MODIFIED SEQUENTIAL BATCH REACTOR (MSBR) A NEW PROCESS OF WASTEWATER TREATMENT

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ABSTRACT

The application of MSBR in wastewater treatment including its principal base, operational instruction and technical feature are presented. As a newly developed modified SBR (Sequential Batch Reactor) MSBR has the advantages of both SBR and conventional activated active sludge processes. Both the primary and secondary sedimentation tanks can be omitted and continuous operation with full filling tanks of constant liquid level will be completed. This is a quite new technology for wastewater treatment of high effective, economical, flexible and easy to computer aided automation.

Key words: Wastewater treatment; Sequential Batch Reactor (SBR); Modified Sequential Batch Reactor (MSBR)

INTRODUCTION

The Sequencing Batch Reactor (SBR) is a biological wastewater treatment process developed by the founders of SBR Technologies, Inc. The SBR is a time-oriented system where each tank is filled for a discrete period of time and then operated as a batch reactor. Optimization of aeration and mixing strategies will lead to increased removal of carbon, nitrogen, phosphorus, and target organic compounds from industrial wastewaters. Since the SBR is a batch operation, it has significantly more flexibility than conventional systems allowing for more variances in the effluent levels. Given its structural simplicity, existing continuous-flow systems can be retrofitted to operate in batch.

Operation of the SBR

In its most basic form, the SBR system is a set of tanks that operate on a fill-and-draw basis. 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 settle and the clarified supernatant is then drawn from the tank.

The cycle for each tank in a typical SBR is divided into five discrete time periods: Fill, React, Settle, Draw and Idle as shown in Figure 1. There are several types of Fill and React periods, which vary according to aeration and mixing procedures. Sludge wasting may take place near the end of React, or during Settle, Draw, or Idle. Central to SBR design is the use of a single tank for multiple aspects of wastewater treatment. A detailed discussion of each period of the SBR is provided in the following subsections, along with a description of typical process equipment and hardware associated with each.

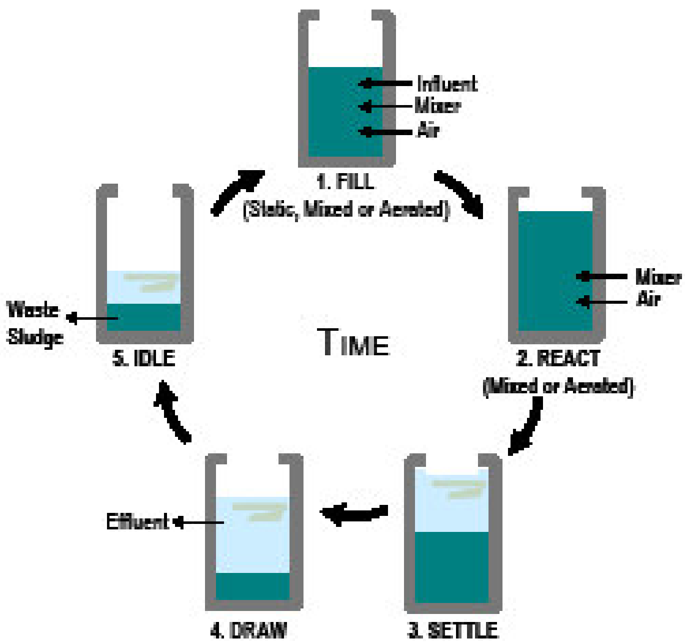

Figure 1. SBR operation for each tank for one cycle for the five discrete time periods of Fill, React, Settle, Draw, and Idle

1. **Fill**

   The influent to the tank may be either raw wastewater (screened and degritted) or primary effluent. It may be either pumped in or allowed to flow in by gravity. The feed volume is determined based on a number of factors including desired loading and detention time and expected settling characteristics of the organisms. The time of Fill depends upon the volume of each tank, the number of parallel tanks in operation, and the extent of diurnal variations in the wastewater flow rate.

   Virtually any aeration system (e.g., diffused, floating mechanical, or jet) can be used. The ideal aeration system, however, must be able to provide both a range of mixing intensities, from zero to complete agitation, and the flexibility of mixing without aeration. Level sensing devices, or timers, or in-tank probes (e.g., for the measurement of either dissolved oxygen or ammonia nitrogen) can be used to switch the aerators and/or mixers on and off as desired.

