Sequencing Batch Reactor

Engin GÜRTEKİN
Faculty of Engineering, Department of Environmental Engineering Firat University, Turkey

Abstract

Sequencing batch reactor (SBR) is a fill-and-draw activated sludge system for wastewater treatment. Although the processes involved in SBR are identical to the conventional activated sludge process, SBR is compact and time oriented system and all the processes are carried out sequentially in the same tank. This paper reviews the description of SBR proces, applicability, advantages and disadvantages, design criteria, operation and maintaince aspects, performance and costs.

Key words: Sequencing batch reactor, design criteria, performance, costs.

1. Introduction

A sequencing batch reactor is a fill-and-draw type reactor system involving a single complete mix reactor in which all steps of the activated-sludge occur. The unit processes involved in the SBR and conventional activated sludge systems are identical. Aeration and sedimentation/clarification are carried out in both systems. However, there is one important difference in conventional plants, the processes are carried out simultaneously in separate tanks, whereas in SBR operation the processes are carried out sequentially in the same tank [1].

Fill-and-draw batch processes similar to the SBR are not a recent development as commonly thought. Between 1914 and 1920, several full-scale fill-and draw systems were in operation. In the late 1950s and early 1960s, 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. SBR systems have been successfully used to treat both municipal and industrial wastewater. They are uniquely suited for wastewater treatment applications characterized by low or intermittent flow conditions. [2].

2. SBR technology description

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

*Corresponding author: Address: Faculty of Engineering, Department of Environmental Engineering Firat University, 23119, Elazığ TURKEY. E-mail address: egurtekin@firat.edu.tr, Phone: +904242370000 Fax: +904242415526

2.1. Fill

During fill, the influent wastewater is added to the biomass that was left in the tank from the previous cycle. It may be either the raw wastewater or the primary effluent [3]. The length of the fill period depends on the number of SBRs, the volume of the SBRs, and the nature of the flow of the wastewater source, which can be intermittent or continuous. Depending upon the treatment objective, the fill may be static, mixed or aerated.

Under a static-fill scenario, there is no mixing or aeration while the influent wastewater is entering the tank. Because the mixers and aerators remain off, static fill results in minimum energy input, allowing the accumulation of substrate (food) in the reactor. A high food to microorganisms (F/M) ratio leads to an environment which is favourable to floc forming organisms, thereby avoiding filamentous organism [2]. 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.

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.

Under an aerated-fill scenario, both the aerators and the mechanical mixing unit are activated. Aerated fills result in the beginning of aerobic reactions holds substrate concentrations low, which may be of importance if biodegradable constituents exist that are toxic at high concentrations [4].

2.2. React

During the react phase, biomass consumes the substrate under controlled environmental conditions (aerobic, anoxic or anaerobic) depending on wastewater treatment. During aerated react, the organic matter oxidation and nitrification take place. If the mixed reaction is applied, denitrification can be attained. Anaerobic conditions can also be achieved in the mixed react mode for phosphorus removal.The time dedicated to react can be as high as 50% or more of total cycle time.

2.3. Settle

In the SBR, solids separation takes place under quiescent conditions (i.e., without inflow or outflow) in a tank, which may have a volume more than ten times that of the secondary clarifier used for conventional continuous-flow activated sludge plant [5]. Quiescent conditions developed give rise to the better solid separation than that of conventional clarifiers. This phase normally lasts between 0.5 and 1.5 hours to avoid the solids blanket from floating due to gas buildup.

2.4. Draw

After the settle phase, the clarified supernatant is discharged from the reactor as effluent. The withdrawal mechanism may take one of several forms, including a pipe fixed at some predetermined level with the flow regulated by an automatic valve or a pump, or an adjustable or floating weir at or just beneath the liquid surface. In any case, the withdrawal mechanism should be designed and operated in a manner that prevents floating matter from being discharged. The time dedicated to Draw can range from 5 to more than 30% of the total cycle time. The time in Draw, however, should not be overly extended because of possible problems with rising sludge.

2.5. Idle

The period between draw and fill is termed as idle. This phase is most necessary when SBR is used with a continuous wastewater flow. This time can be effectively used to waste sludge.

3. Applicability

SBRs are typically used at flowrates of 219 L/s (5MGD) or less. The more sophisticated operation required at larger SBR plants tends to discourage the use of these plants for large flowrates. The SBR technology is particularly attractive for treating smaller wastewater flows. The majority of plants were designed at wastewater flow rates of less than 22 L/s (0.5MGD) [6]. The cost-effectiveness of SBRs may limit their utilization to flows less than 440 L/s (10MGD) [7].

