STUDIES ON SEQUENCING BATCH REACTOR FOR WASTEWATER TREATMENT WITH SPECIAL REFERENCE TO AJMER, RAJASTHAN

Ujala Mishra, Dr. Munna Verma

Department of Civil Engineering, Bhagwant University, Ajmer, Rajasthan

ABSTRACT

The Sequencing Batch Reactor (SBR) is a widely recognized technology for wastewater treatment due to its operational flexibility, high treatment efficiency, and cost-effectiveness. This study focuses on the application of SBR technology in the context of wastewater treatment in Ajmer, Rajasthan, highlighting its relevance and potential benefits for addressing the region's wastewater management challenges.

Ajmer, located in the arid state of Rajasthan, faces significant wastewater management issues due to rapid urbanization, industrialization, and population growth. The conventional wastewater treatment infrastructure in the region often struggles to meet the increasing demands and stringent regulatory standards, leading to environmental pollution and public health concerns.

The adoption of SBR technology offers a sustainable solution to these challenges by providing a compact, versatile, and efficient wastewater treatment process. SBR systems operate in a cyclic batch mode, allowing for sequential phases of filling, reaction, settling, and decanting within a single reactor, thereby achieving biological nutrient removal, solids separation, and disinfection in a single vessel.

Keywords: *SBR, Population growth, Single reactor, High treatment efficiency, and Cost-effectiveness etc.*

1. INTRODUCTION

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. Interest in SBRs was revived in the late 1950s and early 1960s, with the development of new equipment and technology. Improvements in aeration devices and controls have allowed SBRs to successfully compete with conventional activated sludge systems. The unit processes of the SBR and conventional activated sludge systems are the same. A 1983 U.S. EPA report, summarized this by stating that “the SBR is no more than an activated sludge system which operates in time rather than in space.” The difference between the two technologies is that the SBR performs equalization, biological treatment, and secondary clarification in a single tank using a timed control sequence. This type of reactor does, in some cases, also perform primary clarification. In a conventional activated sludge system, these unit processes would be accomplished by using separate tanks. A modified version of the SBR is the Intermittent Cycle Extended Aeration System (ICEAS). In the ICEAS system, influent wastewater flows into the reactor on a continuous basis. As such, this is not a true batch reactor, as is the conventional SBR. A baffle wall may be used in the ICEAS to buffer this continuous inflow. The design configurations of the ICEAS and the SBR are otherwise very similar.

The sequencing batch reactor (SBR) is a fill-and draw activated sludge system for wastewater treatment. In this system, wastewater is added to a single “batch” reactor, treated to remove undesirable components, and then discharged. Equalization, aeration, and clarification can all be achieved using a single batch reactor. To optimize the performance of the system, two or more batch reactors are used in a predetermined sequence of operations. 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.

The major benefits of implementing SBR technology in Ajmer include:

Operational Flexibility: SBR systems can adapt to fluctuations in wastewater flow rates and pollutant loading, making them suitable for variable influent characteristics common in urban and industrial settings.

Enhanced treatment performance: Sequencing of treatment steps in SBR enables optimization of biological processes, improving the removal efficiency of organic matter, nutrients (such as nitrogen and phosphorus) and pathogens.

Space efficiency: SBRs require a relatively small land footprint compared to conventional treatment systems, making them suitable for urban areas with limited available space for infrastructure development.

Energy and cost savings: SBR technology offers potential energy savings through reduced aeration requirements and minimal sludge production, reducing operating costs throughout the treatment lifecycle.

Compliance with regulations: By achieving high-quality effluent standards, SBRs facilitate compliance with local and national wastewater discharge regulations, thereby reducing environmental pollution and protecting public health.

Modularity and Scalability: The SBR system can be easily expanded or retrofitted to accommodate future growth or changes in wastewater treatment requirements, providing a scalable solution to Ajmer's evolving needs.

2. ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of SBR are listed below:

Advantages

• Equalization, primary clarification (in most cases), biological treatment, and secondary clarification can be achieved in the same reactor vessel.

• Operational flexibility and control.

• Minimal footprint.

• Potential capital cost savings by eliminating clarifiers and other equipment.

Disadvantages

• Requires a higher level of sophistication (compared to conventional systems), especially for larger systems, of timing units and controls.

• Higher levels of maintenance (compared to conventional systems) associated with more sophisticated controls, automatic switches and automatic valves.

• Potential for discharge of floating or frozen sludge during the draw or decant phase with some SBR configurations.