2. **React**

   Biological reactions, which were initiated during Fill, are completed during React. As in Fill, alternating conditions of low dissolved oxygen concentrations (e.g., Mixed React) and high dissolved oxygen concentrations (e.g. Aerated React) may be required. While Figure 1 suggests that the liquid level remains at the maximum throughout React, sludge wasting can take place during this period as a simple means for controlling the sludge age. By wasting during React, sludge is removed from the reactor as a means of maintaining or decreasing the volume of sludge in the reactor and decreases the solids volume. Time dedicated to React can be as high as 50% or more of total cycle time.

   The end of React may be dictated by a time specification (e.g. the time in React shall always be 1.5 h) or a level controller in an adjacent tank.

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. This major advantage in the clarification process results from the fact that the entire aeration tank serves as the clarifier during the period when no flow enters the tank. Because all of the biomass remains in the tank until some fraction must be wasted, there is no need for underflow hardware ormally found in conventional clarifiers. By way of contrast, mixed liquor is continuously removed from a continuous-flow activated-sludge aeration tank and passed through the clarifiers only to have a major portion of the sludge returned to the aeration tank.

4. **Draw**

   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(1-5). 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.

5. **Idle**

   The period between Draw and Fill is termed Idle. Despite its name, this “idle” time can be used effectively to waste settled sludge. While sludge wasting can be as infrequent as once every 2 to 3 months, more frequent sludge wasting programs are recommended to maintain process efficiency and sludge settling.

Biological Processes In the SBR

SBRs can be operated in such a way to manipulate both the organism distribution established in the reactor and the physiological state of the organisms developed since they subject organisms to variable concentrations of waste components and dissolved

oxygen. SBR operation can be adjusted to accomplish nitrogen removal,(3,9,10,11) biological phosphorus removal,(4,12,13) filament control (3,5,14-16) as well as the removal of specific organics in industrial wastes, (17) and the destruction of hazardous waste.(6-8,18)
The clear objective of the many possible operating control strategies for the SBR is to manipulate the various selective pressures, to enrich and maintain the organism distribution that produces the desired result. Two examples of how the SBR uses selective pressures to enhance water treatment are illustrated.

1. Growth Rate Variations

Static Fill conveniently allows substrate to accumulate to a very high concentration in the SBR so that when mixing and/or aeration is provided to the system the organisms grow at a rate that is greater than would be possible if the substrate were allowed to be utilized throughout a completely Aerated Fill.(19) Thus, Static Fill can be used to enhance feast conditions in the SBR.
Famine conditions naturally result late in React, when many of the substrates have been utilized, without additional raw waste. Organisms that are able to quickly assimilate the prevalent carbon sources available during feast and aggressively use recalcitrant substrates during famine will be enriched in the SBR system. Other organisms will be washed out of the system or play only a minor role in system performance.

2. Oxygen Tension Variations

Mixed Fill (without aeration) promotes the utilization of alternative electron acceptors such as nitrite and nitrate. Thus, if oxidized forms of nitrogen are generated by nitrification in the SBR during Aerated Fill, denitrification will take place during a subsequent Mixed Fill.(3,10,11,20) of course, the organism distribution established by forcing organisms to survive under alternating aerobic, anoxic, and anaerobic periods should be expected to be markedly different from the distribution established under strictly aerobic conditions. While the nitrification/denitrification sequence described earlier illustrates this, the best example is probably biological phosphorus removal. In this system, the anoxic and anaerobic conditions established during Mixed Fill enrich for the desired organism distribution. This distribution includes fermentation-product manufacturing organisms that convert the organics in the feed to short-chain fatty acids (e.g., acetic acid) and biological phosphorus-removing organisms, which use the fatty acids as a food source. Enrichment of the proper distribution of microorganisms requires both the correct operating system strategy and cycle time, with cycle times as high as six weeks. (13)

Benefits Of Batch Operation Compared to Continuous-Flow Tank Systems

1. **Lower effluent COD**: The batch nature of the process and high organic concentrations (feast) during Fill encourages the growth of organisms with high

organic uptake rates. Famine period at the end of React encourages the utilization of recalcitrant organics. The combined effect of the feast and famine periods is the optimal removal of BOD and COD.