As these systems have a relatively small footprint, they are useful for areas where the available land is limited. In addition, cycles within the system can be easily modified for nutrient removal in the future, if it becomes necessary. This makes SBRs extremely flexible to adapt to regulatory changes for effluent parameters like nutrient removal. SBRs are also very cost effective if treatment beyond biological treatment is required, such as filtration [2].

4. Advantages and disadvantages

4.1. Advantages

1. The SBR system provides the flexibility needed to treat a variable wastewater (load and composition) by simply adjusting the cycle, the duration of each phase or the mixing /aeration pattern during each cycle [8,9].

2. The operational flexibility of an SBR allows the control of filamentous bacteria through feast/famine cycles. A high substrate concentration may be imposed by a static fill

operation and the react phase may be followed by an extended phase of starvation which, in turn, promotes the enrichment of flock-forming bacteria and the accumulation of exopolymers [10,11].

3. The operation conditions (alternating high/low substrate concentration) induce the selection of robust bacteria[12]. The sludge adaptation to variations in the oxygen and substrate concentrations, in the course of a cycle and on a long-term basis, renders it capable of maintaining good performance under shock loads [13,14].

4. The ability to hold contaminants until they have been completely degraded makes the system excellent for the treatment of hazardous compounds [15].

5. The capacity to adjust the energy input and the fraction of volume used according to the influent loading can result in a reduction in operational costs. In addition, less space is required as all operations occur in one basin [1, 16].

6. By minimizing eddy currents and turbulence during the settle phase, the concentration of suspended solid (biomass) in the effluent can be kept low.

7. Sludge thickening can be extended during settle phase, thereby decreasing the water content of the sludge wasted.

4.2. Disadvantages

1. A higher level of sophistication is required (compared to conventional systems), especially for larger systems of timing units and controls

2. Higher level of maintenance (compared to conventional systems) associated with more sophisticated controls, automated switches, and automated valves

3. Potential of discharging floating or settled biosolids during the draw or decant phase with some SBR configurations

4. Potential plugging of aeration devices during selected operating cycles, depending on the aeration system used by the manufacturer

5. Potential requirement for equalization after the SBR, depending on the downstream processes

5. Design criteria

The design of an SBR plant should be based on the results of pilot studies whenever possible. For industrial wastewater facilities, studies should almost always be performed on bench or pilot scale. For municipal wastewater treatment facilities, studies are not normally required but should

be considered because the potential cost savings in both capital investment and operating expenses can be significant [12].
For either municipal or industrial applications, mass balance considerations should be used to optimize the preliminary designs of SBR plants, just as is done for conventional continuous flow constant-volume activated sludge systems. Such applications can be facilitated by using any one of a number of treatment plant simulators including the IWAQ Activated Sludge Models [17].

Due to the many different types of fill-and-draw reactors, designing is also very diversified and difficult to be presented in a general principle. The guideline of German Waste and Wastewater Association (ATV) has given a detail designing for SBR, namely ATV-M210 [18].

The steps for designing a SBR plant according to ATV-M210 can be summarized as follows:

1. Definition of input data: inflow under dry weather and peak flow conditions; loads; time variations.
2. Process configuration: plant with or without influent holding tank; filling strategy (continuous, short time).
3. Cycle design (process parameters): sludge age; volume exchange ratio; duration of a cycle; sequence of phases (filling, aeration, mixing, sedimentation, drawing, excess sludge removal); duration of phases; start and stop of single actions.
4. Hydraulic dimensioning: number of SBRs; volume of the reactors, pre-storage and post tanks (if necessary).
5. Dimensioning of machines: aerators; pumps; mixers.
6. Verification of function: nitrogen balance; dynamic simulation (if necessary); pilot tests (if necessary).

Like the continuous activated sludge system, the most important parameter for designing a SBR is the sludge age (SRT). This parameter is always required to define the biological process in the system to achieve the particular treatment goals. The ATV-M210 defines a scheme to calculate the specific sludge age of a SBR. The necessary sludge age is derived from ATV-A131 taking into account the daily BOD- respectively COD- load, the suspended solids load, the temperature and the aims of treatment (carbon removal, nitrification, denitrification, phosphorus removal, and simultaneous sludge stabilization) [18].

Construction of SBR systems can typically require a smaller footprint than conventional activated sludge systems because the SBR often eliminates the need for primary clarifiers. The SBR never requires secondary clarifiers. The size of the SBR tanks themselves will be site specific, however the SBR system is advantageous if space is limited at the proposed site. Sizing of these systems is site specific and these case studies do not reflect every system at that size [2].

The SBR system consists of a tank, aeration and mixing equipment, a decanter, and a control system [2].

Tanks can be constructed of concrete, of steel or as sealed earthen lagoons, and in any shape or depth. In general, deep tanks are favored because oxygen transfer is improved and high volumetric exchange rates can be established. Besides, the land required to build an SBR plant is comparatively small. However, some decanter mechanisms can limit tank depth because of a limited range of travel, and can limit tank shape of a particular length/width ratio is required [12].

