SEQUENCING BATCH REACTORS: PRINCIPLES, DESIGN/OPERATION AND CASE STUDIES

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Contents

Summary

Sequencing batch reactor (SBR) is a fill-and-draw activated sludge treatment system. 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. SBR system is the upgraded version of the conventional activated sludge process, and is capable of removing nutrients from the wastewater. This paper reviews the fundamentals of the SBR process, design concept, operational and maintenance aspects, and case studies.

1. Background

Activated sludge process, oxidation ponds, aerated lagoons and oxidation ditches are the commonly adopted suspended growth biological treatment systems. Compared to the pond and lagoon systems, activated sludge systems also lend themselves for a number of design and operational control measures to improve performance and achieve desired treated wastewater quality. However, the flexibility in design and process control for these systems comes at the cost of high external energy inputs and skilled operation requirements.

Conventional activated sludge process (ASP) is not designed to remove nitrogen. Further, due to its short detention time, the sludge produced is not well digested warranting an additional sludge digestion treatment. Since the 1970s, a modification of the conventional activated sludge process has made the emergence of the sequencing batch reactor (SBR) process. Conventional ASP systems are space oriented. Wastewater flow moves from one tank into the next on a continuous basis and virtually all tanks have a predetermined liquid volume. The SBR, on the other hand, is a time-oriented system, with flow, energy input, and tank volume varying according to some pre-determined, periodic operating strategy. Hence, SBR is best defined as a time-oriented, batch process, falling under the broad category of an unsteady-state activated sludge system (Irvine et al., 1979).

Current interest in sequencing batch treatment of wastewater would appear to be a return to the original notion of the activated sludge process. The first notable, but short-lived, resurgence of interest in batch biological treatment occurred in the early 1950s when Porges (1955) and his co-workers first studied batch operation of ASP system for treating dairy wastewaters. The second resurgence occurred in the 1970s with the efforts of Irvine and his co-workers investigating the suitability of batch biological processes (Dennis et al., 1979; Irvine et al., 1977; Irvine and Richter, 1976). Around the same period, interest in the batch operated biological treatment systems surfaced also in Australia (Goronszy, 1979). The system developed in Australia was based on the original Pasveer oxidation ditch concept, where a single reaction vessel took the form of an endless loop of shallow ditch in which inflow, aeration, settlement and discharge followed a specific cycle.

Interest in the SBR has endured and work has extended to the use of SBR for nutrient removal (Demoulin et al., 1997; Keller et al., 2000), and for the treatment of industrial and hazardous wastes (Hersbrun, 1984; Ng, 1987; Ng and Chin, 1986).

In this paper, a review on the principles, design, and operation with some case studies of SBR system is provided.

2. The SBR Technology for Wastewater Treatment

In its most basic form, the SBR system is simply a set of tanks that operate on a fill-and-draw basis. The tanks may be an earthen or oxidation ditch, a rectangular basin, or any other concrete/ metal type structure. Each tank in the SBR system is filled during a discrete period of time and then operated as a batch reactor. After desired treatment, the mixed liquor is allowed to settled and the clarified supernatant is drawn from the tank. The essential difference between the SBR and the conventional continuous flow activated sludge system is that SBR carries out functions such as equalization, aeration and sedimentation in a time rather in a space sequence.

One advantage of the time orientation of the SBR is flexibility of operation. The total time in the SBR is used to establish the size of the system and can be related to the total volume of a conventional continuous-flow facility. As a result, the fraction of time devoted to a specific function in the SBR is equivalent to some corresponding tank in a space oriented system. Therefore, the relative tank volumes dedicated to, say, aeration and sedimentation in the SBR can be redistributed easily by adjusting the mechanism which controls the time (and, therefore, share the total volume) planned for either function. In conventional ASP, the relative tank volume is fixed and cannot be shared or redistributed as easily as in SBR.

Because of the flexibility associated with working in time rather than in space, the SBR can be operated either as a labor-intensive, low-energy, high sludge yield systems or as an energy-intensive, low-labor, low sludge yielding system for essentially the same physical plant. Labor, energy and sludge yield can also be traded off with initial capital costs. The operational flexibility also allows designers to use the SBR to meet many different treatment objectives, including one objective at the time of construction (e.g. BOD and suspended solids reduction) and another at a later time (e.g. nitrification/denitrification in addition to BOD and suspended solids removal).