2. **Ability to handle shock loads**: Organisms in the SBR are exposed to severe organic concentration variations during each Fill cycle, which encourages SBR organisms to excel at accommodating unplanned organic spikes in the feed.

3. **Better settling sludge**: The feast-famine conditions that naturally occur in each cycle promote the growth of floc-forming organisms and disfavor filamentous organisms, thereby eliminating the need for polymers.

4. **Ease of downturn**: During low flows, the food-to-microorganism ratio can be maintained by lengthening the Idle period relative to the React period. Also, tanks can be taken out of service for maintenance without impacting effluent quality.

5. **Lower capital and operating costs**: The elimination of the external clarifier alone reduces capital costs by 25 to 40 percent. In addition, system turndown during low flows eliminates excessive blower usage and reduces energy costs (i.e., increasing the time for Idle during low flows).

6. **Smaller footprint**: The elimination of the external clarifier reduces the system footprint. Existing conventional flow systems can be easily and inexpensively retrofitted into an SBR operation when additional capacity is desired, but no additional land and/or tanks are available.

Data on Comparison of SBR's To Conventional Systems

As shown in Fig. 2, the SBR had the best COD removal performance in a controlled test of a completely mixed reactor, tanks in series, and an SBR. While the complete mix system began to fail around week 8, and the tanks in series showed an effluent COD that was static and elevated relative to the SBR, the SBR showed an effluent COD that was consistently lower than the other two systems, and furthermore, the SBR system alone showed a gradual improvement in effluent COD as the organisms acclimated to the wastewater.

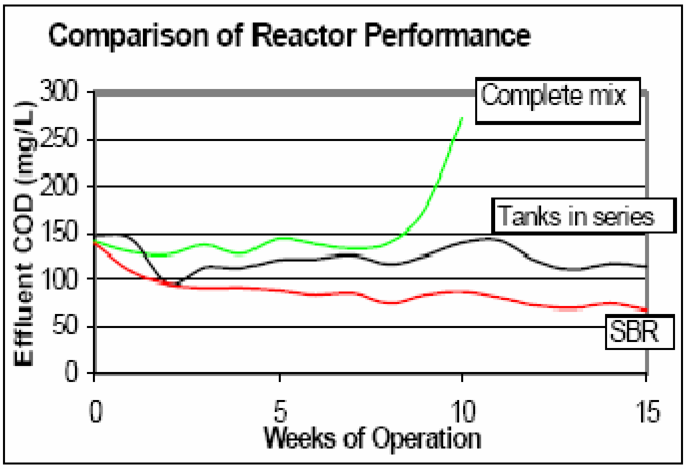

***Figure 2: Comparison of effluent COD concentrations in a test of bench-scale systems**

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Design Criteria

For any wastewater treatment plant design, the first step is to determine the anticipated influent characteristics of the wastewater and the effluent requirements for the proposed system. These influent parameters typically include design flow, maximum daily flow BOD_5 , TSS, pH, alkalinity, wastewater temperature, total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3 - N), and total phosphorus (TP). For industrial and domestic wastewater, other site specific parameters may also be required. The parameters typically permitted for municipal systems are flowrate, BOD_5, TSS, and Fecal Coliform. In addition, the country is moving toward requiring nutrient removal. Therefore, total nitrogen (TN), TKN, NH_3 - N, or TP may also be required. It is imperative to establish effluent requirements because they will impact the operating sequence of the SBR. For example, if there is a nutrient requirement and NH_3 - N or TKN is required, then nitrification will be necessary. If there is a TN limit, then nitrification and denitrification will be necessary. Once the influent and effluent characteristics of the system are determined, the engineer uses these criteria for a recommended design. Based on these parameters, and other site specific parameters such as temperature, key design parameters are selected for the system. An example of these parameters for a wastewater system loading is listed in Table 1.

***Table (1)**

Parameter	Municipal	Industrial
F/M (kg BOD/kg MLSS . day)	0.15 - 0.40	0.15 - 0.60
Treatment cycle duration (hr)	4	4 - 24
Typically low water level MLSS (mg/L)	2,000 - 2,500	2,000 - 4,000
Hydraulic retention time (hr)	6 - 14	Varies

*Eckenfelder, W. W., Jr.

