes
Return sludge required	No	Yes

combines all treatment steps into a single tank whereas the conventional, activated sludge process relies on multiple tanks (Table 1.1). In the 1970s a pre-react selection period (anoxic and/or anaerobic/fermentative time period during the Fill phase) was incorporated in the SBR to control undesired filamentous organism growth. The selection period along with modern aeration equipment and computer control systems has advanced the use of the SBR.

The key to the SBR process is the control system. The system contains a combination of level sensors, timers, and microprocessors that provide flexibility and accuracy in operating the SBR. By varying the phase times for aerobic (oxic), anoxic, and anaerobic/fermentative of a given sequence or cycle, the biological reactions for nitrification, denitrification, and biological phosphorus removal can be controlled.

SBR are used to treat domestic, municipal, and industrial wastewaters, particularly in areas that have low flows or highly variable flow patterns. The use of SBR technology has grown rapidly in small communities that produce less than 1 million gallons per day (MGD). On-site, sequencing batch reactors are ideally suited for use in single-family homes, farms, hotels, small businesses, casinos, and resorts, where centralized wastewater treatment facilities do not exist. Most recently, more and more small communities with up to 10 MGD are using SBR technology to reduce capital expenses and operation and maintenance (O & M) costs and to comply with more stringent effluent requirements, including nutrient removal (Table 1.2). However, there are several disadvantages of SBR, including significant head loss through the system, difficulty in removing floating materials, and intermittent decant that generally requires equalization before downstream treatment processes such as filtration and disinfection (Table 1.3).

TABLE 1.2 Advantages of the SBR as Compared to the Conventional Activated Sludge Process

Anoxic period (mix fill phase) provides for alkalinity recovery
Anoxic period (mix fill phase) provides for better settling floc particles due to the control of undesired filamentous organism growth
Complete quiescent, automatic operation for improved total suspended solids (TSS) removal
Elimination of secondary clarifiers and sludge return pumps
Flexible, adaptable, automatic operation
High degree of automation reduces operational staff requirements
Higher mixed liquor temperatures provide for improved bacterial kinetics
Inherent nitrogen removal capability
Inherent phosphorus removal capability
Internal flow equalization
Less process equipment to maintain
Low land requirement and little yard plumbing, since there is no secondary clarifier
Operation flexible to easily change mode of operation
Reduction in sensitivity to constituent concentration surges, that is, no flow surges

TABLE 1.3 Disadvantages of the SBR as Compared to the Conventional Activated Sludge Process

Frequent stop/start process machinery
Higher level of control sophistication (knowledgeable operators), especially for adjustments in cycle and phase times
Higher maintenance cost due to automated controls
Requires more head drop through plant due to changing liquid level
Two or more basins or a pre-equalization tank for process operation and redundancy

OPERATIONAL COSTS

Major costs associated with the operation of the SBR are (1) electrical consumption (aeration), (2) sludge handling and disposal, and (3) chemicals. Although the bulk of electrical consumption is for aeration (cBOD degradation and nitrification), electrical consumption also is required for the operation of (1) headworks, (2) primary clarifiers, (3) thickener, (4) effluent filters, (5) disinfection, (6) heating, (7) lighting, and (8) post aeration.

Aeration of the SBR is the largest electrical expenditure and is influenced by (1) mean cell residence time (MCRT), especially high MCRT and endogenous respiration; (2) degradation of cBOD—1.8 pounds O_2 per pound cBOD degraded; (3) nitrification—4.6 pounds O_2 per pound ammonium (NH_4^+) oxidized completely to nitrate (NO_3^-); (4) time of aeration; and (5) dissolved oxygen requirement.

SLUDGE HANDLING AND DISPOSAL

Sludge handling and disposal costs are influenced by (1) MCRT, (2) polysaccharide production through nutrient deficiency and Zoogloeal growth or viscous floc, (3) type of thickening and dewatering equipment used, and (4) sludge disposal options (landfill, hazardous waste landfill, incineration, agricultural utilization, and composting).

CHEMICALS

Operational costs associated with chemical applications are influenced by (1) primary treatment requirements, (2) polymer addition to the SBR, (3) coagulant (metal salt) addition to the SBR, (4) nutrient addition, (5) malodor control, (6) pH control, (7) foam control, (8) bioaugmentation, (9) disinfection, (10) phosphorus precipitation, and (11) alkalinity addition.

GENERAL OPERATIONAL AND SYSTEM SIZING GUIDELINES

To obtain ideal operational conditions for wastewater treatment facilities using SBR technology for intermittent feed process, the following guidelines for general operation and system sizing are offered:

- At least three reactors should be available.
- Cycle times should be based on the design maximum daily flow.
- Facilities should be available for the equalization of flows and organic slug discharges.
- Design food-to-microorganism (F/M) ratios and mixed liquor suspended solids (MLSS) concentrations should be similar to other conventional and extended aeration processes. MLSS should be 2000 to 3000 mg/L. For the treatment of domestic wastewater with a nitrification requirement, the F/M should be 0.05 to 0.1. For the treatment of domestic wastewater without a nitrification requirement, the F/M should be 0.15 to 0.4.
- Reactor MLSS and mixed liquor volatile suspended solids (MLVSS) concentrations should be calculated at the low-water level.
- The low-water level should be >10 ft.
- Treatment tanks downstream of the SBR should be sized to handle the peak discharge rate.
- Sampling procedures for each SBR should consider process control as well as compliance reporting.
- For biological phosphorus release the SBR should have dissolved oxygen <0.8 m/L and nitrates (NO_3^-) <8 mg/L, and substrates should be available as soluble cBOD, especially fatty acids.
- For denitrification the SBR should have dissolved oxygen <0.8 m/L.