3. Physical Description of the SBR System

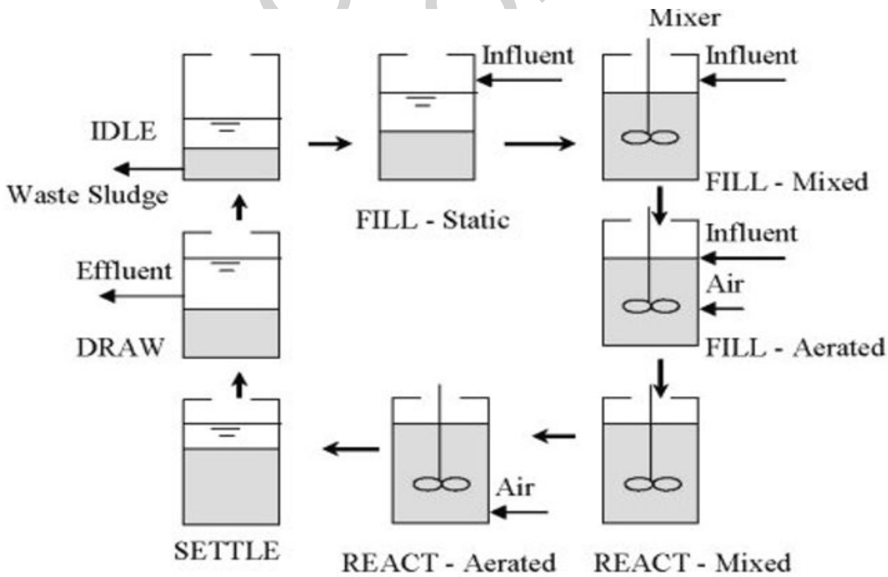

Figure 1. SBR reactor during one complete cycle

An SBR system may be designed as consisting of a single or multiple reactor tanks operating in parallel. Each operating cycle of a SBR reactor comprises five distinctive phases, referred to as: FILL, REACT, SETTLE, DRAW and IDLE phases. Figure 1 illustrates a SBR reactor operation for one cycle (batch) of wastewater treatment.

Overall control of the system is accomplished with level sensors and a timing device or microprocessor. A detailed discussion of each of the phases of the SBR is provided in the following sections:

3.1 FILL Phase

FILL provides for the addition of influent to the reactor. During FILL, the influent wastewater is added to the biomass (i.e. mixed liquor suspended solids) which remained in the tank from the previous cycle. Depending upon the treatment objective, the fill may be static, mixed or aerated. Static FILL (no mixing or aeration) results in minimum energy input and high substrate concentration at the end of this phase.

Mixed FILL (mixing without aeration) results in denitrification, if nitrates are present, a subsequent reduction of BOD and energy input, and in the anoxic or anaerobic conditions required for biological phosphorus removal.

Aerated FILL (mixing and aeration) results in starting of aerobic reactions leading to a reduction of cycle time, and holds substrate at lower concentrations, which may be important if biodegradable constituents present in wastewater are toxic at high concentrations.

Studies recommend static FILL with neither aeration nor mechanical mixing, as this helps promote high fermentation rates with allow flocculent bacteria to outcompete filamentous species, hence prevent sludge bulking (Chudoba et al., 1973; Schroeder, 1982).

3.2 REACT Phase

With the reactor full, the REACT phase begins. In general, vigorous aeration is the feature of this phase. However, as in FILL, the REACT phase may required to be carried out in high dissolved oxygen concentrations (aerated REACT), or in low dissolved oxygen concentrations (mixed REACT). The time allocated for REACT should be sufficient to achieve the desired level of effluent quality. The time dedicated to REACT phase can vary from a low of zero to more than 50% of the total cycle time. If only organics removal is desired, the aeration period can be as short as 15 minutes. However, longer aeration periods in the order of 4 hours or more, are normally required for long term stability of the process and nitrification. Where denitrification following nitrification is required, aeration during the REACT period is interrupted. Anoxic conditions would then prevail over a period of hours followed by a short period of aeration. This will strip away the nitrogen gas bubbles and aid in sedimentation.

3.3 SETTLE Phase

The SETTLE phase allows for separation of biosolids from the treated effluent without any inflow or outflow, in the SBR reactor that may have a volume more than ten times that of a secondary clarifier used for conventional continuous-flow activated sludge plant. The major advantage of SBR is its use as a clarifier, which allows for truly quiescent sedimentation conditions. Because all of the biomass remains in the tank until some fraction must be wasted, there is no need for underflow hardware normally found in conventional clarifiers. In contrast, the conventional ASP systems, continuously remove mixed liquor and passes through the clarifier only to return a major portion of the sludge to the aeration tank. Thus in conventional systems, quiescent conditions are assumed in design, but not achieved in operation as a result of secondary currents.

3.4 DRAW or DECANT Phase

This is the withdrawal phase to discharge the clarified effluent from the reactor. There are several withdrawal mechanisms available. It may be as simple as a pipe fixed at some predetermined depth with the flow regulated by an automatic valve or a pump. Alternatively, an adjustable or floating weir at or just beneath the liquid surface can be used. As with the fixed pipe arrangement, discharge from the weir can be regulated by an automatic valve or a pump. In any case the withdrawal mechanism should be designed and operated in a manner that prevents floating matter from being discharged.