Typical of the SBR is intermittent aeration. In contrast with continuous flow systems the basin is not constantly being aerated, but the aerators are regularly switched on and off. The blowers, pumps and diffusers must be able to withstand these intermittent operation conditions. The mechanical stability of the aeration system also is an important factor. The forces affecting the physical structure of the aeration system can be substantial, and need to be covered by ridged structural means. Some popular aeration systems are: fine bubble aeration, coarse bubble aeration, surface aeration, submersible aerators, jet aeration systems. The primary components of diffused aeration systems are blowers, piping, valves, and diffusers [12].

Mixing is required for the distribution of wastewater constituents and biomass evenly throughout the reactor, for efficient mass transfer from the bulk liquid to the activated bioflocs, and for preventing flocs from coagulating and keeping them in suspension. The mixer systems currently available on the market can be classified in the five types: horizontal mixers fixed in position, vertical mixers fixed in position, floating mixers, pumps and intermittently operated aerators. Depending on the configuration and size of SBR, varying water levels, the aeration strategy etc., one or more types of mixer will be applied [12].

The decanter is the primary piece of equipment that distinguishes different SBR manufacturers. Types of decanters include floating and fixed. Floating decanters offer the advantage of maintaining the inlet orifice slightly below the water surface to minimize the removal of solids in the effluent removed during the DRAW step. Floating decanters also offer the operating flexibility to vary fill-and-draw volumes. Fixed decanters are built into the side of the basin and can be used if the Settle step is extended. Extending the Settle step minimizes the chance that solids in the wastewater will float over the fixed decanter. In some cases, fixed decanters are less expensive and can be designed to allow the operator to lower or raise the level of the decanter. Fixed decanters do not offer the operating flexibility of the floating decanters [2].

The operation of an SBR plant requires a certain degree of automation. At the lowest level of sophistication, pumps, valves, mixers and blowers are controlled by water-level sensors and switched on and off by simple timers. To exploit the capacity inherent in SBR technology, computer-aided process control and management systems are required [12].

6. Operation and maintenance

The SBR typically eliminates the need for separate primary and secondary clarifiers in most municipal systems, which reduces operations and maintenance (O&M) requirements. In addition, RAS pumps are not required. In conventional BNR systems, anoxic basins, anoxic zone mixers, toxic basins, toxic basin aeration equipment, and internal MLSS nitratenitrogen recirculation pumps may be necessary. With the SBR, this can be accomplished in one reactor using aeration/mixing equipment, which will minimize operation and maintenance requirements otherwise be needed for clarifiers and pumps.

Since the heart of the SBR system is the controls, automatic valves, and automatic switches, these systems may require more maintenance than a conventional activated sludge system. An increased level of sophistication usually equates to more items that can fail or require maintenance. The level of sophistication may be very advanced in larger SBR wastewater treatment plants requiring a higher level of maintenance on the automatic valves and switches [2]. The recent advances and cost reductions of microprocessors have been some of the causes of the revival of interest in SBR technology, permitting automated control of the timing and sequence of process phases and operation. The use of timers and DO monitors can be used to reduce costs attributable to over aeration, thereby reducing the lag period of DO depletion and allowing the maximum time for denitrification to occur.

Significant operating flexibility is associated with SBR systems. An SBR can be set up to simulate any conventional activated sludge process, including BNR systems. For example, holding times in the aerated react mode of an SBR can be varied to achieve simulation of a contact stabilization system with a typical hydraulic retention time (HRT) of 3.5–7 h or, on the other end of the spectrum, an extended aeration treatment system with a typical HRT of 18–36 h. For a BNR plant, the aerated react mode (oxic conditions) and the mixed react modes (anoxic conditions) can be alternated to achieve nitrification and denitrification. The mixed fill mode and mixed react mode can be used to achieve denitrification using anoxic conditions. In addition, these modes can ultimately be used to achieve an anaerobic condition at which phosphorus removal can occur. Conventional activated sludge systems typically require additional tank volume to achieve such flexibility. SBRs operate in time rather than in space and the number of cycles per day can be varied to control desired effluent limits, offering additional flexibility with an SBR.

7. Performance

The performance of SBRs is typically comparable to conventional activated sludge systems and depends on system design and site specific criteria. Depending on their mode of operation, SBRs can achieve good BOD and nutrient removal. For SBRs, the BOD removal efficiency is generally 85–95% [2]. SBR manufacturers will typically provide a process guarantee to produce an effluent of less than [2]:

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

8. Cost

Capital and construction cost estimates are site-specific. There is typically an economy of scale associated with construction costs for wastewater treatment, meaning that larger treatment plants can usually be constructed at a lower cost per gallon than smaller systems. The use of common wall construction for larger treatment systems, which can be used for square or rectangular SBR reactors, results in this economy of scale.