Once the key design parameters are determined, the number of cycles per day, number of basins, decant volume, reactor size, and detention times can be calculated. Additionally, the aeration equipment, decanter, and associated piping can then be sized. Other site specific information is needed to size the aeration equipment, such as site elevation above mean sea level, wastewater temperature, and total dissolved solids concentration. The operation of an SBR is based on the fill-and-draw principle, which consists of the following five basic steps: Idle, Fill, React, Settle, and Draw. More than one operating strategy is possible during most of these steps. For industrial wastewater applications, treatability studies are typically required to determine the optimum operating sequence. For most municipal wastewater treatment plants, treatability studies are not required to determine the operating sequence because municipal wastewater flowrates and characteristic variations are usually predictable and most municipal designers will follow conservative design approaches.

The Idle step occurs between the Draw and the Fill steps, during which treated effluent is removed and influent wastewater is added. The length of the Idle step varies depending on the influent flowrate and the operating strategy. Equalization is achieved during this step if variable idle times are used. Mixing to condition the biomass and sludge wasting can also be performed during the Idle step, depending on the operating strategy. Influent wastewater is added to the reactor during the Fill step. The following three variations are used for the Fill step and any or all of them may be used depending on the operating strategy: static fill, mixed fill, and aerated fill. During static fill, influent wastewater is added to the biomass already present in the SBR. Static fill is characterized by no mixing or aeration, meaning that there will be a high substrate (food) concentration when mixing begins. A high food to microorganisms (F:M) ratio creates an environment favorable to floc forming organisms versus filamentous organisms, which provides good settling characteristics for the sludge.

Additionally, static fill conditions favor organisms that produce internal storage products during high substrate conditions, a requirement for biological phosphorus removal. Static fill may be compared to using "selector" compartments in a conventional activated sludge system to control the F:M ratio.Mixed fill is classified by mixing influent organics with the biomass, which initiates biological reactions. During mixed fill, bacteria biologically degrade the organics and use residual oxygen or alternative electron acceptors, such as nitrate-nitrogen. In this environment, denitrification may occur under these anoxic conditions. Denitrification is the biological conversion of nitrate-nitrogen to nitrogen gas. An anoxic condition is defined as an environment in which oxygen is not present and nitrate-nitrogen is used by the microorganisms as the electron acceptor. In a conventional biological nutrient removal (BNR) activated sludge system, mixed fill is comparable to the anoxic zone which is used for denitrification. Anaerobic conditions can also be achieved during the mixed fill phase.

After the microorganisms use the nitrate-nitrogen, sulfate becomes the electron acceptor. Anaerobic conditions are characterized by the lack of oxygen and sulfate as the electron acceptor. Aerated Fill is classified by aerating the contents of the reactor to begin the aerobic reactions completed in the React step. Aerated Fill can reduce the aeration time required in the React step. The biological reactions are completed in the React step, in which mixed react and aerated react modes are available. During aerated react, the aerobic reactions initialized during aerated fill are completed and nitrification can be achieved. Nitrification is the conversion of ammonia-nitrogen to nitrite-nitrogen and ultimately to nitrate-nitrogen. If the mixed react mode is selected, anoxic conditions can be attained to achieve denitrification. Anaerobic conditions can also be achieved in the mixed react mode for phosphorus removal. Settle is typically provided under quiescent conditions in the SBR. In some cases, gentle mixing during the initial stages of settling may result in a clearer effluent and a more concentrated settled sludge. In an SBR, there are no influent or effluent currents to interfere with the settling process as in a conventional activated sludge system. The Draw step uses a decanter to remove the treated effluent, which is the primary distinguishing factor between different SBR manufacturers. In general, there are floating decanters and fixed decanters.

SUMMARY AND CONCLUSION

The SBR is a time-oriented, periodic process that can be designed and operated to simulate virtually all conventional continuous-flow activated sludge systems, from contact stabilization to extended aeration. The SBR's many benefits include its: flexibility, ability to create idle environments for organisms capable of nutrient removal, lower cost, increased effectiveness, and successful historical track record. All of these factors make the SBR an extremely reliable process for treating wastewater. Because of the flexibility of working in time rather than space, the operating policy can be modified to meet new effluent limits, handle changes in wastewater characteristics, and accommodate the fluctuations in seasonal flow rate, all without increasing the sizes of the physical plant. Depending on the need of the wastewater treatment plant and the goals of the company/municipality. SBR's have proven to be an extremely effective and cost-efficient process for treating even the most difficult to treat wastewaters.

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