The time dedicated for DRAW phase can range from 5% to more than 30% of the total cycle time. The time for DRAW should not be overly extended because of possible problems with rising sludge. One hour is the usual time period allowed for this phase of the operation.

3.5 IDLE Phase

IDLE is the phase between discharging the treated effluent and before filling the reactor again. This time can be effectively used to waste sludge. The frequency of sludge wasting is determined by the net solids increase in the reactor for each cycle, and the mixing and aeration equipment capacity. After sludge wasting, aeration and/or mixing can be provided, depending upon the overall system objectives. Alternatively, IDLE can be eliminated altogether. In instances where operation of SBR does not include an IDLE period, as noted earlier, sludge wasting may be achieved by solid wasting from the mixed liquor during the REACT phase.

4. Components and Configuration of SBR System

The principal components of an SBR system are the reactor tank, inlet, outlet, mixing and aeration arrangement, and operations controller. There is a considerable diversity in reactor tank configuration of SBR systems. Goronszy (1979) described two configurations, the first being shallow Pasveer ditches or race-track channels with trapezoidal configuration (Figure 2) (Ng and Droste, 1989).

The width of the channel is generally selected for ease of construction. The choice of depth of channel is influenced by the type of aerators to be used. Float mounted horizontal rotors has been used for aeration and mixing. The decant mechanism consisted of a cast iron bell mouth connected by a 200 mm diameter, flexible armoured-hose to the outlet chamber. A floating scum protector was provided for the bell mouth to prevent floating materials from being discharged with the effluent. The primary disadvantage of the race-track configuration is its relatively large land area requirement.

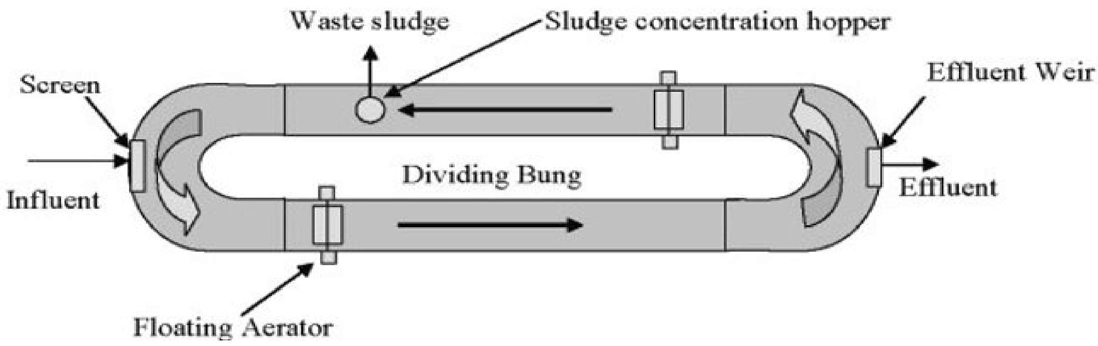

Figure 2. Schematic diagram of a race-track configuration (Adopted from Ng & Droste, 1989)

The second configuration is simple rectangular shape tanks (Figure 3). A minimum length-to-width ratio of 3:1 is often recommended to prevent both short-circuiting and disruption of sludge during SETTLE and DECANT phases. However, this is important primarily for the system where FILL is continuous, but DECANT is intermittent. In systems where both FILL and DECANT are intermittent, the length-to-width ratio would not assume much importance (Ng and Droste, 1989).