3. DESIGN CRITERIA

For any wastewater treatment plant design, the first step is to determine the estimated influent characteristics of the wastewater and the flow requirements for the proposed system. These influent parameters typically include design flow, maximum daily flow BOD5, TSS, pH, alkalinity, wastewater temperature, total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH3-N), and total phosphorus (TP). For industrial and domestic wastewater, other site specific parameters may also be required. The state regulatory agency should be contacted to determine the waste requirements of the proposed plant. These waste discharge parameters will be prescribed by the State in the National Pollutant Discharge Elimination System (NPDES) permit. Commonly allowed parameters for municipal systems are flowrate, BOD5, TSS and fecal coliform. Additionally, many states are moving toward requiring nutrient removal. Therefore, total nitrogen (TN), TKN, NH3-N, or TP may also be required. It is imperative to establish waste requirements as they will impact the operation sequence of the SBR. For example, if a nutrient is needed and NH3-N or TKN is required, nitrification will be necessary. If there is TN limitation, nitrification and denitrification will be necessary. Once the influent and flow characteristics of the system are determined, the engineer will typically consult SBR manufacturers for a recommended design. Based on these parameters and other site specific parameters such as temperature, key design parameters for the system are selected.

TABLE 1 KEY DESIGN PARAMETERS FOR A CONVENTIONAL LOAD

	Municipal	Industrial
Food to Mass (F:M)	0.15 - 0.4/day	0.15 - 0.6/day
Treatment Cycle Duration	4.0 hours	4.0 - 24 hours
Typically Low Water Level Mixed Liquor Suspended Solids	2,000-2,500 mg/L	2,000 - 4,000 mg/L
Hydraulic Retention Time	6 - 14 hours	varies

Source: AquaSBR Design Manual, 1995.

An example of these parameters for wastewater system loading is listed in Table 1. Biological reactions are completed in the reaction stage, with mixed reaction and aerated reaction modes available. During the aerated reaction, the aerobic reactions initiated during aerated filling are completed and nitrification can be achieved. Nitrification is the conversion of ammonia-nitrogen to nitrite-nitrogen and ultimately to nitrate-nitrogen. If mixed reaction mode is selected, anoxic conditions can be achieved to achieve denitrification. Anaerobic conditions can also be achieved in mixed reaction mode for phosphorus removal.

Settle is usually provided in calm conditions in SBR. In some cases, light mixing during the early stages of settlement may result in cleaner effluent and more concentrated settled sludge. In SBR, there are no influent or effluent streams to interfere with the settlement process like conventional activated sludge systems.

The draw stage uses a decanter to remove treated effluent, which is the primary differentiating factor between different SBR manufacturers. In general, there are floating decanters and fixed decanters. As described in the Tank and Equipment Description section, floating decanters offer several advantages over stationary decanters.

4. RESULT ANALYSIS

The actual construction of the SBR tank and equipment may be comparable or simpler than a conventional activated sludge system. For biological nutrient removal (BNR) plants, an SBR eliminates the need for return activated sludge (RAS) pumps and pipes. If it is being used in a conventional BNR system to return nitrate-nitrogen, it can also eliminate the need for internal mixed liquor suspended solids (MLSS) recycling.

TABLE 2 CASE STUDIES FOR SEVERAL SBR INSTALLATIONS

Flow	Reactors			Blowers	
(MGD)	No.	Size (feet)	Volume (MG)	No.	Size (HP)
0.012	1	18 x 12	0.021	1	15
0.10	2	24 x 24	0.069	3	7.5
1.2	2	80 x 80	0.908	3	125
1.0	2	58 x 58	0.479	3	40
1.4	2	69 x 69	0.678	3	60
1.46	2	78 x 78	0.910	4	40
2.0	2	82 x 82	0.958	3	75
4.25	4	104 x 80	1.556	5	200
5.2	4	87 x 87	1.359	5	125

Note: These case studies and sizing estimates were provided by Aqua-Aerobic Systems, Inc. and are site specific to individual treatment systems.

TABLE 3 SBR EQUIPMENT COSTS BASED ON DIFFERENT PROJECTS

Design Flowrate (MGD)	Budget Level Equipment Costs ($)
0.012	94,000
0.015	137,000
1.0	339,000
1.4	405,000
1.46	405,000
2.0	564,000
4.25	1,170,000

Source: Aqua Aerobics Manufacturer Information, 1998.