Operations and Maintenance costs associated with an SBR system may be similar to a conventional activated sludge system. Typical cost items associated with wastewater treatment systems include labor, overhead, supplies, maintenance, operating administration, utilities, chemicals, safety and training, laboratory testing, and solids handling. Labor and maintenance requirements may be reduced in SBRs because clarifiers, clarification equipment, and RAS pumps may not be necessary. On the other hand, the maintenance requirements for the automatic valves and switches that control the sequencing may be more intensive than for a conventional activated sludge system. Operations and Maintenance costs are site specific and may range, in terms of 2009 US Dollars, from $1,000 to $2,500/MG [2].

9. Conclusion

Wastewater treatment has been a challenge throughout the years due to varying influent characteristics and stringent effluent regulations. Use of appropriate operational strategy in SBR seems to be promising as compared to conventional activated sludge systems due to its ease of automation, aeration devices and on-line computer systems. There is the possibility of adjusting the actual length of each phase according to the treatment objectives. But the more sophisticated programmable logic control operation required at larger SBR plants tends to discourage its use for large flow-rates. Also, plugging of aeration devices during selected operating cycles is another problem observed in SBR.

References

[1] Metcalf Eddy. Wastewater Engineering. Treatment, Disposal and Reuse: New York, Mc Graw - Hill Book Company. 1991.

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

[3] Singh M, Srivastava RK. Sequencing batch reactor technology for biological wastewater treatment: a review. Asıa-Pac. J. Chem. Eng. 2011; 6: 3-13.

[4] Ketchum Jr. L.H. Design and physical features of sequencing batch reactors. Wat. Sci. Technol. 1997; 35(1): 11-8.

[5] Al-Rekabi, WS, Qiang H, Qiang WW. Review on sequencing batch reactors. Pak. J. Nut. 2007; 6(1): 11-9.

[6] Deeney KJ, Heidman JA, SchukWW, Young KS, Condren AJ. Implementation of sequencing batch reactor technologies in the United States. 64th Annual Conference of theWater Pollution Control Federation, Toronto, Ontario, 1991.

[7] Irvine RL, Ketchum LH, Breyfogle R, Barth EF. Municipal application of sequencing batch treatment. J. Wat. Pol. Cont. Fed. 1983; 55: 484-92.

[8] Torrijos M, Moletta R. Winery wastewater depollution by sequencing batch reactor. Wat. Sci. Technol. 1997; 35: 248-58.

[9] Mace S, Mata-Alvarez J.R. Utilization of SBR technology for wastewater treatment: an overview. Ind. Eng. Chem. Rem. Res. 2002; 41: 5539-53.

[10] Liao J, Lou I, de los Reyes F.L. Relationship of species-specific filament levels to filamentous bulking in activated sludge. App. Environ. Microbiol. 2004; 70(4): 2420-28.

[11] Ganesh R, Balaji G, Ramanujam RA. Biodegradation of tannery wastewater using sequencing batch reactor-Respirometric assessment. Bioresour. Technol. 2005; 97: 1815–21.

[12] Wilderer, P. A., R. L. Irvine, M. C. Goronszy, N. Artan, G. Demoulin, J. Keller, E. Morgenroth, G. Nyhuis, K. Tanaka, and M. Torrijos, Sequencing bacth reactor technology, *in* I. 3, ed., Scientific and Technical Report No. 10, IWA Scientific and Technical Report Series. IWA Publishing, 2001.

[13] Torrijos M, Vuitton V, Moletta R. The SBR process: an efficient and economic solution for the treatment of wastewater at small cheesemaking dairies in the Jura Mountains. Wat. Sci. Technol. 2001; 43(3): 323-30.

[14] Battistoni P, De Angelis A, Boccadoro, R, Bolzonella D. An automatically controlled alternate oxic-anoxic process for small municipal wastewater treatment plants. Ind. Eng. Chem. Res. 2003; 42: 509-15.

[15] Kolb FR, Wilderer PA. Activated carbon sequencing batch biofilm reactor to treat industrial wastewater. Wat. Sci. Technol. 1997; 35(1): 169-76.

[16] Nowak O, Lindtner S. Investment and operating costs of small WWTPs compared to larger plants: In: 6th Specialist Conference on Small Water and Wastewater Systems. Fremantle WA, Australia, 11-13 February 2004.

[17] Henze M, Gujer W, Mino T, van Loosdrecht M. Activated Sludge Models ASM1, ASM2, ASM2d and ASM3. IWA publishing, London, UK, 2000.

[18] Teichgraber B, Schrett, D. SBR technology in Germany - an overview: Wat. Sci. Technol. 2001; 43: 323-30.