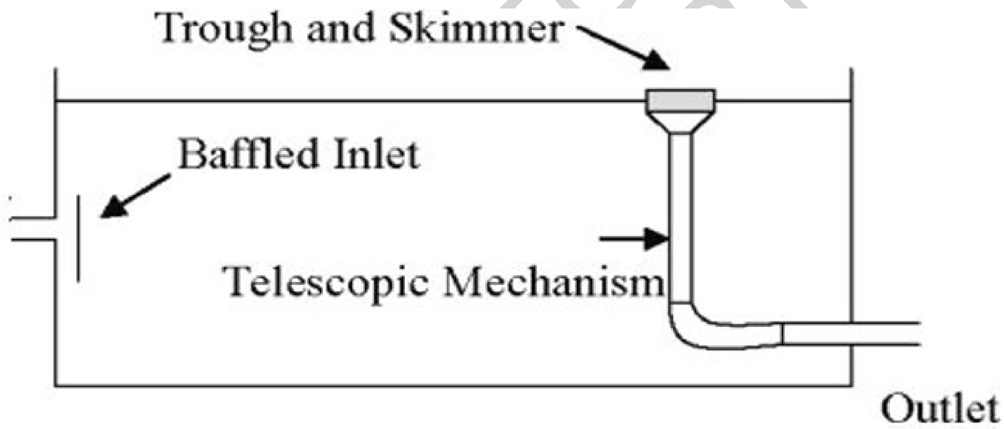

Figure 3. A rectangular configuration of SBR adopted in NSW, Australia

The number of SBRs in parallel is determined mainly the design influent flow rates. Theoretically, there is no limit to the number or size of tanks in a system. An SBR system with just one tank would be quite unusual for common applications. Single tank SBR systems are possible when upstream influent storage is envisaged and also in cases of day schools, amusement parks and industries operating 8 to 16 hours a day, where no wastewater is generated during the remaining hours. In these cases, a second tank would be unnecessary since FILL would end either naturally or by stopping discharge from storage facility. Clearly, REACT, SETTLE and DRAW phases would have to be completed before the wastewater flow resumes.

Where waste streams are larger and of a continuous nature without large diurnal fluctuations, multi-tank systems would be more appropriate. Multi-tank SBR systems are common for most municipal and industrial wastewater treatment, and where the FILL phase is not intended to be overlapping with DRAW phase.

Schroeder (1982) had suggested a three-tank system would perhaps be the best because the minimum FILL and DECANT times were not so short as to present design or operating problems. Ketchum Jr. et al. (1979) described such a three-tank system for domestic wastewater, which included primary clarification before SBR treatment and anaerobic digestion of primary sludge and excess SBR biomass (Figure 4).

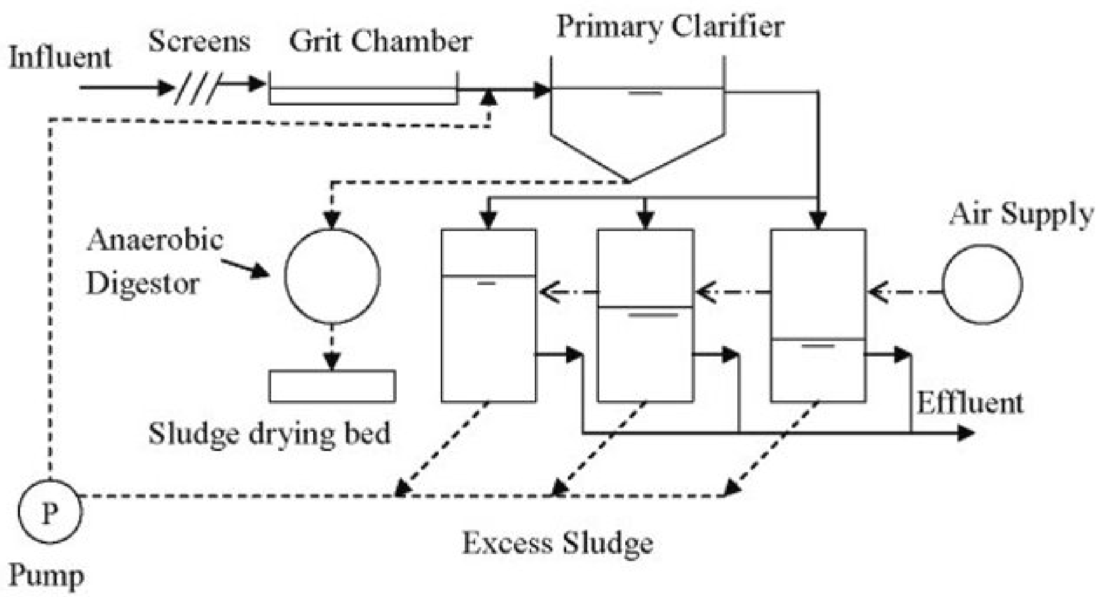

Figure 4. Schematic diagram of a three-tank SBR system for domestic wastewater treatment (adopted from Ketchum et al., 1979)

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Biographical Sketches

Dr S. Vigneswaran has been working on water and wastewater treatment and reuse related research since 1976. During the last twenty years, he has made significant contributions in physico-chemical water treatment related processes such as filtration, flocculation, membrane-filtration and adsorption. His research activities both on new processes development and mathematical modeling are well documented in reputed international journals such as Water Research, American Institute of Chemical Engineers Journal, Chemical Engineering Science, Journal of American Society of Civil Engineers, and Journal of Membrane Science. He has also been involved in a number of consulting activities in this field in Australia, Indonesia, France, Korea, and Thailand through various national and international agencies. He has authored two books in this field at the invitation of CRC press, USA, and has published more than 230 papers in journals and conference's proceedings. Currently a Professor of the Environmental Engineering Group at the University of Technology, Sydney, he was the founding Head of and the founding Co-ordinator of the University Key Research Strength Program in Water and Waste Management. He is coordinating the Urban Water Cycle and Water and Environmental Management of the newly established Research Institutes on Water and Environmental Resources Management and Nano-scale Technology respectively.

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