The SBR system consists of a tank, aeration and mixing equipment, a decanter, and a control system. The central features of the SBR system include the control unit and the automatic switches and valves that sequence and time the various operations. SBR manufacturers should be consulted for recommendations on tanks and equipment. It is typical to use a complete SBR system recommended and supplied by a single SBR manufacturer. However, it is possible for an engineer to design an SBR system, as all the necessary tanks, equipment, and controls are available through a variety of manufacturers. This is not typical for an SBR installation due to the level of sophistication of equipment and controls associated with these systems.

Security should be the primary concern in every design and system operation. A properly designed and operated system will minimize potential health and safety concerns. Manuals such as Manual of Practice (MOP) No. 8, Design of Municipal Wastewater Treatment Plants, and MOP No. 11, Operation of Municipal Wastewater Treatment Plants should be consulted to minimize these risks. Other appropriate industrial wastewater treatment manuals, federal regulations, and state regulations should also be consulted for the design and operation of wastewater treatment systems.

TABLE 4 BUDGET LEVEL EQUIPMENT COSTS BASED ON DIFFERENT FLOW RATES

Design Flowrate (MGD)	Budget Level Equipment Costs ($)
1	150,000 - 350,000
5	459,000 - 730,000
10	1,089,000 - 1,370,000
15	2,200,000
20	2,100,000 - 3,000,000

Note: Budget level cost estimates provided by Babcock King - Wilkinson. L.P.. August 1998.

TABLE 5 INSTALLED COST PER GALLON OF WASTEWATER TREATED

Design Flowrate (MGD)	Budget Level Equipment Cost ($/gallon)
0.5 - 1.0	1.96 - 5.00
1.1 - 1.5	1.83 - 2.69
1.5 - 2.0	1.65 - 3.29

Note: Installed cost estimates obtained from Aqua-Aerobics Systems, Inc., August 1998.

There is significant operational flexibility associated with SBR systems. An SBR can be installed to simulate any conventional activated sludge process, including BNR systems. For example, the holding time in the aerated react mode of the SBR can be varied to achieve simulation of a contact stabilization system with a typical hydraulic retention time (HRT) of 3.5 to 7 hours, or the other end of the spectrum. But, aeration treatment system with an extended 18 to 36 hours typical HRT. For BNR plant, aerated reaction mode (oxic conditions) and mixed reaction mode (anoxic conditions) can be alternated to achieve nitrification and denitrification. Mixed fill mode and mixed reaction mode can be used to achieve denitrification using anoxic conditions. Furthermore, these methods can be used to ultimately achieve anaerobic conditions where phosphorus can be removed. Traditional activated sludge systems typically require additional tank volume to achieve such flexibility. SBRs operate in time rather than space and the number of cycles per day can be varied to control the desired flow range, which provides additional flexibility with SBRs. The budget level cost estimates presented in Table 3 are based on projects conducted from 1995 to 1998. Budget level costs include blower, diffuser, electrically operated valves, mixer, sludge pump, decanter and control panel. All costs have been updated to March 1998 costs, rounded to the nearest thousand dollars, using an ENR construction cost index of 5875 from the March 1998 Engineering News Record. Construction cost ranges for a complete, installed SBR wastewater treatment system are presented in Table 5. Variations in estimates are due to differences in the types of sludge management facilities and systems using existing plant facilities versus newly constructed plants. As such, in some cases these estimates include other processes required in an SBR wastewater treatment plant. The operations and maintenance (O&M) costs associated with an SBR system can be similar to those of a conventional activated sludge system. Typical cost items associated with wastewater treatment systems include labor, overhead, supplies, maintenance, operations administration, utilities, chemicals, safety and training, laboratory testing, and solids management. Labor and maintenance requirements can be reduced in SBR because clarifiers, clarifier equipment and RAS pumps may not be necessary. On the other hand, maintenance requirements for the automatic valves and switches controlling sequencing can be more intensive than for a conventional activated sludge system. O&M costs are site specific and can range from $800 to $2,000 per million gallons treated.

The performance of SBR is generally 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 SBR, BOD removal efficiency is typically 85 to 95 percent.

SBR manufacturers will typically provide a process guarantee to produce a flux of less than:

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

5. CONCLUSION

In conclusion, the implementation of SBR technology holds significant promise for improving wastewater treatment in Ajmer, Rajasthan, providing a sustainable and efficient solution to address the wastewater management challenges of the region. However, successful adoption requires careful planning, stakeholder involvement, and investment in infrastructure and capacity building.

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